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Scientific and Technological Innovation and Cooperation in the Greater Bay Area of China: A Case Study of University Patent Applications and Transformation

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Abstract: This article examines the dynamics of scientific and technological innovation and cooperation in the Guangdong–Hong Kong–Macao Greater Bay Area. It focuses on unraveling the intricate web of influences that steer patenting and transformation within 34 universities in this region. The study reveals the spatial spillover of university patent applications and delves into the nuanced choices universities make in transforming patents. The findings underscore the antecedents of university patent applications and reveal their propensity for spatial spillovers across the region. Key determinants, in particular the government funding and the economic prosperity of the region in which the university is located, do not positively affect university patent applications. Interestingly, institutional distance can assist colleges in the region in generating more patents. Moreover, the study delineates two central pathways for patent transformation within universities: one involves the strategic allocation of internal resources, while the other depends on collaborative ventures between universities and their respective regional ecosystems. This dual approach illuminates viable pathways for the evolution of university patents and provides insights into leveraging internal dynamics and fostering collaborative networks with the broader regional innovation milieu.

Keywords: scientific and technological innovation and cooperation; Guangdong–Hong Kong–Macao Greater Bay Area; university patents; patent application; spatial econometrics; fuzzy-set qualitative comparative analysis; patent transformation path

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1. Introduction

Capabilities for scientific and technological innovation, as well as the cultivation of technical talents, are critical components in assuring regional economic growth and driving sustainable development [1]. Science and technology make it possible to achieve sustainable development without sacrificing the current achievements of society in quality of life or other aspects, but also by improving and developing current achievements further. Patents and publications (theses, dissertations, journal articles, books, etc.) are two main kinds of products of scientific and technological innovation. Patents can encourage inventors to invest in research and the development of sustainable technologies by providing them with exclusive rights to their inventions for a limited period, which can incentivize them to develop and commercialize sustainable technologies [2,3]. Patents can simplify technology transfer by offering a legal framework for the license and commercialization of lasting technologies, supporting the widespread distribution and faster adoption of sustainable technologies. Invention patenting includes several stages: research, application, transformation, and product, etc. Patent applications and transformation are two core stages of the whole patenting process [4,5].

Universities, as innovative entities with significant innovation vitality, play an essential role in the coordinated development of industry, academia, and research. Innovation activities in universities can foster inventive engagement between the government and enterprises, which can help activate the transformation of scientific and technological innovation achievements, thereby improving social productivity [6]. To encourage applied research in universities and advance the development of patent commercialization, some developed countries or regions, including the United States, Italy, and Europe, have introduced corresponding measures and bills to protect the patent rights of universities [7–9]. These measures have led to a surge in patent applications and transformation from universities. Invention patents by universities have accounted for nearly 1/4 of the total invention patents in China. However, a series of problems existed in university patent ventures [10,11]. Since the promulgation of the Chinese Patent Law in 1985, the university patent applications have sharply increased, but few of them have been transformed, utilized or industrialized. In 2022, the transformation rate of invention patents in Chinese universities is only 3.9%, while the rate of American universities has already reached 40% [12]. Although a large number of patents have been applied each year, most of them lacked the application value, and very few have been transformed for practical application. The question that naturally came out is why Chinese universities have so many invention patents but few transfers, and whether there are any different influencing factors between invention patent applications and transformation. Clarifying the antecedents that affect patent applications and transformation paths in universities plays an important reference role in further promoting high-quality innovation growth in developing countries.

Scientific and technological innovation is seen as a significant channel for achieving sustainable services and products. The importance of technological innovation in attaining sustainable development is also influenced by the stage of development of a country or region. The Guangdong–Hong Kong–Macao Greater Bay Area has been planned to be an innovation hub by the Chinese government in 2015. The urban agglomeration under "one country, two systems", is expected to deepen internal cooperation and open to the outside world, which can enable the Greater Bay Area to better serve the national innovation-driven development strategy. Scientific and technological resources, as well as the favorable scientific and technological innovation environment, have contributed to the constant growth of patent activities at universities of the Greater Bay Area. Unlike intra-regional patent activities between European Union countries or other Bay areas, the cross-border institutional differences in the Greater Bay Area have also created a distinct regional innovation research environment.

Regional innovation research has shown that spatial proximity is no longer an obstacle to international cooperation among universities. In fact, diversified international systems can have a positive impact on cross-border university technology transfer [13]. The closer the clustering of innovative subjects in a region is to universities, the greater the potential to enhance diversity and innovation within the industry [14]. The spatial knowledge spillover effect has become a key factor in the innovation output of universities. To examine the different influencing factors from the invention patent application to transformation, this article applies the spatial econometrics model to measure the spatial spillover effects and influencing factors of patent applications by universities in the Greater Bay Area and employs fuzzy-set qualitative comparative analysis (fsQCA) to investigate the path selection of university patent transformation and its influencing factors from the perspective of configuration analysis. This study provides experience promoting invention patent applications and transformation for developing countries.

This paper contributes to the current literature on university patenting in two ways: one is that this study explores the different influencing factors in the university patent applications and transformation, which can contribute to enhancing the policy accuracy, while the existing literature did not differentiate the patent application from the patent transformation. The second point is that the Greater Bay Area is a special region with the cross-border characteristic but part of the same country. Examining the patenting cooperation in this region can contribute to understanding the cross-border science and technology innovation cooperation.

The rest of the article proceeds as follows: Section 2 presents the research design to discuss studies on patent applications and transformation, respectively; Section 3 introduces the methodology on the analysis model/method, variables and data sources; Section 4 describes the research findings; finally, Section 5 discusses the empirical findings and offers some recommendations over the university patent applications and transformation.

2. Research Design

Scientific and technological innovation is the source of the industrial revolution and economic development. Papers and patents are two metrics widely used to assess innovation outputs in science and technology. When comparing them with publications, patents have more practical utility value for industrialization. Multiple stakeholders, including governments, firms, universities, and invention applicants, play a significant role in the process of patent development in universities. Numerous factors influence patent applications and transformation in universities. Mohammed Abdul Fasi emphasizes the importance of interaction between enterprises and university innovation departments in the technology transfer [15]. Industry and commercialization funding support can expand university patent development activities [16]. In addition, scholars analyze the factors affecting patent productivity from the perspective of market fluctuations and policy changes [8,17]. However, there is no universally recognized indicator system for studying the factors that affect university patent activities [18]. Thus, it is valuable to explore the different factors influencing university patent applications and transformation.

