# Understanding China's metro development: A comparative regional analysis

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**Abstract**

Economic growth and infrastructure development in China has appeared to be regionally imbalanced for many years during the post-reform period since 1978. The significant differences in transport infrastructure and facilities among various regions in China can be depicted as "stairs" descending gradually from the higher eastern coastal region to the lower west of China. Metro systems have been developed in both coastal and inland provinces, and they are now present in the four different economic regions of China. The findings in this paper show that the distribution of metro systems from the perspective of spatial and regional development in China tends to be mixed and diverse. Considering the length, numbers of lines and stations, there is a consistent pattern in the medians of the datasets for different regions, with no significant differences in the levels of metro development between coastal provinces and inland provinces, and among the four economic regions. However, the Eastern Region not only has the largest number of cities with extensive metro systems; it also has many prefecture-level cities and non-provincial capital cities with developed metro systems. The analysis also shows that economic and population factors are positively and significantly correlated with the scale of metro development in both coastal and inland regions, and these factors have stronger influence on the scale of metro systems in cities in the inland region compared with cities in the coastal region. In summary, the evidence suggests that the spatial and regional layouts of metro development in China are influenced by economic, population, and institutional and policy factors; the latter having an important role to play in reducing regional imbalances in metro infrastructure development.

**Keywords**

Transport economics; metro systems; institutional and policy factors; socio-economic factors; China; Regional Analysis

## 1. Introduction

China has experienced comprehensive socio-economic transformation and rapid economic development since launching economic reforms in 1978. However, this rapid development has brought problems including environmental degradation and high carbon emissions. In February 2021, a circular was issued by the State Council of the People's Republic of China calling for green, low-carbon and circular development, and plans were announced by the government to change the industrial structure and energy mix to reduce emissions and pollution from the manufacturing, energy and transport sectors by 2025 (Meidan et al., 2021). China has an ambitious goal of achieving peak GHG emissions by 2030 (or sooner) with an emphasis on energy conservation and $CO_2$ emission reduction (Logan et al., 2000). Improving travel demand management to decrease car usage and encourage a mode shift to public transport, along with the rapid deployment of electric vehicles (EVs) has become a key priority (World Bank and the Development Research Center of the State Council, P.R. China, 2014). Since the 11th Five-Year Plan (2006–2010), a focus of development has been to promote increasingly efficient and integrated transport networks, particularly public transport systems. The COVID-19 crisis, whilst creating anxiety about public transport use (see Dong et al., 2021), has accelerated change and enhanced creativity. There are positive changes in behaviour (e.g. an increase in public transport capacity to improve the attractiveness of public transport and to decrease car use and an improvement in urban space use) that can be maintained, extended and enhanced after the pandemic (Hepburn et al., 2021). China's 14th Five-Year Plan (2021–2025) emphasises that China will prioritise the development of urban public transport systems and promote compact development characterised by combined functions, three-dimensional development and co-ordinated utilisation of above-ground and underground spaces. Meanwhile, the 14th Five-Year Plan also emphasises vigorous promotion of the green economy and green upgrades to infrastructure and mandates the increasing use of railway transport. China will promote transport integration in urban areas, accelerate development of intercity railways and suburban railways, and promote orderly development of urban rail transport. During the 14th Five-Year Plan, China will construct and operate 3,000 kilometres (km) of urban rail transit lines.

Metro has been developed by many cities for solving environmental and traffic problems, and issues caused by high-density urban development (Cui and Nelson, 2019). In China, metro systems are the main form of underground public transport and urban rail transit systems. In China, the term "metro" usually refers to high-capacity urban mass transport systems, using exclusive right of way and mostly operating through underground tunnels. Whereas the first metro lines were opened in Beijing in 1969 and in Tianjin in 1984, by 2009 only 10 cities in China had metro systems (Krüsmann, 2019). In China, there has been exceptionally rapid expansion of urban metro networks during the past twenty years (Lin et al., 2021a, 2021b). The total length of metro systems in mainland China's 37 cities at the end of 2019 was 5180.6 km (CAMET, 2020). Four metro systems in China were included in the top ten longest metro systems in the world at the end of 2017 (International Association of Public Transport, 2018). The rapid development of metro systems in China's cities in recent years has had significant impacts on society, the economy, and the environment. Metro systems impact on land and property prices and value, with the impacts varying in different locations (Guan and Peiser 2018; Li et al., 2019a; Sun et al., 2016; Tang et al., 2021; Tian et al., 2020; Yang et al., 2022). Metro operation reduces air pollution and greenhouse gas emissions due to reduced energy consumption (Xiao et al., 2020), reduced road transport (Lu et al., 2018), use of cleaner energy (Lu et al., 2018), mitigation of traffic congestion and improvement in air quality (Li et al., 2019b). The social impacts of metro development have been primarily on equality of transit opportunity (Liu et al., 2021), public health (Xiao et al., 2021), happiness (Li et al., 2018), and life satisfaction (Yin et al., 2021).

The scale of development (e.g. as indicated by operation length, number of lines and number of stations) of these metro systems varies significantly. Urban economy and infrastructure development in China have appeared to be regionally imbalanced for many years during the post-reform period, and this imbalance may affect the regional distribution of metro systems. Since fiscal decentralisation in the 1990s, the construction of transport infrastructure was preferred by governments for attracting investment from national state-owned enterprises and foreign direct investment (Yu et al., 2012a). However, the decentralisation process has occurred alongside China's transition towards a market-based economy, resulting in contrasting influences on regional infrastructure provision. On the one hand, having better knowledge of local situations and preferences, local governments have generally reoriented efforts to satisfy needs for the public good. On the other hand, local governments at different administrative levels have been given greater autonomy that has generated unexpected impacts on infrastructure development (Démurger, 2001). From the beginning of reform until the mid-to-late 1990s, the dominant strategy became non-balanced development, allowing the coastal provinces to be leaders in development to increase the entire country's economic competitiveness (Du, 2014). This interprovincial inequality has increased during China's transition towards a market-oriented economy, and a regional bias in policy has resulted in the largest share of public investment being made in the coastal regions (Wei, 1999).

