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Enhancing economic growth through financial industry agglomeration: Policy recommendations for the Guangdong-Hong Kong-Macao Greater Bay Area

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ABSTRACT

This study provides an in-depth empirical analysis of the determinants of regional economic growth in the Guangdong-Hong Kong-Macao Greater Bay Area, focusing on the roles of financial industry agglomeration, innovation, environmental regulation intensity, urbanization, and population density from 2007 to 2021. Utilizing a comprehensive panel dataset across 21 cities and employing advanced econometric techniques including the Method of Moments Quantile Regression this research uncovers robust evidence that financial development and innovation are consistent and powerful drivers of economic growth, regardless of city size or developmental stage. The findings indicate that, although advancement and innovation in the financial sector are universal drivers of economic performance, the impacts of environmental regulation and urbanization are more complex and highly heterogeneous across various quantiles of economic growth. Specifically, environmental regulation tends to promote growth in less developed cities but may impose constraints in more developed urban centers, whereas urbanization is more influential at early stages but diminishes as a city grows. The supported long-term cointegrating relationships between the variables also highlight that the regions involved require uniform, region-specific measures to maintain balanced, sustainable, and innovation-driven growth. These findings contribute to existing research in regional economics and offer transparent, applicable policy insights for decision-makers aiming to facilitate inclusive and resilient urban growth within one of China's most vibrant metropolitan areas.

Contribution/Originality: This study contributes to the existing literature by examining the determinants of regional economic growth in the Greater Bay Area. It employs a new estimation methodology through the Method of Moments Quantile Regression. This study is among the few that have investigated financial agglomeration, innovation, regulation, and urbanization simultaneously.

1. INTRODUCTION

Nine cities from Guangdong Province, along with Hong Kong and Macao Special Administrative Regions in the Greater Bay Area (GBA), form one of China's most comprehensive regional development plans. As a result, this region has achieved significant economic strength, contributing to China's GDP and playing a major role in shaping the global economy. The GBA's combined GDP exceeded 13 trillion yuan, demonstrating the region's rapid and impressive growth compared to New York, Tokyo, and London (Newswire, 2024). Thanks to the unique combination of economic, cultural, institutional, and innovative features, the GBA is now a focal point of regional economic

research, primarily emphasizing the significance of financial industry gatherings for economic growth and development (Peng & Qiu, 2023).

For a long time, experts have viewed the grouping of financial institutions and similar economic activities in the same location as a main reason for economic expansion (Pandit, Cook, & Swann, 2001; Wenger, Harris, Sivanpillai, & DeVault, 1999). During the 1980s, Weber pointed out that being close to each other decreases the costs of business transactions, allows knowledge to spread, boosts innovation, and supports growth in productivity. Brülhart and Mathys (2008) continued this research, demonstrating with evidence that concentrations of economic activities tend to improve European regions' productivity and chances for fair competition.

People have noticed the benefits of financial agglomeration in the GBA context, including improved allocation of funds, higher efficiency in financial businesses, and increased innovative activities through information sharing in the area (Wang, Wang, Ding, & Guo, 2023). Financial institutions benefit from clusters by saving money, recruiting skilled individuals, and fostering knowledge sharing, all of which bolster economic activity in the area (Wei et al., 2024). Experience in other major global financial centers such as Singapore and New York proves that strong financial aggregation can help regional economies remain stable during global financial disturbances (Leung & Unteroberdoerster, 2008).

Although many recognize these positive effects, people remain uncertain about what financial agglomeration specifically does for local economies in different regions, especially in rapidly growing areas focused on the environment, such as the GBA. Previously, research on financial agglomeration mainly explained overall trends but did not thoroughly examine differences in its effects across various economic tiers or integrate features such as environmental laws, urban growth, innovation strengths, and population statistics into the analysis (Wang, 2021). In more detail, studies thus far fail to explain the intricacies that come from different cities in the GBA regarding development, institutions, and regulations (Wang, Zhang, & Zhang, 2021).

When one examines how the region supports major China-led projects, such as the Belt and Road Initiative and the plan for high-quality development, it is clear that the research gap is becoming more serious. For this reason, policymakers must rely on precise empirical information to adopt policies that suit each region's needs, reduce disparities, and promote balanced growth across regions. Previous literature offers limited guidance on managing potential negative externalities associated with agglomeration, such as environmental degradation and increased resource pressures, necessitating a more comprehensive approach to analyzing regional economic dynamics (Correia & Roseland, 2022).

Considering these gaps, the current study aims to systematically analyze how financial industry agglomeration influences regional economic growth within the GBA across various economic quantiles. This research explicitly assesses and quantifies the effects of financial development, innovation (proxied through patent activities), environmental regulation intensity, urbanization, and population density on regional economic performance measured via regional gross domestic product (RGDP). The research objectives are threefold: firstly, to investigate the direct impacts of financial industry agglomeration and related economic determinants on regional growth; secondly, to explore whether these impacts differ significantly across various economic quantiles, capturing heterogeneity in agglomeration effects; and thirdly, to evaluate the moderating roles of innovation, environmental regulation, and urbanization on the agglomeration-growth nexus.