2.1. Patent Applications

The role of government and business in innovation has been debated. Some argue that the government plays a larger role, while others believe that business is more important [19–21]. In well-developed nations, the strong market forces provide sufficient resources for the universities to explore the frontiers of science and technology. However, for less-developed countries, particularly those lacking large enterprises, government funding may play a more important role for scientific and technological innovation in universities. Allocation of university research funding by the government may positively impact patents, articles and other academic outputs [22,23]. It can be inferred whether the successful patent application is related to research funding. In addition, the human capital of universities is crucial for successful patenting. In the current research funding system, the interaction between researchers and funding bodies is of paramount importance. Researchers may redirect their research to match the funding priority [24–26]. Thus, we propose Hypothesis 1.

H1: *Government funding for scientific research in universities has a positive relationship with patent applications in universities.*

Studies on regional innovation development show that there is an interactive coupling relationship between varied innovation agents and the regional economy. On the one hand, innovation development might propel regional economic growth through engaging in inventive activities and spreading innovative capacity [27,28]. On the other hand, the level of regional economic development is likewise essential to patent activities and has an equivalent impact on university patent applications. The more specialized the regional economy, the more the university's patent output in the corresponding industrial field [29,30]. China's GDP has dramatically grown since 1980 to the second largest one, while its development of scientific and technological innovation is also advancing at a rapid pace, particularly in well-developed regions. Universities, as the key drivers of scientific and technological innovation, play a critical role in patent applications and transformation. It is expected that the government and enterprises in the well-developed region have more resources for local university development and more funding to innovation and patenting, which can contribute to the growth of university patenting activities. Thus, Hypothesis 2 is proposed as follows:

H2: *The level of economic development in the region where the university is located has a positive impact on patent applications made by the university.*

Institutional distance refers to the difference and resemblance in the institutional environment of countries (regions), including regulatory, cognitive, and normative systems [31]. In cross-border research, institutional environmental factors have become one variable that cannot be ignored. Scholars have different views on the impact of institutional factors on cross-border collaboration. Some researchers believe that institutional distance has created misunderstanding among co-inventors and increased the cooperation cost, considering borders as impediments, while others argue that cross-border collaboration brings in new innovations as borders are dynamic institutions; differences in culture and institutions can spur innovation [32–35]. According to OECD data, over the last three decades, the proportion of patents involving a co-inventor from another country has increased from 10% to 20% [36]. This illustrates the increasing interest in cross-border research. Unlike cross-border flows between countries, the Greater Bay Area, China's new science and technology innovation highland, is a special area with three highly autonomous regions under one country, two systems, three legal systems and three separate customs territories [37]. The Greater Bay Area has exhibited enormous innovation potential. The cooperation of the Greater Bay Area inspires sparks from the collision of diverse cultures and ideas, which consequently contributes to invention and patents [38,39]. Therefore, Hypothesis 3 is proposed.

H3: *As institutional distance increases within the Greater Bay Area, the number of patent applications from universities will increase.*

2.2. Patent Transformation

Patent transformation is a way to transfer technology for the purpose of achieving the final target of patenting by third parties [40]. Studies use patent transfer data to measure the innovation efficiency and the driving factors of patent transfers. Some research employs social network analysis with patent transfers as indicators to examine inventive collaboration in innovation networks [41,42]. Others apply innovation indicators and econometric models to investigate the influence of patent transfers on the quality of innovation in cities, enterprises, and other fields [43,44].

Among these research subjects, university patents are particularly significant, since they constitute a unique and highly visible type of "technology transfer" [45]. Scholars focus on knowledge spillover, driving factors and resource allocation in the patent transfer process in this research. Timothy R. Anderson uses data envelopment analysis approach to measure the efficiency of university technology transfer [46]. Xuemei Xie explores how the innovation ecosystem promotes product innovation, and multiple impact paths are shown by using fuzzy-set qualitative comparative analysis (fsQCA) [47]. Inés Macho-Stadler explores the role of the technology transfer office in patent transformation [48]. Considering the impact of multiple variables on the transfer of university patents, we wish to investigate the appropriate path through cohort analysis using fsQCA.

3. Methodology

This study endeavors to investigate the differences in influencing factors between university patent applications and their subsequent transformation. Our approach involves the utilization of both spatial econometrics models and fuzzy-set qualitative comparative analysis (fsQCA) to explore the determinants shaping university patent applications and transformations within the Greater Bay Area. The spatial econometrics model will rigorously test three hypotheses concerning patent applications, whereas fsQCA will focus on delineating the intricate pathways of university innovation patents' transformations. To address the distinctions in influencing factors between the stages of the application and transformation, we maintain consistency by employing identical independent (conditional) variables in both methodologies. The combination of the two approaches allows for a more comprehensive observation of the influencing factors affecting university patent applications and transformation, ensuring multiple analyses from both a monofactor and cohort perspective. The integration of these two analytical approaches within a singular study is not unprecedented, having been successfully employed in prior scholarly endeavors [49,50].

3.1. Spatial Econometrics Model and Variables

3.1.1. Spatial Econometrics Model

Spatial econometrics is a method of modeling spatial variables to explore spatial dependence or spatial heterogeneity [51]. In order to study the spillover effect of patent application activities of universities in the Greater Bay Area, this paper draws on the Cobb–Douglas function to explain the relationship between knowledge input and output [52], and establishes an Ordinary Least Squares regression (OLS) model as

$$IP_i = \alpha + \beta_1 TR_i + \beta_2 TF_i + \beta_3 \mathrm{TP}_i + \beta_4 \mathrm{PGDP}_i + \beta_5 \mathrm{PIP}_i + \varepsilon_i \quad (1)$$