The most remarkable regional disparity in the transport infrastructure availability can be seen between the coastal and inland provinces of China. The significant differences in transport infrastructure and facilities among various regions in China can be depicted as "stairs" descending gradually from the higher eastern coastal region to the lower west of China. While most eastern coastal provinces have many high-quality transport facilities, in remote western provinces the transport infrastructure density is still very low. This inequality reflects the imbalanced development that occurred between coastal and inland provinces during the reform process (Démurger, 2001; Yu et al., 2012a; Yu et al., 2013). Since the late 1990s, the dominant strategy has become co-ordinated development that aims to resolve the rising regional disparity. The plan for co-ordinated development is to develop the Western Region, revitalise the Northeast Region and promote the Central Region. At the same time, the plan allows the Eastern Region to continue leading development. Through this plan, China has effectively reduced regional imbalances and enhanced co-ordinated development as part of the reform process (Du, 2014). However, because of the large geographic scale of China, different geographic conditions and economic development levels exist in different areas of China. Therefore, regional inequality in infrastructure development is still an apparent phenomenon during China's transition process towards a market-oriented economy (Yu et al., 2012b).

Metro systems have been developed in both coastal and inland provinces, and they are now present in all economic regions in China, but with spatial and regional differences in their availability. Therefore, the objective of this paper is to conduct an in-depth analysis and comparison of various regions with metro development to understand the spatial and regional differences in infrastructure development. The findings also make a valuable contribution to understanding metro development and modern transport systems in China. The paper is organised as follows: section 2 describes spatial development of transport infrastructure in China; section 3 explains research methods and data and discusses spatial and regional development of metro systems in China; and section 4 discusses key findings before concludes the paper.

## 2. Spatial development of transport infrastructure in China

Transport infrastructure has significant importance for China, a country of large geographical scale, given that industrial activities normally are located far from raw material sources, while in urban areas mass transit is essential to support daily travel. Hence, China's authorities have paid close attention to transport infrastructure development since 1949 when the People's Republic of China was established (Yu et al., 2012a). Over the past decades, transport infrastructure development has been affected by the country's various institutional reforms. Before launching the economic reforms, the government applied its authority in various sectors of the economy, including all decisions concerning the development of infrastructure (Fan and Chan-Kang, 2008).

Since the beginning of reforms in 1978, remarkable economic growth has occurred in China, along with dramatic increases in inequality (Fan et al., 2011). In the 1980s, economic reform facilitated industrial spatial restructuring, and coastal regions received great benefits from this reform (Fan, 2006; Wei and Ma, 1996). Since the early 1990s, investment in infrastructure has been included in governments' key policy priorities, resulting in a considerably increased share for transport in state fixed-assets investment. To-day the Eastern Region has better developed infrastructure than the Western Region and Central Region. The reasons for this are greater transport demand in the Eastern Region, the central government's priorities favouring the Eastern Region at the beginning of China's economic reforms, and the decentralisation process, which provides local governments with more financial autonomy to collect funds and develop infrastructure. The decentralisation process has resulted in an increase in regional imbalance in infrastructure provision because the regions' ability to raise funds primarily relies on their ability to communicate with the central government and local government revenues (Démurger, 2001). Since the Eastern Region has a higher ability to raise funds it has benefited more from the decentralisation process (Hong et al., 2011).

It is argued by some policy-makers and academics that increased infrastructure development in the lagging regions may lead to greater contribution to economic development and less regional imbalance (Démurger, 2001). Since the late 1990s, the central government has released several specific spatial policies to reduce regional differences. These include the Western Development Policy (*xibu dakaifa*), the Revitalisation of the Northeast (*zhenxing dongbei*) and the Rise of Central China (*zhongbu jueqi*) (Chen and Zheng, 2008; Démurger, 2014), which all emphasise the construction of transport infrastructure. Moreover, in response to increasing regional imbalances, in 2005 the Chinese government put forward a new developmental objective of Harmonious Society. A key dimension of this concept is balanced regional development. Numerous investment plans and strategies have been created to stimulate growth and improve the quality of life of residents in the underdeveloped Western Region (Fan et al., 2011). Despite these initiatives, the large scale of the country regional imbalance is still a characteristic of infrastructure development in China. Although remarkable progress has been achieved in diminishing regional differences in transport infrastructure, the gap between coastal and inland regions with regard to access to quality infrastructure remains considerable (Démurger, 2014). The reasons may lie in the different levels of economic development of various regions and their ability to attract funds to finance infrastructure investment (Démurger, 2001). China's economic activities are primarily concentrated in the eastern coastal areas, such as the Bohai Bay Economic Rim, the Pearl River Delta and the Yangtze River Delta. The imbalanced distribution pattern of economic development activities from the core (eastern coastal region) to the periphery (inland region) is still apparent in China (Yu et al., 2016).