This research carries considerable theoretical and practical significance. Theoretically, it integrates insights from endogenous growth theory, new economic geography, and agglomeration economics to deepen the understanding of how clustered economic activities specifically translate into measurable regional growth outcomes within complex metropolitan frameworks (Krugman, 1991; Romer, 1994). Practically, findings from this research will assist policymakers and regional planners within the GBA in formulating strategies that harness financial agglomeration effectively while mitigating associated risks, particularly in areas experiencing rapid urbanization and stringent environmental regulatory environments.

It is also important to look at how patent activities can stand in for innovation to observe the effect of technology and cluster formations in communities on their stability and adaptability (Lyu, Sun, & Huang, 2019). New evidence underlines that innovation is very important for the success of metropolitan zones across the globe, which is why it should be a main focus in regional development analyses (Bloom, Jones, Van Reenen, & Webb, 2020). When these points are concerned, understanding the function of environmental regulation aids sustainability in economic development discussions, especially as many nations and groups now seek to link growth with environmental protection.

In addition, employing Method of Moments Quantile Regression (MMQR) in this research makes the study empirically valuable. According to Machado and Silva (2019) MMQR helps address the formal barriers in previous linear panel data models thanks to its identification of dissimilar effects at different economic levels, leading to more meaningful insights. Due to the careful approaches used, the research results will provide helpful policy guidance relevant to the economy and social situation in the GBA.

Since it considers research gaps and helps develop the theoretical and research aspects of the subject, this study supports and expands research within regional economics on the role of financial agglomeration in promoting balanced growth, sustainability, and regional unity. The results of this research are not limited to the GBA area and can contribute to a better understanding of similar issues affecting other rapidly growing metropolitan regions worldwide.

Therefore, this research presents useful ideas that enable policymakers in the GBA and similar regions to better utilize the benefits of financial agglomeration. As a result, it actively contributes to discussions on promoting fair and sustainable development in the region, especially as the world faces numerous institutional, technological, and environmental challenges.

The rest of the paper is divided as follows: after this introduction, a literature review carefully considers current research on financial industry grouping, economic growth, innovation, environmental regulations, and population growth. The review clarifies that this study relates to recent developments in the field. Next, information on data sources, included variables, and methods used ensures transparency and reproducibility. The methodology section presents key results, explains their theoretical implications, and discusses potential policy impacts. Finally, the conclusion summarizes main points, recommends policy measures based on findings, acknowledges limitations, and suggests areas for future research.

2. LITERATURE REVIEW

For many years, the impact of financial industry agglomeration on regional economic growth has played a key role in economic geography, urban economics, and regional development. Marshal is considered the founder of these theories, as he suggested that by congregating, similar firms help boost efficiency through the pooling of labor, sharing of resources, and transferring new ideas (Marshall, 1890). Later, Weber (1982) added that when firms are located close to each other, they can achieve better productivity since moving goods is easier and there is more chance for collaboration. Such classical ideas provide a solid base for people today who research finance, its locations, and their effects on developing economies (Brülhart & Mathys, 2008; Krugman, 1991).

Agglomeration economies are particularly relevant for the financial sector, which relies heavily on information exchange, trust, and rapid transaction processing. The clustering of banks, insurance companies, venture capital firms, and fintech enterprises creates fertile ground for knowledge diffusion and innovation (Pandit et al., 2001). In global financial centers such as London, New York, and Singapore, the agglomeration of financial services has been associated with increased productivity, specialization, and the emergence of sophisticated capital markets (Leung & Unteroberdoerster, 2008; Wójcik, Liam, Vladimír, Michael, & Wu, 2022). In the Chinese context, financial agglomeration is regarded as a strategic driver of economic modernization, especially within high-growth

metropolitan regions such as the Yangtze River Delta, the Beijing-Tianjin-Hebei area, and the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) (Peng & Qiu, 2023).

Many studies have proven that having financial institutions concentrated in one region boosts its economic growth. Yuan (2020) pointed out that when the financial industry is located together, it helps Chinese provinces grow faster due to improved use of funds, a rise in productive investment, and support for innovation. According to (Lu, Wang, & Zhu, 2019), financial agglomeration helps local economies and, at the same time, provides benefits to nearby regions. Peng and Qiu (2023) noted that the financial sectors being concentrated in certain Chinese cities help these cities resist financial shocks due to their access to a broader range of financial tools and a more robust institutional setting.