Based on the research of scholars [53], taking into account the lag effect of patents, the spatial lag model is set as

$$\begin{gathered} IP_i = \alpha + \rho W * IP_i + \beta_1 TR_i + \beta_2 TF_i + \beta_3 \mathrm{TP}_i + \beta_4 \mathrm{PGDP}_i + \beta_5 \mathrm{PIP}_i \\ + \varepsilon_i, \varepsilon \sim N\left[0, \sigma^2 I\right],\ i = 1,\ 2,\ \ldots\ldots,\ 34 \end{gathered} \quad (2)$$

At the same time, two spatial weight matrices are generated based on the distance between universities and external institutional differences. The formula is as follows:

$$W_{dis} = \begin{cases} \frac{1}{d^2{}_{ij}},\ i \neq j; \\ 0,\ i = j \end{cases} \quad (3)$$

$$W_{ins} = \begin{cases} institution_{ij},\ i \neq j; \\ 0,\ i = j \end{cases} \quad (4)$$

In Formulas (1) and (2), the parameter vector β represents the influence of the explanatory variable on the dependent variable, ρ is the spatial effect coefficient and W is the spatial weight matrix. In Formula (3), d is the distance between the geographical center locations of the two universities. $institution_{ij}$ in Formula (4) represents the institutional environment of the regions where the two universities are located.

3.1.2. Variables

The number of invention patent applications is a crucial indicator for measuring the basic innovation capabilities of universities [54–56]. Considering the time lag of output transformation and financial investment, this paper chooses the number of invention patent applications of universities as the dependable variable and selects the application data of 2016 and 2017. To be more directional, the study uniformly selects China's invention patents as the research index of universities in the Greater Bay Area.

Spatial econometrics analysis is intended to test the impact of government funding, the level of regional economy and technological innovation, and the institutional environment on university innovation patent application activities. The following variables are included: human capital, government funding, project research and development, level of economic development, and science and technology innovation and development. Scientific and technological achievements in universities heavily relied upon government funding. The government funding for academic research is allocated to each university or college through research projects. Meanwhile, faculties are the main drivers of patented inventions in universities and play a significant role in measuring the level of scientific innovation in universities. They all ensure the quality of scientific research products [57,58]. Here, we adopt total number of faculty and scientific research funds to measure these two variables, respectively. Besides the inner factors of universities, the patenting activities of universities are influenced by the overall development environment of the region in which the university is located. Gross national product per capita is used as a measure of the level of economic development. In general, scientific and technological innovation development and economic development are mutually supportive. Thus, the indicator of invention patent ownership per 10,000 people is used as a specific reference for the development of science and innovation [59,60]. The specific description of the above variables is shown in Table 1.

Table 1. Description of factors influencing patent applications by universities in the Guangdong–Hong Kong–Macao Greater Bay Area.

Variable	Variable Description	Symbol
Productivity	Number of patent applications/piece	IP
Human capital	Total number of faculty/person	TR
Government funding	Scientific research funds/100 million yuan	TF
Project research and development	Scientific research projects/item	TP
The level of economic development	Gross national product per capita/10,000 yuan	PGDP
Science and technology innovation and development	Number of invention patents owned/10,000 people	PIP

Institutional environment (dummy variable): In order to quantify the uniqueness of "one country, two systems, three customs" in the Greater Bay Area, the institutional environment indicator based on regional conditions is introduced. Here, we rely on Yang's study [61]. The paper distinguishes a hierarchy of cities in the three regions. In terms of institutions, the nine cities in Guangdong operated under a socialist system, while Hong Kong and Macao operated under a capitalist system. The cities in Guangdong have the same customs territory, while Hong Kong and Macao have their own customs territories respectively. In terms of administrative level, Guangzhou and Shenzhen are sub-provincial cities; the other seven cities in Guangdong are prefectural cities while Hong Kong and Macao are Special Administrative Regions (SARs) regarded as provincial cities. Based on the above grading, we assigned values 1–4 to these cities.

3.2. Fuzzy-Set Qualitative Comparative Analysis and Variables

3.2.1. Fuzzy-Set Qualitative Comparative Analysis

Fuzzy-set qualitative comparative analysis (fsQCA) aims to explore the influence of relevant variables on the university patents transformation from the perspective of configuration analysis. Qualitative comparative analysis (QCA) is a research method that combines qualitative analysis and quantitative methods to explore the combination of occurrence conditions for complex problems by identifying the sufficient and necessary relationships between the explained results and the combination (or configuration) of antecedent conditions [62]. Fuzzy-set qualitative comparative analysis (fsQCA) is a variant of QCA that solves the problem of binary variables in QCA analysis. It can further analyze degree changes and partial membership problems based on dealing with category problems [63]. Consistency and coverage are the two most important factors for measuring fitting parameters in fsQCA. Consistency demonstrates the robustness of set indicator interaction, which refers to the degree to which causal combinations produce the same effect. Coverage is similar to R^2, which reports the proportion of variance in classical regression [64,65].

3.2.2. Variables

This article employs the technology transfer revenue of year 2017 in transformation analysis as the outcome variable (similar to the number of patent applications as the dependent variable at the patent application stage). Independent variables (human capital, government funding, project research and development, the level of economic development, and science and technology innovation and development) applied in the spatial econometrics analysis on the patent application are also adopted as conditional variables in the fsQCA on the patent transformation.

3.3. Data Source

The study includes 34 universities located in three regions, namely 27 in Guangdong Province, 6 in Hong Kong, and 1 in Macao. The sample excludes universities that did not apply for patents in 2016 or 2017 and those that were not established in or before 2016. Patent data are sourced from the Incopat database. Data on human capital, research funding, and project research and development of universities in mainland China were obtained from the 2016–2017 "Compilation of Science and Technology Statistics in Colleges and Universities" released by the Ministry of Education. Considering that the choice of patent transformation path in universities is the combined result of multiple factors, the data were processed over one lag year. Therefore, the outcome variable used 2017 data, and the condition variable used 2016 data for antecedent analysis [66]. University data of Hong Kong were obtained from the Hong Kong University Grants Committee, while university data of Macao were obtained from respective official university websites and the Macao Bureau of Statistics. Data on regional economic development, financial allocations, and scientific and technological innovation development in mainland China were sourced from the "China Statistical Yearbook" and various local "Statistical Yearbooks". Hong Kong and Macao data were sourced from local statistics bureaus and the World Bank. The Hong Kong and Macao data were converted into RMB in exchange rate of 2016 and 2017, respectively, and missing data were filled in using linear interpolation.