## 3. Regional analysis of China's metro development

### 3.1 Methods and data

This research aims to conduct a spatial and regional analysis of metro development in mainland China. Economic regions and inland versus coastal regions are two major spatial scales used to examine infrastructure development in China. In this paper, we focus on the development patterns of metro networks in two different categories of regions: the four economic regions (Eastern Region, Central Region, Western Region and Northeast Region); and inland versus coastal regions. As mentioned above, the extent of economic development in different economic regions and in coast and inland regions in China is different. Mainland China as of the end of 2019 had metro systems in operation in 37 cities, but the scale of development of metro systems varies. For the analysis we collected metro data (length (km), numbers of lines and stations) for 37 metro cities at the end of 2019. In China, there are requirements regarding general public budget revenues (> 30 billion CNY), GDP (> 300 billion CNY) and resident populations in urban areas (> 3 million) as preconditions for building metros in China (General Office of the State Council of the People's Republic of China, 2018). Therefore, we also collected economic and population data for the 37 metro cities. Data sources were open information and data from official metro and urban rail transit websites (for various cities), central and local government websites and the Statistical Communique on Economic and Social Development (for various cities). The original data were analysed using IBM SPSS Statistics (Version 27) predictive analytics software. As the data are non-normally distributed, nonparametric tests were used. Box Plot, Kruskal-Wallis H test and Mann-Whitney U test were performed to investigate the differences and similarities of metro development at the regional scale. As regional differences in the development of transport infrastructure between coastal and inland provinces have existed for decades, Spearman's correlation test was further performed to examine the relationship between economic and population factors and metro scales in coastal and inland regions to identify differences and similarities between the two regions. Table 1 shows the geographical characteristics of cities with metro development in China. Table 2 shows the development of metro systems in urban China at the end of 2019.

Table 1
Geographical characteristics of cities with metro development in China

| Cities | Administrative Division | Provinces/ Autonomous Regions/ Municipalities | Economic Regions | Coastal/Inland Regions |
|---|---|---|---|---|
| **Beijing** | Centrally administered municipalities | Beijing | Eastern Region | Inland Region |
| **Changchun** | Sub-provincial cities | Jilin | Northeast Region | Inland Region |
| **Changsha** | Prefecture-level cities | Hunan | Central Region | Inland Region |
| **Changzhou** | Prefecture-level cities | Jiangsu | Eastern Region | Coastal Region |
| **Chengdu** | Sub-provincial cities | Sichuan | Western Region | Inland Region |
| **Chongqing** | Centrally administered municipalities | Chongqing | Western Region | Inland Region |
| **Dalian** | Sub-provincial cities | Liaoning | Northeast Region | Coastal Region |
| **Dongguan** | Prefecture-level cities | Guangdong | Eastern Region | Coastal Region |
| **Foshan** | Prefecture-level cities | Guangdong | Eastern Region | Coastal Region |
| **Fuzhou** | Prefecture-level cities | Fujian | Eastern Region | Coastal Region |
| **Guangzhou** | Sub-provincial cities | Guangdong | Eastern Region | Coastal Region |
| **Guiyang** | Prefecture-level cities | Guizhou | Western Region | Inland Region |
| **Hangzhou** | Sub-provincial cities | Zhejiang | Eastern Region | Coastal Region |
| **Harbin** | Sub-provincial cities | Heilongjiang | Northeast Region | Inland Region |
| **Hefei** | Prefecture-level cities | Anhui | Central Region | Inland Region |
| **Hohhot** | Prefecture-level cities | Inner Mongolia | Western Region | Inland Region |
| **Jinan** | Sub-provincial cities | Shandong | Eastern Region | Coastal Region |
| **Kunming** | Prefecture-level cities | Yunnan | Western Region | Inland Region |
| **Lanzhou** | Prefecture-level cities | Gansu | Western Region | Inland Region |
| **Nanchang** | Prefecture-level cities | Jiangxi | Central Region | Inland Region |
| **Nanjing** | Sub-provincial cities | Jiangsu | Eastern Region | Coastal Region |
| **Nanning** | Prefecture-level cities | Guangxi | Western Region | Coastal Region |
| **Ningbo** | Sub-provincial cities | Zhejiang | Eastern Region | Coastal Region |
| **Qingdao** | Sub-provincial cities | Shandong | Eastern Region | Coastal Region |
| **Shanghai** | Centrally administered municipalities | Shanghai | Eastern Region | Coastal Region |
| **Shenyang** | Sub-provincial cities | Liaoning | Northeast Region | Coastal Region |
| **Shenzhen** | Sub-provincial cities | Guangdong | Eastern Region | Coastal Region |
| **Shijiazhuang** | Prefecture-level cities | Hebei | Eastern Region | Coastal Region |
| **Suzhou** | Prefecture-level cities | Jiangsu | Eastern Region | Coastal Region |
| **Tianjin** | Centrally administered municipalities | Tianjin | Eastern Region | Coastal Region |
| **Urumqi** | Prefecture-level cities | Xinjiang | Western Region | Inland Region |
| **Wuhan** | Sub-provincial cities | Hubei | Central Region | Inland Region |
| **Wuxi** | Prefecture-level cities | Jiangsu | Eastern Region | Coastal Region |
| **Xiamen** | Sub-provincial cities | Fujian | Eastern Region | Coastal Region |
| **Xi'an** | Sub-provincial cities | Shaanxi | Western Region | Inland Region |
| **Xuzhou** | Prefecture-level cities | Jiangsu | Eastern Region | Coastal Region |
| **Zhengzhou** | Prefecture-level cities | Henan | Central Region | Inland Region |