Similar views are supported by experts from different countries. Porter (1998) as well as Glaeser, Kallal, Scheinkman, and Shleifer (1992) explain that clusters support the competitiveness of regions by gathering capital and skilled employees, whereas Camagni (1991) and Jacobs (2016) emphasize that heterogeneous urban settings highly encourage new ideas and business ventures. Current evidence from Europe (Brülhart & Mathys, 2008), North America (Hill et al., 2012), and Asian markets (Wei et al., 2024) points out that financial clustering encourages economic activities and builds more protective regional areas against world shocks.

Financial agglomeration leads to economic growth mainly because of innovation. When financial sectors are strong, the region will attract experts, boost research activities, and record many patents (Bloom et al., 2020). Li, Zhu, Chen, and Jiang (2019) revealed that more financial agglomeration in cities of China leads to more patent applications and an increase in knowledge-intensive industries. Financial clusters, both young startups and mature companies, can access venture capital and other tools for managing risks needed to introduce new technologies to the market (Audretsch & Feldman, 2004; Wang, Yanan, Youxia, Kaiji, & Chen, 2021).

Because of Shenzhen's growing number of tech businesses, venture capitalists, and financial institutions, the GBA is known for a clear link between financial agglomeration and innovation. Yi Liu and He (2024) highlight that combined industrial development in the GBA has encouraged the region to improve its development and transition to more advanced sectors.

The roles of environmental regulations in determining the impacts of financial agglomeration are being widely studied. Porter and Van Der Linde (1995) believe that strict environmental policies motivate firms to innovate, which helps reduce their compliance expenses and contributes to their lasting advantage in the market. Li et al. (2019) and Ren, Liu, and Zhao (2020) indicate that strict environmental policies in financial centres result in better green innovation and higher eco-efficiency in China.

Still, the results of environmental regulation differ from one situation to another. In specific places, strict regulatory policies may stop investors from putting money in and slow down the rate of growth (Stamm & Vorisek, 2023). Weng, Qin, and Li (2020) discovered that different industries in the Beijing-Tianjin-Hebei area are affected differently by regulation, and the effect depends on how well-developed their finances are. Wang et al. (2021) further noted that while environmental policies can enhance economic efficiency in finance-driven clusters, they may inadvertently widen regional disparities if less-developed areas lack the resources to comply or innovate.

Urbanization is widely acknowledged as a major driver of financial agglomeration and economic growth (Yejin Liu, Yang, & Cui, 2024; Wang et al., 2021). Densely populated urban regions offer financial institutions large client bases, access to talent, and network effects that promote innovation (Jacobs, 2016). In China, rapid urbanization has been associated with increased financial sector development, particularly in megacities such as Shanghai, Beijing, and Shenzhen (Wong, Li, Zhang, Kong, & Cai, 2021). Urbanization also enables the pooling of human capital, which is crucial for sustaining innovation and entrepreneurship in finance and related sectors (Florida, 2003).

Yet, the literature recognizes challenges linked to rapid urbanization. Infrastructure congestion, pollution, and social inequality can offset the benefits of financial clustering if not properly managed (Han, Zhou, Li, & Qian, 2018). Moreover, regional disparities in urbanization and population density often lead to unequal access to financial

services, limiting the positive effects of agglomeration in less-developed cities (Leung & Unteroberdoerster, 2008; Wójcik et al., 2022). Experts state that combining efforts in urban planning, environmental policy, and the financial field can lead to the greatest benefits from urban agglomeration (Luo et al., 2024).

Many studies point out that traditional linear econometric models have trouble analyzing the impacts of agglomeration in rapidly changing and diverse regions. Typically used models, for instance fixed and random effects, may obscure major differences in how agglomeration affects the distribution of economic performance (Machado & Silva, 2019). Two types of research with advanced panel approaches have found that how agglomeration helps growth is not the same in different regions, indicating a need for more detailed ways to study this issue (Hansen, 2007; Liu, Yang, Zhang, Wu, & Wan, 2024).

As shown by Ganda (2020), there are variations in the responsiveness of GDP to the financial sector's concentration in Chinese provinces due to their original economies and local policies. It was found by Wang et al. (2021) that financial agglomeration helps green economic efficiency more in advanced and ingenious cities. Using MMQR, researchers can determine which groups in society benefit the most from economic concentration.

It is possible to study how financial agglomeration, innovation, protective measures, urbanization, and population levels have similar or different impacts in the GBA. Attributes of this type are deep differences between Hong Kong and Macao on the one hand, and mainland cities on the other, especially in legal and financial terms. Because of the mixed impact of cross-border traffic and high complexity, there are now more opportunities and more problems for joint regional development (Liu & He, 2024; Tang, Cai, & Wang, 2025).

Latest studies, Wong et al. (2021) and Peng and Qiu (2023), prove how the GBA is doing its best to be a hotspot for finance, but it has revealed continuous differences among cities. While Guangzhou, Shenzhen, and Hong Kong are financially focused with many innovations, Zhuhai and Foshan are less innovative (Luo et al., 2024). The literature suggests that targeted policy interventions addressing gaps in human capital, infrastructure, and environmental standards are needed to ensure more balanced regional growth (Mohanty & Kumar, 2021; Peng & Qiu, 2023).