4. Research Results

4.1. Current Status of Patent Activities in the Guangdong–Hong Kong–Macao Greater Bay Area

The application for invention patents is the foundation of patent transformation. Prior to conducting empirical analysis, we sorted out the number of invention patent applications in various cities in the Greater Bay Area. As illustrated in Figure 1, Shenzhen ranks first in the number of invention patent applications, and the number of applications in Guangzhou and Foshan also significantly exceeds that of other cities. Based on the China patent data, in comparison to the mainland counterparts, the number of applications applied from Hong Kong and Macao indicates that patent activities in these two regions are not very active.

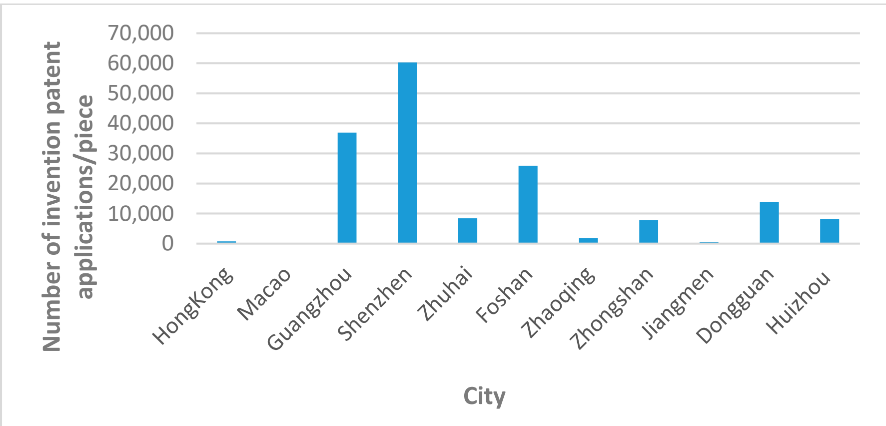

Figure 1. Number of invention patent applications in cities in the Guangdong–Hong Kong–Macao Greater Bay Area in 2017.

4.2. Empirical Analysis of Spatial Econometrics

Table 2 presents the factors that influence invention patent applications in universities, including geographical spatial effects. The first column of the table uses an OLS model to study the direct impact of explanatory variables on university patent activities. The coefficients of TP and PIP are both positive and significant at the 0.01 and 0.05 levels, respectively. This indicates that the number of scientific research projects and the degree of regional patent activities have a significant impact on the number of university patent applications. In contrast, the coefficient of TF is not significant, and this variable does not have a significant impact on patent applications in universities.

Table 2. Results of OLS and spatial lag model regression.

	OLS	Distance	Institution
TR	−0.542 *	−0.752 ** (−2.03)	−1.005 ** (−2.95)
TF	−0.287	−0.200 (−1.06)	−0.059 (−0.34)
TP	1.398 ***	1.343 *** (4.42)	1.432 *** (5.31)
PGDP	−1.779 **	−1.356 ** (−2.66)	−0.082 (−0.013)
PIP	0.645 *	0.616 * (2.23)	−0.313 (−0.93)
ρ		0.166 ** (2.21)	0.011 *** (3.81)
δ^2		1.272	1.001
R^2	0.589	0.619	0.702

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The second and third columns of the table include distance and institutional environment elements to further study the indirect influence of science and technology investment in surrounding universities on patent activities. Under the influence of spatial distance and institutional factors, ρ is positive and significant at the 0.05 and 0.01 levels, respectively. This shows that there is a spatial spillover effect, and the patent activities of spatially adjacent universities could affect each other. Specifically, under the influence of distance, the coefficients of TP and PIP are positive and significant at the 0.05 and 0.1 levels, indicating that the investment of neighboring universities and the development of innovation in neighboring regions will also affect the university's patent applications. In contrast, TR and PGDP are negatively correlated with the increase in applications. This suggests that universities in areas with higher economic development or more researchers do not have many patent applications. Meanwhile, ρ for institutional distance was shown to be positive and significant. It suggests that in the Greater Bay Area, institutional distance is not a barrier, but a spark that promotes the development of science and innovation among universities, resulting in a positive impact.

In summary, Hypothesis 1 and Hypothesis 2 were rejected. Within the Greater Bay Area, institutional distance contributes significantly and positively to the development of university patenting, confirming Hypothesis 3. Under the influence of institutional distance, the effects of TP and PIP on university patenting are consistent and there is some spillover effect, while none of the regional environment variables are significant and have no impact on university patenting.

4.3. Analysis Results of University Patent Transformation Paths

In order to study the choice of patent transformation paths in a more systematic way, we decide to focus on colleges and universities themselves. Given the different research funding allocation systems in the Mainland, Hong Kong, and Macao, we choose 16 universities in Guangdong Province as cases. It ensures samples under the same funding system. Although there are many universities in Guangdong, some of them do not have patent transformation, or have very few, which is unrelated to our study, so we only choose those colleges or universities with a certain number of patent transformations as samples. Therefore, to a certain extent, these universities can reflect the level of science and technology innovation in Guangdong universities. Generally speaking, different types of universities will also show differences in their output of scientific and technological innovation [46,67]. In this article, we classified universities based on their types as comprehensive university, technical-science university, medical university, agriculture university and normal university. Our aim is to make a simple distinction among universities to study the transformation path of patents rather than explore the impact of different types of universities. Thus, for the anonymization purpose, only university characteristics are reported to avoid controversy over the results.

To assign a membership degree to the specific condition set of the case, the original data were further calibrated into a dataset with a score of 0–1 [68]. Following Fiss's research [69], this paper utilized fsQCA to calibrate data by using three registration points: the fully affiliated point (95% quantile), the intersection point (50% quantile), and the fully unaffiliated point (5% quantile). The partial membership of the anchor points was adjusted by −0.001 to eliminate overlap between the anchor points and the original data. Table 3 shows the calibration anchor points for the five condition variables.

Table 3. Fuzzy-set membership calibrations and sample descriptive statistics.