Table 2
The development of metro systems in urban China (at the end of 2019)

| Metro Operation Length | | | | Number of Metro Stations | | | | Number of Metro Lines | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| >300 km | 101–300 km | 50–100 km | <50 km | >200 | 101–200 | 50–100 | <50 | >7 | 5–7 | 3–4 | 1–2 |
| Shanghai | Chongqing | Ningbo | Jinan | Shanghai | Nanjing | Zhengzhou | Wuxi | Beijing | Chengdu | Hangzhou | Wuxi |
| Beijing | Qingdao | Shenyang | Shijiazhuang | Beijing | Chongqing | Hangzhou | Dalian | Shanghai | Chongqing | Suzhou | Fuzhou |
| Guangzhou | Tianjin | Hefei | Changchun | Guangzhou | Suzhou | Qingdao | Fuzhou | Guangzhou | Xi’an | Kunming | Harbin |
| Nanjing | Suzhou | Kunming | Dongguan | Wuhan | Tianjin | Hefei | Changchun | Nanjing | Tianjin | Qingdao | Dalian |
| Wuhan | Xi’an | Nanning | Guiyang | Chengdu | Xi’an | Shenyang | Shijiazhuang | Wuhan | Zhengzhou | Shenyang | Nanchang |
| Chengdu | Zhengzhou | Changsha | Harbin | Shenzhen | | Ningbo | Changzhou | Shenzhen | | Changsha | Changchun |
| Shenzhen | Hangzhou | Xiamen | Changzhou | | | Nanning | Harbin | | | Nanning | Shijiazhuang |
| | | Wuxi | Urumqi | | | Changsha | Guiyang | | | Ningbo | Jinan |
| | | Nanchang | Lanzhou | | | Kunming | Jinan | | | Hefei | Xiamen |
| | | Dalian | Xuzhou | | | Xiamen | Urumqi | | | | Guiyang |
| | | Fuzhou | Hohhot | | | Nanchang | Hohhot | | | | Dongguan |
| | | | Foshan | | | | Lanzhou | | | | Lanzhou |
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| | | | | | | | Dongguan | | | | Hohhot |
| | | | | | | | Foshan | | | | Foshan |
| | | | | | | | | | | | Changzhou |
| | | | | | | | | | | | Xuzhou |

3.2 Box plot and nonparametric tests: the four economic regions and inland versus coastal regions

A box plot is a type of chart often used in explanatory data analysis to represent central tendency, dispersion, skewness, and extremes in data. A box plot is a way of visually showing the numerical data distributions through their quartiles and allows intercomparison within the datasets. Figures 1, 2 and 3 show the distributions of the data of metro operation length, and numbers of metro lines and stations of cities with metros, respectively, in the four economic regions in China. Interquartile ranges, medians, lower and upper quartiles, and outliers are presented in the figures.

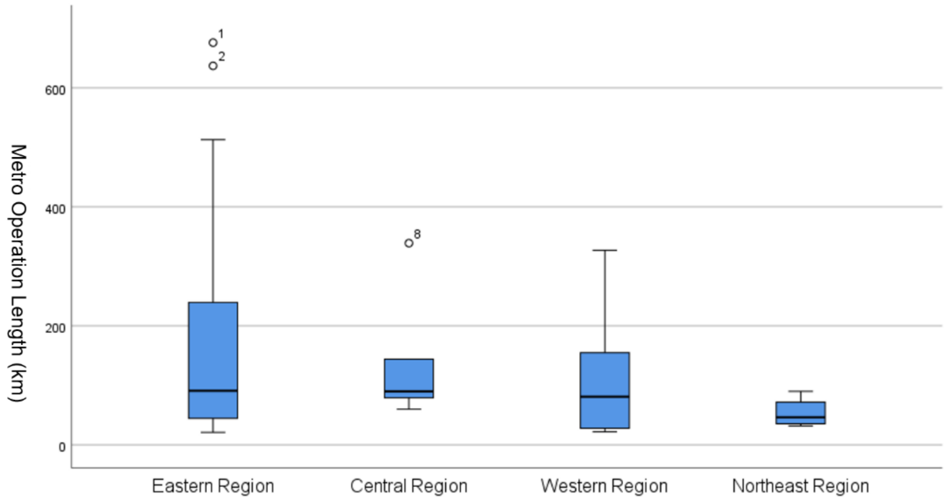


Figure 1 Box plot diagram of the metro operation length of cities in China's four economic regions

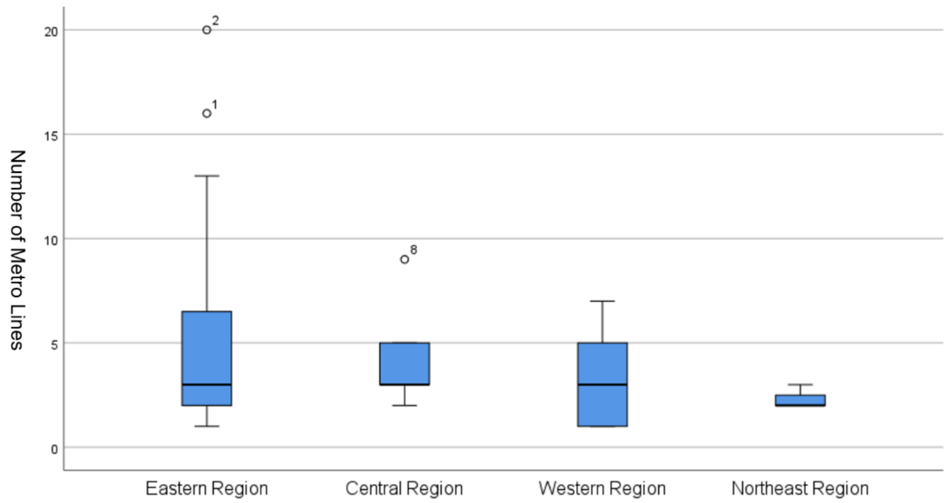


Figure 2 Box plot diagram of the number of metro lines of cities in China's four economic regions