Notwithstanding an expanding knowledge base on the topic of financial agglomeration and the economic growth of regions, there remain considerable constraints to the current literature. First, the vast majority of the previous research is limited to the national or provincial level, as this conceals the existence of significant intra-regional imbalances and does not account for the level of city-level heterogeneity, which is key to economically diverse regions like the GBA. Second, prior studies usually base their analysis on outdated methods of linear modeling that are unfit to capture the nonlinearities and heterogeneous influences of the regional development spectrum (Liu et al., 2024; Machado & Silva, 2019). This often results in the neglect of subtle relationships, such as the potential differences in growth determinants between less-developed and advanced cities. Third, a significant lack of integrative models involving the dynamic interaction of the factors of financial agglomeration, innovation, environmental regulation, urbanization, and population density can also be observed. The bulk of literature tends to cover these factors individually, instead of studying their overall and possibly interacting effects, especially in such complex and multi-jurisdictional areas as the GBA. This paper presents a new contribution by alleviating these weaknesses to shed light on the differential effects of such determinants using sophisticated panel quantile regression techniques, which allow us to use context-sensitive detailed explanations of regional growth processes and be able to provide more actionable information to policymakers in designing specific types of policies to address those effects.

This study contributes to the literature by employing a panel MMQR approach to examine the heterogeneous effects of financial industry agglomeration, innovation, environmental regulation intensity, urbanization, and population on economic growth across the GBA's diverse cities. The research finds the people and situations where agglomeration policies have the best results through analyzing multiple quantiles. This detailed perspective provides insights to policymakers who are creating policies for sustainable growth in many regions.

3. METHODOLOGY

Here, we describe the empirical model, source of data, terms for variables, and the methodology used to determine the link between industries in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) and the region's economic development. We have used a balanced panel dataset that spans from 2007 to 2021 to analyze 21 cities in Guangdong Province, as detailed below.

The main purpose of this study is to measure how financial development, innovations, environmental laws, urbanization, and population numbers affect economic growth in regions. The above panel regression model was developed with the help of such recent research studies as Yuan (2020) and Machado and Silva (2019).

$$RGDP_{it} = \alpha_0 + \beta_1 FDL_{it} + \beta_2 PATENT_{it} + \beta_3 ERI_{it} + \beta_4 URBAN_{it} + \beta_5 POP_{it} + \mu_i + \varepsilon_{it}$$

Where:

$RGDP_{it}$: The log of regional GDP for the city i at time t.
FDL_{it} : The financial development level.
$PATENT_{it}$: The number of patent applications (Proxy for innovation).
ERI_{it} : Environmental regulation intensity.
$URBAN_{it}$: The urbanization rate.
POP_{it} : Population density.
μ_i : Captures unobserved city-specific effects.
ε_{it} : The idiosyncratic error term.

Various studies apply this model to look at the influence of institutions, demographics, and policies on the development of different regions (see (Brülhart & Mathys, 2008; Wang & He, 2023)).

In the dataset, there are 315 observations, reflecting 21 cities and 15 years from 2007 to 2021. The included cities are: Guangzhou, Shaoguan, Shenzhen, Zhuhai, Shantou, Foshan, Jiangmen, Zhanjiang, Maoming, Zhaoqing, Huizhou, Meizhou, Shanwei, Heyuan, Yangjiang, Qingyuan, Dongguan, Zhongshan, Chaozhou, Jieyang, and Yunfu.

Data were gathered using information from the CSMAR database as well as the China Energy Statistical Yearbook Li et al. (2019). All variables have descriptions to ensure that city comparisons can be conducted consistently over time. Table 1 presents the definitions, measurements, and data sources of the variables.

Table 1. Variable definitions and data sources.

Symbol	Description	Measurement	Source
RGDP	Economic growth	Log of regional GDP	China stock market & accounting research database (CSMAR)
FDL	Financial development level	Composite index	CSMAR, authors' calculations
PATENT	Regional innovation	Log of patent applications	CSMAR, local yearbooks
ERI	Environmental regulation intensity	Composite index	News reports, Govt. documents
URBAN	Urbanization rate	% of urban population	CSMAR, local yearbooks
POP	Population density	Persons per km²	CSMAR, local yearbooks

Because the dataset could be cross-sectionally dependent, non-stationary, and exhibit heterogeneous effects, a comprehensive multi-step strategy was chosen for econometric analysis. To identify main trends and early relationships between variables, the research began with descriptive statistics and pairwise correlation analysis, as is typical in panel data investigations (Aldamen & Duncan, 2016; Baltagi, 1998). To ensure the accuracy of the estimates derived from the regression, tests for cross-sectional dependence (CD) and panel unit root tests, as suggested by Pesaran (2014), have been conducted. The evidence indicates that significant connections exist among the variables, each exhibiting its own level of integration, which necessitates the use of cointegration analysis. In the long run, it was necessary to check if the primary variables formed stable relationships among themselves using both (Pedroni, 1999) and Westerlund (2007) panel cointegration tests. The finding of cointegration justified calculating long-run effects in the panel data (Pedroni, 1999; Westerlund, 2007).