Condition Variable	Full Affiliation Point	Intersection	Completely Unaffiliated
Science and technology innovation transformation level	49,762.75	1501	45.25
Human capital	6138	1115	337.75
Government funding	1,094,656.5	278,238.5	5111.75
Project research and development	6,385.75	958	77.5
The level of economic development	151,766.99	145,254.39	52,972.963
Science and technology innovation and development	45.125	22.4	5.924

Table 4 presents the calibrated values of 16 universities' overall ability to transform scientific and technological achievements. The table shows that the average comprehensive ability of the 16 universities in patent transformation is 0.389. From the perspective of transformation ability, the top two universities have relative advantages. Among the 16 universities, their transformation level is the highest. There are seven universities with a transformation level between 0.5–0.9, accounting for 43.75%. This is consistent with the number of colleges and universities with comprehensive capabilities below 0.4. In terms of university types, colleges, and universities with a significant preference for subjects such as science, engineering, and medicine have better achievement transformation capabilities. The top three universities have more transformation advantages than other comprehensive universities. There are substantial variances in the total transformation capabilities of scientific and technological achievements in 16 institutions in Guangdong Province.

Table 4. The scientific and technological achievement transformation capabilities of 16 universities in Guangdong Province in 2017.

College Number	College Type	Transformation Ability	College Number	College Type	Transformation Ability
1	Technical–science university	1	9	Comprehensive university	0.47
2	Medical university	0.9	10	Normal university	0.16
3	Medical university	0.62	11	Normal university	0.12
4	Comprehensive university	0.61	12	Comprehensive university	0.06
5	Agricultural university	0.54	13	Comprehensive university	0.05
6	Technical–science university	0.53	14	Technical–science university	0.05
7	Comprehensive university	0.51	15	Technical–science university	0.05
8	Normal university	0.5	16	Comprehensive university	0.05

4.3.1. Necessity Analysis of Conditional Variables

We checked whether the five requirements in the conditional variables (including the "non" condition) were required conditions that affect the transformation of scientific and technological achievements in universities in Guangdong Province before completing the standard analysis (see Table 5). If the consistency of the variables in the test is greater than 0.9, the condition variable is considered a required condition, has a significant impact on the generation of results, and will almost certainly be included in the result route analysis. Table 5 clearly shows that there are no necessary conditions.

Table 5. Analysis results of necessary conditions for universities in Guangdong Province.

Condition Variable	Consistency	Coverage	~Condition Variable	Consistency	Coverage
Total number of faculty	0.891	0.814	~Total number of faculty	0.870	0.926
Research funding	0.842	0.790	~Research funding	0.858	0.895
Scientific research projects	0.843	0.772	~Scientific research projects	0.758	0.851
GDP per capita	0.793	0.676	~GDP per capita	0.716	0.843
Number of invention patents owned by 10,000 people	0.790	0.639	~Number of invention patents owned by 10,000 people	0.842	0.894

Note: "~" means "not" in logical operations.

4.3.2. Adequacy Analysis of Conditional Configuration

Before conducting configuration analysis, two important indicators need to be established: the minimum case frequency and the consistency threshold. In this study, we set the minimum case frequency to 1 and the consistency threshold to 0.8. We then built a truth table to determine the proportional reduction inconsistency (PRI) value, which was found to be greater than or equal to 0.7 [70]. We performed configuration analysis on the five conditional variables and investigated numerous combination paths that affect the result variables. Eventually, we obtained complex, parsimonious, and intermediate solutions. To accurately evaluate the results, we used the intermediate solution supported by the parsimonious solution. The consistency of this solution was found to be 0.715, the coverage of the solution was 0.882, and the overall interpretability was high.

The study presents the conditional variable combination paths that affect the scientific and technological innovation capabilities of universities in Guangdong Province, as shown in Table 6. The transformation structure of scientific and technological achievements in colleges and universities comprises three paths. Path 1 and Path 2 are a couple of high-level transformation configurations. The consistency of the paths and the solution is greater than the consistency threshold of 0.8, and the raw coverage of the two paths is 0.615 and 0.686, respectively. This demonstrates that the two configuration paths lead to the same result variable. Based on the different results of the configured paths, the study further analyzed the two paths.

Configuration 1—Intrinsic resource support path

In configuration 1, the allocation of scientific research funding plays a central role. This highlights the importance of funding for universities to continue carrying out patent research and development during the patent transformation period. The management of scientific research funds by universities directly affects the allocation management of personnel and the smooth development of follow-up work [71]. Meanwhile, the absence of the region–context factor in this path area shows that even in areas with imperfect financial resources, the rational allocation of universities' own resources can also play a role in the level of transformation.

Configuration 2—Reasonable resource allocation path

In configuration 2, the increase in scientific researchers, scientific research projects, GDP per capita, and invention patent ownership per 10,000 people are sufficient conditions to affect the ability of universities to transform scientific and technological achievements.

Among them, research funding is still the core condition, which promotes the implementation of patent transformation in universities. The other variables are edge conditions. While the government vigorously promotes scientific and technological development, the high-quality talent resource of universities, and high-quality hardware facilities are both distinct advantages that promote the quality of scientific research and the transformation of results [72].

Table 6. Configuration analysis results of scientific and technological innovation capabilities of universities in Guangdong Province.

Condition Variable	Scientific and Technological Achievements Transformation Configuration		
	1	2	3
Human capital	•	•	⊙
Government funding	●	●	●
Project research and development	•	•	⊙
The level of economic development	⊙	•	⊙
Science and technology innovation and development	⊙	•	⊙
Consistency	0.907	0.910	0.811
Raw coverage	0.615	0.686	0.376
Unique coverage	0.019	0.076	0.024
Solution consistency		0.715	
Coverage of solution		0.882	

Note: ● indicates the existence of the core condition, ⊙ indicates the absence of the core condition, • indicates the existence of the edge condition.

5. Conclusions and Suggestions

Through examining the university patent applications and transformation, this paper explored scientific and technological innovation in the Greater Bay Area of South China. Some interesting findings have been observed. The scientific and technological innovation achievements of universities in the Greater Bay Area have a certain spatial spillover effect. This suggests that a network for scientific and technological innovation has been established within the Greater Bay Area, and universities positively collaborate in terms of patent research and development. However, universities are also affected by various aspects concerning patent applications and transformation.