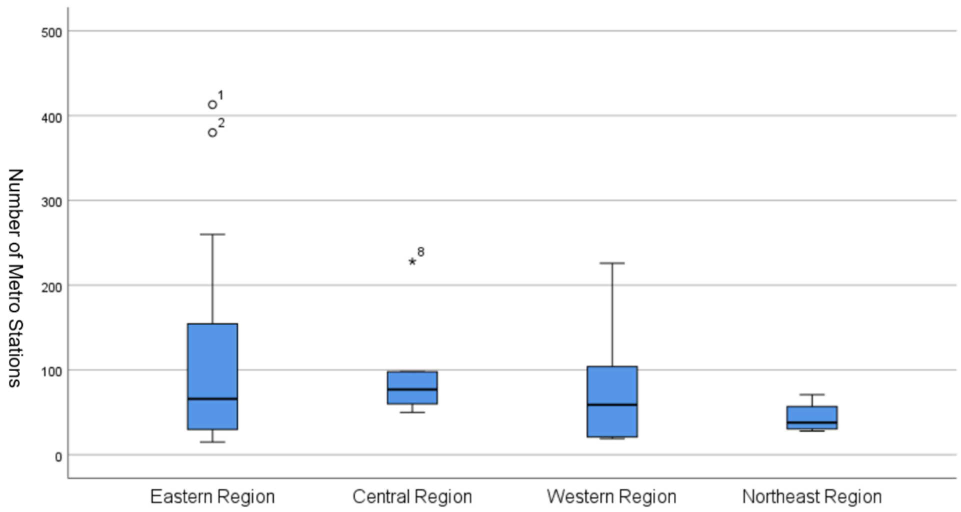


Figure 3 Box plot diagram of the number of metro stations of cities in China’s four economic regions

From Figure 1, we can see that the box plots of the Eastern Region and the Western Region are comparatively longer than those of the Central Region and the Northeast Region. This suggests that the data on metro length of cities in the Eastern and Western Regions are more dispersed than those of the other two regions. Also, we can see that the interquartile ranges for the Eastern and the Western Regions are larger than for the Central and Northeast Regions. This means the middle 50% of the data on metro length in the Eastern Region and the Western Region are widely spaced. The findings suggest that the scale of development of metro length in the Central Region and the Northeast Region are more concentrated than for the other two regions. From Figure 1, it also can be seen that the upper whiskers of the Eastern Region and the Western Region are longer and taller than for the other two regions. This means that the top 25% of the data on metro length in both the Eastern Region and the Western Region are much larger and more dispersed than for the other two regions. For example, the cities with the top five longest metros in the Eastern Region (Shanghai, Beijing, Guangzhou, Nanjing and Shenzhen) have metro lines longer than 300 km, and the cities with the top two longest metros in the Western Region (Chengdu and Chongqing) have metro lines longer than 200 km. In contrast, all cities in the Central Region except Wuhan have metro lines less than 150 km, and all cities in the Northeast Region have metro lines less than 100 km. We can see three outliers in Figure 1 including two cities in the Eastern Region (Beijing and Shanghai) and one city in the Central Region (Wuhan). This means that the metro lines in Beijing and Shanghai are much longer than those of the other cities in the Eastern Region, and that Wuhan is the only city in Central Region that has an extensive metro network. Metro lines in both Beijing and Shanghai are longer than 600 km, and Wuhan metro is longer than 300 km. However, we can see that the medians of the data on metro length across the four regions are fairly consistent even though the distributions of data are very different. This means that the medians of the data on metro length are similar in the four regions, but their ranges of metro length are quite different. The reason for this is that although there are some cities with extensive metro development in the Eastern and Western Regions, about half of the cities in these two regions have metro lines less than 100 km. Figures 2 and 3 show the distributions of the data on numbers of metro lines and metro stations, respectively, of cities in the four economic regions in China. As metro length is normally closely related to numbers of metro lines and metro stations, the distributions of the data on numbers of metro stations and lines of cities in the four regions show similarities with those for metro length (Figure 1), as can be seen from the box plots, interquartile range boxes, whiskers and outliers. There is also a consistent pattern in the medians of the data on metro operation length, and numbers of metro lines and metro stations of cities across the four regions, as shown in Figures 1, 2 and 3.

The findings indicate that the Eastern Region has the most extensive metro systems and the largest number of metro cities. This is because the Eastern Region is the most economically developed region in China. The Western Region also has a comparatively large scale of metro development. The major reason is that metro, as modern transport infrastructure, has mostly been developed in the past decade in China. Policies like the Belt and Road Initiative and the construction of National Central Cities strategy introduced by the Chinese government have promoted infrastructure development in cities in the Western Region. Chongqing, Chengdu and Xi'an are three major National Central Cities in the Western Region that have developed highly extensive metro systems in recent years and therefore have contributed significantly to the development of metro networks in the Western Region. To summarise, although the medians of the data on metro development of cities across the four regions are similar, the Eastern Region and the Western Region have larger scales of metro development than the other two regions in terms of the number of cities with metro development and the number of large-scale metro systems.