This study chose to apply the Method of Moments Quantile Regression (MMQR) to measure the various ways growth impacts each part of the distribution (Machado & Silva, 2019). MMQR model advances by enabling the estimation of different effects of variables across various parts (quantiles) of the growth distribution, which is useful for studying diverse cities (Liu et al., 2024). Using this technique addresses the common problems of non-linearity and unobserved heterogeneity that exist in regional panel data studies (Hansen, 2007). To ensure the results were robust, alternative models were considered, and the standard errors were grouped by city.

The selection of the sample period from 2007 to 2021 is motivated by the rapid transformation of the Guangdong-Hong Kong-Macao Greater Bay Area (GBA) into a major economic hub during these years, marked by significant reforms in financial sector development, urbanization, and innovation policy. This period encompasses the processes before and after the financial crisis and coincides with the establishment of major regional integration programs, allowing for a more comprehensive examination of the changing growth drivers. All selected variables financial development, innovation (patent applications), intensity of environmental regulation, urbanization, and population density are distinct and deemed among the most appropriate variables in light of both theory and evidence for their use in the study of regional development literature. They are also complemented by a particular interest in the context occupied by the GBA as a multi-jurisdictional metropolitan region. The use of advanced panel data techniques, particularly the Method of Moments Quantile Regression (MMQR), is justified by the need to address unobserved heterogeneity, cross-sectional dependence, and the likelihood of nonlinear, quantile-specific effects among cities at different stages of development. This methodological choice is more specific and comprehensive in explaining the multi-faceted and multi-dimensional factors underlying economic growth in the region, thereby filling gaps and addressing methodological shortcomings in past literature.

4. RESULTS AND DISCUSSION

Following the methods section, the next section presents and explains the study's empirical findings using the models outlined earlier. Utilizing a balanced panel data set of 21 cities in the Guangdong-Hong Kong-Macao Greater Bay Area from 2007 to 2021, the results are displayed in a series of tables that include various statistics, correlation matrices, cross-sectional dependence tests, panel unit root tests, cointegration tests, and the estimated results from MMQR. These tables emphasize the significant relationships between financial development, innovation, environmental regulation strength, urbanization level, population size, and economic development at the regional level. Subsequently, the results are analyzed through existing theories and related research papers, highlighting how this research is unique and valuable for managing the GBA's economy and supporting its sustainable development.

Table 2. Summary of statistical analysis.

Variables	Mean	SD	Min.	Max.
RGDP	3.282	0.442	2.433	4.487
FDI	2.232	0.904	0.784	5.909
PATENT	4.005	0.693	1.851	5.633
ERI	0.003	0.001	0.000	0.009
URBAN	0.629	0.199	0.351	1.000
POP	2.763	0.298	2.242	3.423

Table 2 presents the summary of statistical analysis for the main variables included in the analysis, providing a snapshot of their distributions across 315 city-year observations. The regional GDP (RGDP) has a mean value of 3.282 with a standard deviation of 0.442, and ranges from 2.433 to 4.487, reflecting notable variation in economic output among the 21 cities in the Guangdong-Hong Kong-Macao Greater Bay Area over the study period. The financial development index (FDI) also shows considerable dispersion, with a mean of 2.232 and values spanning from 0.784 to 5.909, indicating differing levels of financial sector advancement across cities. The innovation indicator,

measured by the logarithm of patent applications (PATENT), has a mean of 4.005 and ranges from 1.851 to 5.633, demonstrating significant heterogeneity in regional innovative capacity.

Environmental regulation intensity (ERI) has a very low mean of 0.003 and minimal variation, which may reflect the generally modest or consistent levels of regulatory stringency across the sample. Urbanization (URBAN) shows a mean of 0.629 and ranges from 0.351 to 1.000, suggesting that while some cities are fully urbanized, others are still in transition. Population density (POP) exhibits a mean of 2.763, with a relatively narrow range, indicating moderate differences in demographic concentration. Overall, these statistics highlight the diversity and dynamic nature of the GBA cities, which is essential for exploring heterogeneous effects in the econometric analysis.

Table 3. Correlation matrix.