In the period of the patent application, government funding does not directly affect the number of university patent applications. Meanwhile, the economic development of the region where the university is located does not affect the amount of patent applications of the university. Considering the special situation of "one country, two systems, and three customs" in the Greater Bay Area, we added dummy variables to measure institutional distance. The result shows that the institutional distance in the Greater Bay Area can promote the patent applications of universities in the region. It suggests that different institutions in the Greater Bay Area have certain advantages in the patent applications of universities. In further exploring the configuration analysis of individual patent transformation in universities, the result reveals that two paths affect the efficiency of patent transformation in mainland universities. The first path is the optimization of the university's own resources, including university researchers, research projects, and research funds. The second path is the combined efforts of the university and the region. Except for universities, the development of the regional economy and technological innovation can impact the transformation of university patents. From the empirical results, it is easy to observe that in both paths, research funding is a necessary condition to promote the patent transformation.

Based upon our study, the promotion of scientific and technological innovation output by universities in the Greater Bay Area requires efforts from the government and university. First of all, the government needs to transfer the fiscal support from the university patent application to the patent transformation, and launch supporting policies prioritizing the output of scientific and technological innovation. Since there is risk in transferring the patent and producing profitability, this requires the government to provide the venture fund to support and encourage patent transformation. Additionally, the government needs to establish technology transfer companies to support technology transfer, since it is a long and complex process involving different professional talents in product production, management and sales, which is beyond the capacity of patent inventors. Such measures may ensure the universities' enthusiasm towards patent applications and transformation. Well-developed regions should increase investments in university patent transformation to promote the local economy, and all cities within the Greater Bay Area under the 'one Country, two Systems' need to prioritize the output of scientific and technological innovation and regard the patent activities of universities as one of the driving forces for regional development. Secondly, patent applications are influenced more by universities' internal incentive policies than by the external environment, so it is worthwhile to adopt universities' incentive policies to encourage patent applications. Universities should optimize the allocation of talents, research projects and research funds to stimulate invention and patent applications. Finally, local governments and universities in the Greater Bay Area should acknowledge the advantages of the region's distinct institutions. They need to give priority to cooperation in scientific and technological innovation among universities and enterprises, enhance the vitality of innovation, and promote knowledge circulation within the Greater Bay Area.

This study has two limitations. First, the sample size of the data is small. If more data can be obtained, the causality of the research design can be more accurately deduced. Second, this paper mainly focuses on the Greater Bay Area in China. The Greater Bay Area under the 'one country, two systems' is different from the San Francisco Bay Area and European Union; thus, it would be worth conducting a comparative analysis over those different regions. Additionally, it is worthy of another try to explore science and technology innovation by applying another indicator—publications (articles, theses)—which could yield novel and intriguing findings.

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References

1. Zhou, M.; Wei, P.; Deng, L. Research on the Factorial Effect of Science and Technology Innovation (STI) Policy Mix Using Multifactor Analysis of Variance (ANOVA). *J. Innov. Knowl.* **2022**, *7*, 100249. [CrossRef]
2. Fernandes, C.I.; Veiga, P.M.; Ferreira, J.J.M.; Hughes, M. Green growth versus economic growth: Do sustainable technology transfer and innovations lead to an imperfect choice? *Bus. Strategy Environ.* **2021**, *30*, 2021–2037. [CrossRef]
3. Vimalnath, P.; Tietze, F.; Jain, A.; Gurtoo, A.; Eppinger, E.; Elsen, M. Intellectual property strategies for green innovations—An analysis of the European Inventor Awards. *J. Clean. Prod.* **2022**, *377*, 134325. [CrossRef]
4. Basberg, B.L. Foreign patenting in the U.S. as a technology indicator: The case of Norway. *Res. Policy* **1983**, *12*, 227–237. [CrossRef]
5. Basberg, B.L. Patents and the measurement of technological change: A survey of the literature. *Res. Policy* **1987**, *16*, 131–141. [CrossRef]
6. Kobicheva, A.; Baranova, T.; Tokareva, E. The Development of an Interaction Mechanism between Universities and Other Innovation System Actors: Its Influence on University Innovation Activity Effectiveness. *J. Open Innov. Technol. Mark. Complex.* **2020**, *6*, 109. [CrossRef]
7. Sampat, B.N.; Mowery, D.C.; Ziedonis, A.A. Changes in University Patent Quality after the Bayh–Dole Act: A Re-Examination. *Int. J. Ind. Organ.* **2003**, *21*, 1371–1390. [CrossRef]
8. Baldini, N.; Grimaldi, R.; Sobrero, M. Institutional Changes and the Commercialization of Academic Knowledge: A Study of Italian Universities' Patenting Activities between 1965 and 2002. *Res. Policy* **2006**, *35*, 518–532. [CrossRef]