The Kruskal-Wallis H test was performed to further evaluate if there are any statistically significant differences in the levels of metro development among various economic regions. A $p$-value of less than 0.05 was considered to indicate a significant difference. The results show there is no significant difference in the metro length in cities in the four economic regions (Kruskal-Wallis H test, $H = 2.819$, df = 3, $p = 0.420$). In addition, there is no significant difference in the number of metro lines in cities in the four economic regions (Kruskal-Wallis H test, $H = 1.781$, df = 3, $p = 0.619$). Moreover, there is no significant difference in the number of metro stations in cities in the four economic regions (Kruskal-Wallis H test, $H = 2.142$, df = 3, $p = 0.543$). The results of the Kruskal-Wallis H test show that there is no statistically significant difference in the scale of metro development measured by metro operation length, and numbers of lines and stations in cities in the four economic regions. This result is not surprising since the medians of the data in all three box plots are similar, although the total number of cities with metro systems and the distributions of the scale of development of metros in these cities are significantly different across economic regions. However, the examination may have some limitations because, compared with other regions, the Northeast Region only has a small number of cities with metro systems and is also the only region with all individual cities with metros having metro length less than 90 km. At this stage the analysis has not taken account of economic and population aspects.

Figures 4, 5 and 6 show the distributions of the data on metro operation length, and numbers of lines and stations, respectively, of cities with metro development in China's coastal and inland provinces. We can see from Figures 4 and 6 that the interquartile ranges, medians, and lower and upper quartiles of the data of cities in the coastal and inland regions are similar, which means there are no obvious differences in the range of data on metro length and number of stations between coastal and inland regions. Figure 5 shows that the coastal region has comparatively shorter interquartile range and upper whiskers, indicating that the distribution of data on the number of metro lines in coastal regions is more concentrated than for the inland regions. From Figures 4, 5 and 6, it also can be seen that there are four outliers (Shanghai, Guangzhou, Nanjing and Shenzhen) in the coastal provinces but only one (Beijing) in the inland region. This implies firstly, that these cities had the most extensive metro networks compared with other cities in their regions at the end of 2019; and secondly, the coastal region has more cities with highly extensive metro systems than the inland region. However, the medians of the data are similar in coastal and inland regions in all three figures.

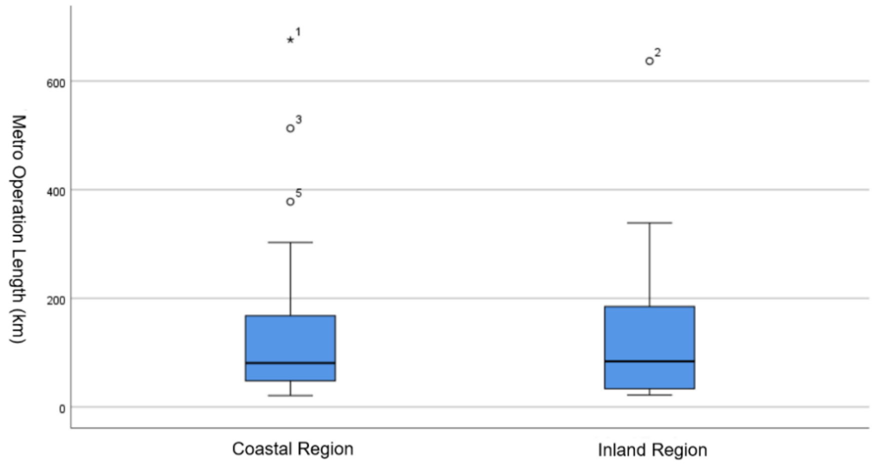


Figure 4 Box plot diagram of the metro operation length of cities in the inland and coastal regions of China

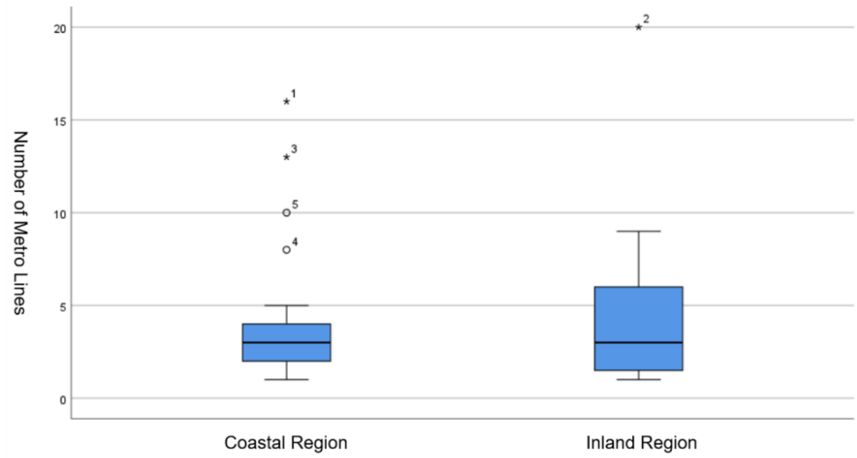


Figure 5 Box plot diagram of the number of metro lines of cities in the inland and coastal regions of China

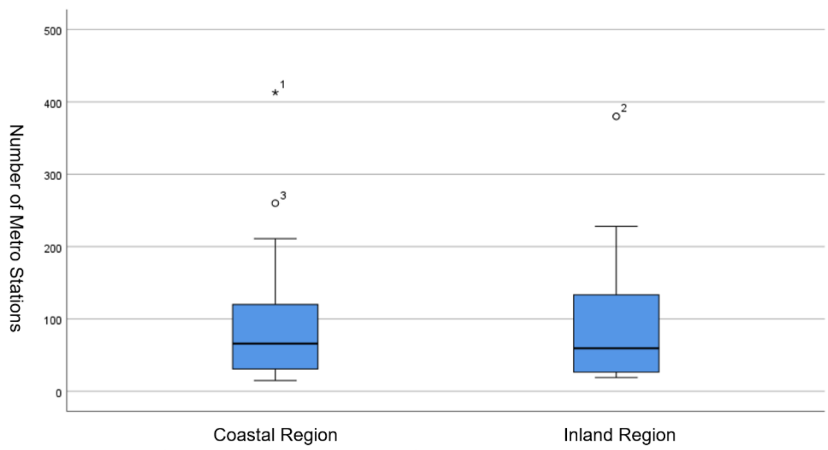


Figure 6 Box plot diagram of the number of metro stations of cities in the inland and coastal regions of China