Variables	RGDP	FDI	PATENT	ERI	URBAN	POP
RGDP	1					
FDI	0.695	1				
PATENT	0.6372	0.504	1			
ERI	-0.0103	-0.0304	-0.0775	1		
URBAN	0.7356	0.6899	0.6472	-0.0093	1	
POP	0.5218	0.3157	0.3806	-0.1511	0.5587	1

Table 3 presents the correlation matrix for the main variables, offering insights into the linear associations among economic growth, financial development, innovation, environmental regulation, urbanization, and population density across the cities in the Guangdong-Hong Kong-Macao Greater Bay Area. Regional GDP (RGDP) exhibits strong positive correlations with financial development (FDI, 0.695), patent activity (PATENT, 0.6372), and urbanization (URBAN, 0.7356), indicating that higher economic growth is closely linked with more advanced financial sectors, greater innovation output, and higher levels of urbanization. Population density (POP) also shows a positive correlation with RGDP (0.5218), though it is somewhat weaker than the other variables, suggesting that denser cities tend to experience greater economic output.

The correlation between financial development and innovation is moderate (0.504), highlighting the complementary relationship between a well-developed financial sector and regional innovative capacity. Urbanization is positively correlated with both FDI (0.6899) and PATENT (0.6472), further emphasizing the role of urban dynamics in fostering economic and technological growth. In contrast, environmental regulation intensity (ERI) has weak or even slightly negative correlations with all other variables, most notably with population (-0.1511) and patent activity (-0.0775), suggesting that ERI may operate independently of economic or demographic factors in this context. Overall, these patterns support the relevance of all variables for inclusion in the subsequent econometric modeling.

Table 4. CD Test.

Variables	CD-test	p-value	Corr.	abs(corr.)
RGDP	55.140	0.000	0.982	0.982
FDI	46.540	0.000	0.829	0.829
PATENT	13.880	0.000	0.247	0.438
ERI	6.550	0.000	0.117	0.273
URBAN	31.530	0.000	0.562	0.663
POP	35.820	0.000	0.638	0.898

Table 4 reports the results of the Cross-Sectional Dependence (CD) test for each variable, assessing whether there are statistically significant interdependencies across cities in the panel dataset. The CD-test statistics are all highly significant (p-values = 0.000), strongly rejecting the null hypothesis of cross-sectional independence. This indicates that economic growth, financial development, innovation, environmental regulation, urbanization, and

population density in one city are not isolated from those in other cities but instead tend to move together to some degree, likely reflecting common shocks, regional integration, and shared economic policies in the Greater Bay Area.

The correlation coefficients further illustrate the strength of these interlinkages. For instance, RGDP and FDI have very high correlation values (0.982 and 0.829, respectively), indicating that economic output and financial development levels are closely synchronized across cities. Urbanization (0.562), population (0.638), and patent activity (0.247) also display moderate to strong correlations, while environmental regulation intensity, though lower (0.117), is still significant. The high values of absolute correlation suggest that ignoring cross-sectional dependence could bias standard panel estimates. Thus, these findings justify the application of econometric techniques, such as panel cointegration and quantile regression, that can appropriately account for inter-city dependencies in the empirical analysis.

Table 5. Pesaran panel unit root test.

	Level		First Diff.	
Variable	**Cal**	**tab**	**Cal**	**tab**
RGDP	-1.205	-2.14	-2.714	-2.14
FDI	-2.363	-2.14		
PATENT	-1.73	-2.14	-2.898	-2.14
ERI	-2.973	-2.14		
URBAN	-1.893	-2.14	-3.127	-2.14
POP	-1.223	-2.14	-2.311	-2.14

Table 5 displays the results of the Pesaran panel unit root test, which evaluates the stationarity properties of each variable in the panel dataset. The "cal" column shows the calculated test statistic, while "tab" indicates the critical value at the 5% significance level (−2.14). For a variable to be considered stationary, its calculated value must be lower (more negative) than the tabulated value.

At levels, several variables (RGDP, PATENT, URBAN, POP) have test statistics greater than the critical value (e.g., RGDP: $-1.205 > -2.14$), indicating the presence of a unit root and thus non-stationarity in their original forms. However, after first differencing, the test statistics for these variables drop below the critical value (e.g., RGDP: $-2.714 < -2.14$), suggesting that they become stationary at first difference and are thus integrated of order one, I(1). In contrast, FDI and ERI have calculated statistics at levels lower than the critical value (e.g., FDI: $-2.363 < -2.14$; ERI: $-2.973 < -2.14$), meaning these variables are stationary in levels, or I(0).

These results confirm that the panel data is a mix of I(0) and I(1) processes, justifying the use of cointegration techniques to test for long-run equilibrium relationships among variables. It also underscores the importance of appropriate transformation and modeling strategies in the subsequent empirical analysis.

Table 6. Pedroni Cointegration test for cointegration.

Test	Statistics	Prob.
Modified Phillips-Perron test	6.232	0.000
Phillips-Perron test	-0.360	0.360
Augmented Dickey-Fuller test	0.665	0.253

Table 6 reports the results of the Pedroni cointegration test, which is used to assess the existence of a long-run equilibrium relationship among the variables in the panel data model. The Pedroni framework employs several different test statistics; here, the Modified Phillips-Perron t, the Phillips-Perron t, and the Augmented Dickey-Fuller t statistics are presented.