9. Geuna, A.; Rossi, F. Changes to University IPR Regulations in Europe and the Impact on Academic Patenting. *Res. Policy* **2011**, *40*, 1068–1076. [CrossRef]
10. Bagheri, S.K.; Goodarzi, M.; Mahdad, M.; Ali Eshtehardi, M.S. Popularity of Patent Commercialization Policies: Iran as a Case. *World Pat. Inf.* **2021**, *66*, 102063. [CrossRef]
11. Bond, E.W.; Saggi, K. Patent Protection in Developing Countries and Global Welfare: WTO Obligations versus Flexibilities. *J. Int. Econ.* **2020**, *122*, 103281. [CrossRef]
12. State Intellectual Property Office Strategic Research Recent Progress of Patent Transfer and Transformation in Foreign Universities. Available online: https://www.cnipa.gov.cn/art/2015/5/25/art_1415_133136.html (accessed on 16 November 2023).
13. Malik, T.H. National Institutional Differences and Cross-Border University–Industry Knowledge Transfer. *Res. Policy* **2013**, *42*, 776–787. [CrossRef]
14. Mowery, D.C.; Ziedonis, A.A. Markets versus Spillovers in Outflows of University Research. *Res. Policy* **2015**, *44*, 50–66. [CrossRef]
15. Fasi, M.A. An Overview on Patenting Trends and Technology Commercialization Practices in the University Technology Transfer Offices in USA and China. *World Patent Inf.* **2022**, *68*, 102097. [CrossRef]
16. Cowan, R.; Zinovyeva, N. University Effects on Regional Innovation. *Res. Policy* **2013**, *42*, 788–800. [CrossRef]
17. Huggett, B. Reinventing Tech Transfer. *Nat. Biotechnol.* **2014**, *32*, 1184–1191. [CrossRef]
18. Shen, H.; Coreynen, W.; Huang, C. Prestige and Technology-Transaction Prices: Evidence from Patent-Selling by Chinese Universities. *Technovation* **2023**, *123*, 102710. [CrossRef]
19. Hsu, C.-W. Formation of industrial innovation mechanisms through the research institute. *Technovation* **2005**, *25*, 1317–1329. [CrossRef]
20. Etzkowitz, H. Innovation in Innovation: The Triple Helix of University-Industry-Government Relations. *Soc. Sci. Inf.* **2003**, *42*, 293–337. [CrossRef]
21. Etzkowitz, H. Incubation of incubators: Innovation as a triple helix of university-industry-government networks. *Sci. Public Policy* **2002**, *29*, 115–128. [CrossRef]
22. Hicks, D. Performance-Based University Research Funding Systems. *Res. Policy* **2012**, *41*, 251–261. [CrossRef]
23. Goldfarb, B. The Effect of Government Contracting on Academic Research: Does the Source of Funding Affect Scientific Output? *Res. Policy* **2008**, *37*, 41–58. [CrossRef]
24. Caviggioli, F.; Colombelli, A.; De Marco, A.; Scellato, G.; Ughetto, E. The Impact of University Patenting on the Technological Specialization of European Regions: A Technology-Level Analysis. *Technol. Forecast. Soc. Chang.* **2023**, *188*, 122216. [CrossRef]
25. Williams, K. Playing the Fields: Theorizing Research Impact and Its Assessment. *Res. Eval.* **2020**, *29*, 191–202. [CrossRef]
26. Fu, Y. The Impact of Government Funding on Research Innovation: An Empirical Analysis of Chinese Universities. *Manag. Decis. Econ.* **2023**, *44*, 285–296. [CrossRef]
27. Batabyal, A.A.; Nijkamp, P. Human capital use, innovation, patent protection, and economic growth in multiple regions. *Econ. Innov. New Technol.* **2013**, *22*, 113–126. [CrossRef]
28. Quatraro, F. Diffusion of Regional Innovation Capabilities: Evidence from Italian Patent Data. *Reg. Stud.* **2009**, *43*, 1333–1348. [CrossRef]
29. Coronado, D.; Flores, E.; Martínez, M.Á. The Role of Regional Economic Specialization in the Production of University-Owned Patents. *Ann. Reg. Sci.* **2017**, *59*, 513–533. [CrossRef]
30. Zhuang, T.; Zhao, S.; Zheng, M.; Chu, J. Triple Helix Relationship Research on China's Regional University–Industry–Government Collaborative Innovation: Based on Provincial Patent Data. *Growth Chang.* **2021**, *52*, 1361–1386. [CrossRef]
31. Kostova, T.; Zaheer, S. Organizational Legitimacy under Conditions of Complexity: The Case of the Multinational Enterprise. *Acad. Manag. Rev.* **1999**, *24*, 64–81. [CrossRef]
32. Sohn, C. Modelling Cross-Border Integration: The Role of Borders as a Resource. *Geopolitics* **2014**, *19*, 587–608. [CrossRef]
33. Koschatzky, K. A River is a River-Cross-Border Networking Between Baden and Alsace. *Eur. Plan. Stud.* **2000**, *8*, 429–449. [CrossRef]
34. Platonov, V.; Bergman, J. Cross-Border Cooperative Network in the Perspective of Innovation Dynamics. *Int. J. Knowl.-Based Organ.* **2011**, *1*, 1–19. [CrossRef]
35. Jue, W.; Chandra, K.; Du, C.; Ding, W.; Wu, X. Assessing the Potential of Cross-Border Regional Innovation Systems:A Case Study of the Hong Kong -Shenzhen Region. *Technol. Soc.* **2021**, *65*, 101557. [CrossRef]
36. OECD. *Regions and Innovation: Collaborating across Borders*; OECD Reviews of Regional Innovation; OECD Publishing: Washington, DC, USA, 2013.
37. Yang, Z.; Lin, Z.; Li, L.; Lam, F.I. The Guangdong-Hong Kong-Macao greater Bay area cooperation under 'one country, two systems' Comparison with European Union and San Francisco Bay Area. *Hong Kong J. Soc. Sci.* **2022**, *58*, 1–29.
38. Li, L.C.; Luo, M.; Yang, S. Institutional Differences and Institutional Innovation: Reforms in the Greater Bay Area under the Interaction of Multiple Institutions. *Public Adm. Rev.* **2020**, *13*, 23–39.
39. Guo, K. Greater Bay Area Leads in China's Overseas Invention Patents Licensed: Report. Available online: https://www.chinadaily.com.cn/a/202305/21/WS6469505ea310b6054fad4280.html (accessed on 17 November 2023).
40. Lemley, M.A.; Feldman, R. Patent Licensing, Technology Transfer, and Innovation. *Am. Econ. Rev.* **2016**, *106*, 188–192. [CrossRef]
41. Zhang, G.; Duan, H.; Zhou, J. Investigating determinants of inter-regional technology transfer in China: A network analysis with provincial patent data. *Rev. Manag. Sci.* **2016**, *10*, 345–364. [CrossRef]