The Mann-Whitney U test was performed to evaluate whether there were statistically significant differences between the coastal and inland regions with regard to scale of metro development. A $p$-value of less than 0.05 was considered to indicate a significant difference. The results show there is no significant difference in the metro length in cities in the coastal and inland regions (Mann-Whitney U test, $U = 156.000$, $Z = -0.368$, $p = 0.713$). In addition, there is no significant difference in the number of metro lines in cities in the coastal and inland regions (Mann-Whitney U test, $U = 163.500$, $Z = -0.140$, $p = 0.889$). Moreover, there is no significant difference in the number of metro stations in cities in the coastal and inland regions (Mann-Whitney U test, $U = 166.000$, $Z = -0.061$, $p = 0.951$). The results of the Mann-Whitney U test show there is no statistically significant difference in the scale of metro development between coastal and inland regions.

3.3 Correlation analysis in coastal and inland regions

In China, the most remarkable regional imbalance in the availability of transport infrastructure can be seen between the coastal and inland regions. Metro has been one of the most important and fastest-growing types of infrastructure in urban China during the past decade. However, this analysis found that the situation regarding difference in metro development between coastal and inland regions is complicated: the medians of the data on metro operation length, and numbers of lines and stations of cities with metro development are similar in the coastal and inland regions, and there is no statistically significant difference in the scale of metro development between the coastal and inland regions; on the other hand, the coastal region has more cities with highly extensive metro systems than the inland region. It is worth investigating the reason for this phenomenon. As noted earlier, in China, GDP, amount of revenue in the municipal government's general public budget, and resident populations in urban districts are preconditions for cities to build metro systems. Therefore, economic and population factors are important influencing factors for metro development. To further investigate whether there are any differences in the relationship between these potential influencing factors and metro development in coastal and inland regions, we conducted a correlation analysis of these factors and metro development in the coastal and inland regions.

Spearman's correlation was performed to identify any statistically significant relationships between the scale of metro systems and potential influencing factors (including GDP, general public budget revenue and resident populations in urban districts) in China. The results indicate that there are statistically significant relationships among the three factors and metro development in the coastal and inland regions (Table 3 and Table 4). We can see that the variables of GDP, general public budget revenue and resident populations in urban districts are positively and significantly correlated with metro operation length, and numbers of lines and stations of cities in both coastal and inland regions. However, all the values (0.912, 0.916 and 0.938) of Spearman's correlation coefficient between GDP and the scale of metro development (metro operation length, and numbers of lines and stations) in inland provinces are much higher than the values (0.703, 0.707 and 0.681) of Spearman's correlation coefficient for coastal provinces. All the values (0.903, 0.935 and 0.924) of Spearman's correlation coefficient between resident populations in urban districts and the scale of metro development in inland provinces are also much higher than the values (0.572, 0.622 and 0.569) for coastal provinces. There are similar results in the correlation analysis for general public budget revenue and the scale of metro development in the coastal region (Table 3) and inland region (Table 4) respectively. The results of the analysis show that both economic factors (GDP and general public budget revenue) and population factors have stronger impacts on the scale of development of metro systems in cities in the inland region than in the coastal region.

Table 3
Spearman's correlation between the scale of metro development and economic and population factors in metro cities in the inland region of China

| | | | Gross Domestic Product (billion CNY) | General Public Budget Revenue (billion CNY) | Resident Population in Urban Areas (million) |
|---|---|---|---|---|---|
| Spearman's rho | Metro Operation Length (km) | Correlation Coefficient | 0.912** | 0.950** | 0.903** |
| | | Sig. (2-tailed) | 0.000 | 0.000 | 0.000 |
| | | N | 16 | 16 | 16 |
| | Number of Metro Lines | Correlation Coefficient | 0.916** | 0.935** | 0.935** |
| | | Sig. (2-tailed) | 0.000 | 0.000 | 0.000 |
| | | N | 16 | 16 | 16 |
| | Number of Metro Stations | Correlation Coefficient | 0.938** | 0.953** | 0.924** |
| | | Sig. (2-tailed) | 0.000 | 0.000 | 0.000 |
| | | N | 16 | 16 | 16 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table 4
Spearman's correlation between the scale of metro development and economic and population factors in metro cities in the coastal region of China

| | | | Gross Domestic Product (billion CNY) | General Public Budget Revenue (billion CNY) | Resident Population in Urban Areas (million) |
|---|---|---|---|---|---|
| Spearman's rho | Metro Operation Length (km) | Correlation Coefficient | 0.703** | 0.831** | 0.572** |
| | | Sig. (2-tailed) | 0.000 | 0.000 | 0.007 |
| | | N | 21 | 21 | 21 |
| | Number of Metro Lines | Correlation Coefficient | 0.707** | 0.811** | 0.622** |
| | | Sig. (2-tailed) | 0.000 | 0.000 | 0.003 |
| | | N | 21 | 21 | 21 |
| | Number of Metro Stations | Correlation Coefficient | 0.681** | 0.823** | 0.569** |
| | | Sig. (2-tailed) | 0.001 | 0.000 | 0.007 |
| | | N | 21 | 21 | 21 |