The Modified Phillips-Perron t statistic is highly significant, with a value of 6.232 and a p-value of 0.000, indicating strong evidence to reject the null hypothesis of no cointegration. This suggests that, despite the mixed integration order found in the previous unit root tests, there is a stable, long-term relationship among economic

growth, financial development, innovation, environmental regulation, urbanization, and population density across the cities in the panel. The other two statistics, Phillips-Perron t (−0.360, p = 0.360) and Augmented Dickey-Fuller t (0.665, p = 0.253), are not statistically significant. However, cointegration panel tests often report several statistics, and the Modified Phillips-Perron t is considered more robust, especially in panels with heterogeneous dynamics (Pedroni, 1999).

Overall, these findings justify the use of panel cointegration and long-run modeling approaches, confirming that the core variables move together over time and that meaningful long-run policy implications can be drawn from the econometric analysis.

Table 7. Westerlund test for cointegration.

Test	Statistics	Prob.
Variance ratio	3.0796	0.001

Table 7 presents the results of the Westerlund test for cointegration, specifically the variance ratio statistic. The statistic value is 3.0796, with a highly significant p-value of 0.001. This result strongly rejects the null hypothesis of no cointegration, providing robust evidence that a long-run equilibrium relationship exists among the variables in the panel. The significance of this finding, alongside the Pedroni test results, further supports the appropriateness of modeling the interactions among economic growth, financial development, innovation, environmental regulation, urbanization, and population density using cointegrated panel techniques.

Table 8. MMQR Results.

Variables	10	20	30	40	50	60	70	80	90
FDI	0.175	0.176	0.176	0.176	0.176	0.176	0.177	0.177	0.177
SE	0.036	0.029	0.026	0.024	0.023	0.023	0.023	0.025	0.028
z-stat	4.85	5.99	6.69	7.2	7.64	7.77	7.62	7.04	6.42
PATENT	0.141	0.146	0.149	0.152	0.154	0.157	0.159	0.163	0.166
SE	0.041	0.033	0.03	0.028	0.026	0.026	0.026	0.028	0.031
z-stat	3.47	4.43	5.05	5.51	5.94	6.13	6.11	5.76	5.33
ERI	45.632	34.41	28.096	23.115	17.303	12.342	6.947	-0.326	-6.225
SE	16.832	13.671	12.212	11.363	10.719	10.584	10.806	11.634	12.743
z-stat	2.71	2.52	2.3	2.03	1.61	1.17	0.64	-0.03	-0.49
URBAN	0.557	0.527	0.51	0.497	0.482	0.469	0.454	0.435	0.419
SE	0.198	0.161	0.144	0.134	0.127	0.125	0.127	0.138	0.152
z-stat	2.81	3.27	3.54	3.7	3.8	3.76	3.57	3.15	2.76
POP	0.183	0.231	0.258	0.279	0.304	0.325	0.348	0.379	0.404
SE	0.095	0.077	0.069	0.064	0.06	0.06	0.061	0.066	0.072
z-stat	1.94	3	3.75	4.36	5.03	5.46	5.72	5.77	5.61
C	0.978	1.021	1.045	1.064	1.086	1.104	1.125	1.153	1.175
SE	0.258	0.209	0.188	0.175	0.165	0.162	0.165	0.179	0.197
z-stat	3.8	4.88	5.57	6.1	6.59	6.81	6.8	6.42	5.95

Table 8 reports the results of the Method of Moments Quantile Regression (MMQR), which estimates the effects of the core explanatory variables on regional economic growth (RGDP) at different points (quantiles) of the growth distribution, specifically from the 10th to the 90th quantile. This approach enables a nuanced understanding of how financial development, innovation, environmental regulation, urbanization, and population density influence economic performance across cities at varying development stages within the Guangdong-Hong Kong-Macao Greater Bay Area.

The results reveal that financial development (FDI) consistently exerts a positive and statistically significant effect across all quantiles, with coefficients ranging from 0.175 (10th quantile) to 0.177 (90th quantile). The significance and stability of these coefficients suggest that financial sector advancement robustly promotes economic

growth in both lower-performing and higher-performing cities, underscoring the universal importance of deepening financial industry agglomeration in regional economic strategies.

Innovation (PATENT), proxied by patent applications, also shows a consistently positive and significant effect on economic growth, with the magnitude gradually increasing from 0.141 at the 10th quantile to 0.166 at the 90th quantile. This indicates that innovation becomes even more critical for economic performance in cities that are already further along the development spectrum, reinforcing the need for policies that support technological advancement and knowledge creation.

The coefficient for environmental regulation intensity (ERI) is positive and significant at lower quantiles (45.632 at the 10th quantile, z-stat 2.71) but declines rapidly and turns negative at the upper quantiles (-6.225 at the 90th quantile, z-stat −0.49). This pattern suggests that stricter environmental regulations may support growth in less-developed cities, possibly by improving environmental quality or encouraging innovation, but could impose constraints on already highly developed or industrialized cities, perhaps due to higher compliance costs or diminishing returns.