42. Sternitzke, C.; Bartkowski, A.; Schramm, R. Visualizing patent statistics by means of social network analysis tools. *World Pat. Inf.* **2008**, *30*, 115–131. [CrossRef]
43. Kotabe, M.; Dunlap-Hinkler, D.; Parente, R.; Mishra, H.A. Determinants of cross-national knowledge transfer and its effect on firm innovation. *J. Int. Bus. Stud.* **2007**, *38*, 259–282. [CrossRef]
44. Jin, P.; Mangla, S.K.; Song, M. The power of innovation diffusion: How patent transfer affects urban innovation quality. *J. Bus. Res.* **2022**, *145*, 414–425. [CrossRef]
45. Henderson, R.; Jaffe, A.B.; Trajtenberg, M. Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965–1988. *Rev. Econ. Stat.* **1998**, *80*, 119–127. [CrossRef]
46. Anderson, T.R.; Daim, T.U.; Lavoie, F.F. Measuring the efficiency of university technology transfer. *Technovation* **2007**, *27*, 306–318. [CrossRef]
47. Xie, X.; Wang, H. How can open innovation ecosystem modes push product innovation forward? An fsQCA analysis. *J. Bus. Res.* **2020**, *108*, 29–41. [CrossRef]
48. Macho-Stadler, I.; Pérez-Castrillo, D.; Veugelers, R. Licensing of university inventions: The role of a technology transfer office. *Int. J. Ind. Organ.* **2007**, *25*, 483–510. [CrossRef]
49. Ho, J.; Plewa, C.; Lu, V.N. Examining strategic orientation complementarity using multiple regression analysis and fuzzy set QCA. *J. Bus. Res.* **2016**, *69*, 2199–2205. [CrossRef]
50. Bouncken, R.B.; Fredrich, V.; Sinkovics, N.; Sinkovics, R.R. Digitalization of cross-border R&D alliances: Configurational insights and cognitive digitalization biases. *Glob. Strategy J.* **2023**, *13*, 281–314. [CrossRef]
51. Anselin, L. *Spatial Econometrics: Methods and Models*; Springer Science & Business Media: Dordrecht, The Netherlands, 1988.
52. Anselin, L.; Florax, R.; Rey, S.J. *Advances in Spatial Econometrics: Methodology, Tools and Applications*; Springer Science & Business Media: Dordrecht, The Netherlands, 2013.
53. Fingleton, B.; Le Gallo, J. Estimating Spatial Models with Endogenous Variables, a Spatial Lag and Spatially Dependent Disturbances: Finite Sample Properties. *Pap. Reg. Sci.* **2008**, *87*, 319–339. [CrossRef]
54. Dalmarco, G.; Dewes, M.d.F.; Zawislak, P.A.; Padula, A.D. Universities' Intellectual Property: Path for Innovation or Patent Competition? *J. Technol. Manag. Innov.* **2011**, *6*, 159–170. [CrossRef]
55. Verspagen, B. University Research, Intellectual Property Rights and European Innovation Systems. *J. Econ. Surv.* **2006**, *20*, 607–632. [CrossRef]
56. Rafferty, M. The Bayh–Dole Act and university research and development. *Res. Policy* **2008**, *37*, 29–40. [CrossRef]
57. Christopher, O.; Iyabo, M. Impact of Information Literacy Skills on Academic Staff Research Productivity in Nigerian Federal Universities. *Inf. Knowl. Manag.* **2013**, *3*, 9–18.
58. Guerzoni, M.; Aldridge, T.T.; Audretsch, D.B.; Desai, S. A New Industry Creation and Originality: Insight from the Funding Sources of University Patents. In *Universities and the Entrepreneurial Ecosystem*; Edward Elgar Publishing: Cheltenham, UK, 2017; pp. 199–208.
59. Azagra-Caro, J.; Archontakis, F.; Yegros-Yegros, A. In Which Regions Do Universities Patent and Publish More? *Scientometrics* **2007**, *70*, 251–266. [CrossRef]
60. Acosta, M.; Coronado, D.; Martínez, M.Á. Spatial Differences in the Quality of University Patenting: Do Regions Matter? *Res. Policy* **2012**, *41*, 692–703. [CrossRef]
61. Yang, W.; Fan, F.; Wang, X.; Yu, H. Knowledge Innovation Network Externalities in the Guangdong–Hong Kong–Macao Greater Bay Area: Borrowing Size or Agglomeration Shadow? *Technol. Anal. Strateg. Manag.* **2022**, *34*, 1020–1037. [CrossRef]
62. Ragin, C.C. *The Comparative Method: Moving Beyond Qualitative and Quantitative Strategies*; University of California Press: Berkeley, CA, USA, 1987.
63. Du, Y.Z.; Jia, L.D. Configuration Perspective and Qualitative Comparative Analysis (QCA): A New Way of Management Research. *Manag. World* **2017**, *6*, 155–167. [CrossRef]
64. Veri, F. Coverage in Fuzzy Set Qualitative Comparative Analysis (fsQCA): A New Fuzzy Proposition for Describing Empirical Relevance. *Comp. Sociol.* **2018**, *17*, 133–158. [CrossRef]
65. Dogra, N.; Adil, M.; Sadiq, M.; Dash, G.; Paul, J. Unraveling Customer Repurchase Intention in OFDL Context: An Investigation Using a Hybrid Technique of SEM and fsQCA. *J. Retail. Consum. Serv.* **2023**, *72*, 103281. [CrossRef]
66. Rogers, E.M.; Takegami, S.; Yin, J. Lessons Learned about Technology Transfer. *Technovation* **2001**, *21*, 253–261. [CrossRef]
67. Mansfield, E.; Lee, J.-Y. The modern university: Contributor to industrial innovation and recipient of industrial R&D support. *Res. Policy* **1996**, *25*, 1047–1058. [CrossRef]
68. Schneider, C.Q.; Wagemann, C. *Set-Theoretic Methods for the Social Sciences: A Guide to Qualitative Comparative Analysis*; Strategies for Social Inquiry; Cambridge University Press: Cambridge, UK, 2012. [CrossRef]
69. Fiss, P.C. Building Better Causal Theories: A Fuzzy Set Approach to Typologies in Organization Research. *Acad. Manag. J.* **2011**, *54*, 393–420. [CrossRef]
70. Thomas, G.; Santi, F.; Fiss, P.C.; Aguilera, R.V. Studying Configurations with Qualitative Comparative Analysis: Best Practices in Strategy and Organization Research. *Strateg. Organ.* **2018**, *16*, 482–495. [CrossRef]

71. Sun, Y. Thoughts on the management of scientific research funds from the current situation of scientific research project management in colleges and universities. *China Econ.* **2006**, *8*, 125–148. [CrossRef]
72. Xu, X.M. Human Capital Investment Compensation of Scientific Research Projects in Universi-ties: Based on the Regulation of Expenditures in Scientific Research Funds. *China Soft Sci.* **2009**, *12*, 32–38. [CrossRef]