Urbanization (URBAN) demonstrates a strong and significant positive relationship with economic growth throughout the distribution, though the effect gradually diminishes from 0.557 at the 10th quantile to 0.419 at the 90th quantile. This implies that urbanization is particularly transformative for less-developed cities, likely by fostering agglomeration economies and infrastructure improvements, but its marginal contribution decreases as cities mature.

Lastly, population density (POP) exerts a consistently positive and increasingly strong effect on growth, with coefficients rising from 0.183 to 0.404. Therefore, having a larger population in higher-growth cities leads to better economic performance due to stronger markets and beneficial connections.

The findings, in general, are in agreement with this research's main aim by exposing different influences of financial agglomeration, innovation, regulation, and urbanization factors on various cities. It is evident from the findings that when policies are adapted to the progress of local areas, the GBA's economic growth is enhanced.

In line with what the earlier studies showed, this study provides a detailed and thorough view of how financial industry clustering impacts local economies. Based on the previous literature, financial development (FDI) is found to have a stable and positive effect on economic growth at all its levels. As mentioned by Yuan (2020), Wang et al. (2021), and Peng and Qiu (2023), financial agglomeration improves sharing of resources, matches capital flow, and increases the economic stability of all cities in the GBA, whether they are less developed or advanced. As a result, financial development policies are useful for promoting regional development irrespective of initial city conditions, which matches the study's first goal to measure the direct influence of financial hubs on the regional economy.

Innovation, as captured by patent activity, also demonstrates a robust and increasing positive impact as cities progress through higher quantiles of economic growth. This is consistent with the arguments of Bloom et al. (2020), Li et al. (2019), and Tang et al. (2025), who identified innovation as a critical driver of regional competitiveness, particularly in more developed and innovation-oriented urban centers. The increasing effect of innovation at higher quantiles suggests that as cities move up the development ladder, their capacity to benefit from technological advancement and R&D becomes even more pronounced. Thus, fostering an innovation ecosystem through supportive financial instruments, human capital development, and institutional quality is essential for cities aspiring to join the ranks of global knowledge hubs.

The effect of environmental regulation intensity (ERI) is more complex, echoing the mixed findings in the literature. At lower quantiles, stricter environmental regulation appears to stimulate economic growth, which resonates with the Porter Hypothesis (Porter & Van Der Linde, 1995) and empirical evidence by Li et al. (2019) and Ren et al. (2020) suggesting that well-calibrated regulation can drive efficiency and green innovation in less-developed contexts. However, the negative or diminishing effects at higher quantiles may reflect increased regulatory burden or diminishing innovation returns in already advanced cities, as suggested by Stamm and Vorisek (2023).

The results for urbanization and population density reinforce the findings of Bettencourt, Lobo, Helbing, Kühnert, and West (2007) and Wei et al. (2024), highlighting the importance of agglomeration economies and network effects, particularly in the earlier stages of development. However, the decreasing marginal impact of urbanization as cities mature also warns against overreliance on urban expansion as a growth strategy, supporting calls in the literature for balanced development and infrastructure investment.

In sum, this study confirms the heterogeneous impacts of financial agglomeration, innovation, regulatory, and demographic factors across city contexts, underscoring the necessity for differentiated, context-sensitive policy approaches. These findings directly fulfill the research objectives and contribute actionable insights for sustainable and inclusive growth in the GBA.

5. CONCLUSION, POLICY IMPLICATIONS, AND FUTURE RESEARCH DIRECTIONS

This study provides new empirical evidence on the multifaceted effects of financial industry agglomeration, innovation, environmental regulation, urbanization, and population density on regional economic growth within the Guangdong-Hong Kong-Macao Greater Bay Area. Using advanced methods, the results show that growth is boosted by financial progress and new financial ideas alike in any kind of city, but environmental policies and urban population have different influences at different stages of development. It underlines that development and innovations in the financial sector are major motors for economic growth everywhere, while both demographic and regulatory effects have various implications. The presence of cointegration among the variables suggests robust long-run equilibrium relationships, reinforcing the strategic significance of coordinated development policies. These insights directly address the research objectives, providing a nuanced, data-driven foundation for both academic understanding and regional policy formulation. Overall, this research advances the literature by illustrating that tailored, stage-specific strategies are essential for fostering balanced, sustainable, and innovation-led growth in complex metropolitan regions.

From a policy perspective, the results emphasize the need for differentiated, locally adapted interventions. Policymakers should support financial sector deepening, foster innovation ecosystems, and calibrate environmental regulations to city-specific development stages. Looking ahead, future research should incorporate more granular city-level data, explore potential endogeneity using instrumental variable techniques, and examine additional moderating factors such as digitalization or global connectivity that may shape the evolving landscape of regional economic growth.

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