**. Correlation is significant at the 0.01 level (2-tailed).

Lower correlation coefficients in the coastal region than in the inland region indicate that, in addition to economic and population factors, there are other important factors affecting the scale of metro development of cities in coastal regions. Interestingly, we found that all metro cities in the inland region are centrally administered municipalities or provincial capital cities. In contrast, metro cities in the coastal region belong to various administrative divisions, including centrally administered municipalities, sub-provincial cities, provincial capital cities and prefecture-level cities. This means that administrative divisions may be another important factor influencing metro development in China, particularly in the coastal region. In China, normally, cities at high administrative levels are prioritised in allocation of resources (Jiang et al., 2018; Wu et al., 2007). Therefore, cities at high administrative levels may also be prioritised in metro development. On the other hand, the results also indicate that the overall level of metro development in the coastal region is higher than in the inland region. The coastal region has many metro cities with diverse levels of administrative divisions. These cities include not only centrally administered municipalities and provincial capital cities, but also many prefecture-level cities (such as Wuxi, Xuzhou and Dongguan). In addition, some coastal provinces such as Guangdong, Jiangsu, Shandong and Zhejiang even have two or more cities with metro systems. In contrast, no province in the inland region has two or more cities with metros in operation. This means that the overall level of metro development in the coastal region is higher than that of the inland region.

## 4. Discussion

Previous studies have investigated the relationship between the development of transport infrastructure and regional economies (e.g. Ozbay et al., 2003; Rokicki and Stępniak, 2018; Li, Wang and Chen, 2021). There are few studies that provide evidence of spatial and regional differences in the development of transport infrastructure in China. Metro is the main urban transport infrastructure chosen by many large cities in China for addressing traffic congestion and solving environmental issues. Mainland China as of the end of 2019 had 37 cities that opened metro systems with a total length of 5180.6 km. Metro systems have been developed in both coastal provinces and inland provinces, as well as across the four economic regions of China.

The findings of this study show that the distribution of metro systems in China tends to be mixed and diverse, from the perspective of spatial and regional development. On the one hand, the results from box plot and nonparametric tests indicate that there is a consistent pattern in the medians of the datasets and no significant differences in the scale of metro development in terms of metro operation length, and numbers of lines and stations between coastal regions and inland regions. There are similar medians from the datasets and no significant differences in the scale of metro development among the four economic regions. On the other hand, due to the Eastern Region being China’s most developed region, there is an opportunity for the Eastern Region to have not only the largest number of cities with extensive metro systems but also many prefecture-level cities and non-provincial capital cities with the opportunity to build metros. This also indicates that metro development is more advanced and comprehensive in the Eastern Region compared with the other regions, since not just cities in the top levels of the structural hierarchy of administrative divisions (centrally administered municipalities and provincial capital cities) in the Eastern Region can develop metro infrastructure. It is worth noting that in recent years, the Belt and Road Initiative and the construction of National Central Cities strategy have facilitated metro development in the traditionally lagging Western Region. Spearman’s correlation analysis suggests that economic factors (GDP and general public budget revenue) and resident populations in urban districts are positively and significantly correlated with the scale of metro systems in both the coastal and inland regions. However, these factors have stronger impacts on the scale of metro systems in the inland region than in the coastal region. There are likely to be other key factors that impact on metro development in the coastal region. Institutional context such as administrative division may be a key influencing factor for metro development in the coastal region; as the coastal region has metro cities with more diverse levels in administrative divisions than the inland region, this means the overall level of metro development in the coastal region is higher than in the inland region.

## 5. Conclusion

During China's transition process towards a market-oriented economy, regional imbalance in infrastructure development is an obvious phenomenon (Yu et al., 2012b). Current spatial and regional differences in China's transport development have been influenced by various policy and institutional factors. Economic reforms resulted in industrial spatial restructuring, and the coastal region obtained more benefits from this than the inland region. Given its large geographic scale, China is divided into various administrative units which have attained considerable financial power due to China's fiscal decentralisation, a development which has also contributed to regional inequality in infrastructure development. Normally, cities at high administrative levels are prioritised in allocation of resources and are developed rapidly to build infrastructure. This indicates that administrative divisions may be another important factor influencing metro development in China. Metro systems have been developed in different economic regions of China and they are present in both coastal and inland provinces. National policies such as the Western Development Policy, the Belt and Road Initiative and the construction of National Central Cities policy have contributed to reducing regional imbalances in metro infrastructure development. These policies also may impact on the spatial and regional distribution of metro development.

The research reveals that the distribution of metro systems in China is mixed and diverse, from the perspective of spatial and regional development. The medians of the datasets for different regions show a consistent pattern, with no significant differences in the levels of metro development between coastal provinces and inland provinces, or among the four economic regions. However, in the Eastern Region, China's most developed region, the overall level of metro development is more advanced and comprehensive compared with the other regions (Central Region, Western Region and Northeast Region). The Eastern Region not only has the largest number of cities with extensive metro systems; it also has many prefecture-level cities and non-provincial capital cities with developed metro systems. The research also reveals that the economy and population size are significantly associated with the level of metro development in both coastal and inland regions, indicating that the economy and population size are important influencing factors for metro development in China. Cities with stronger economies and larger populations tend to develop more extensive metro systems. In addition, the economy and population size have greater influence on the scale of metro systems in cities in the inland region compared with cities in the coastal region.

It is now commonly acknowledged in both developed and developing countries that transport investment is positively related to economic development (Banister and Berechman, 2001; Saidi et al., 2020). In China, transport upgrades play a significant role in promoting urban and regional economies whilst also contributing to decarbonisation and social development. Since metro is one of the most important and fastest-growing types of transport infrastructure in urban China, it is important to examine investment in metro and its impacts on economic development in the future. In addition, questions about how China's metro systems impact on urban environments including both natural and built environments as well as social aspects such as travel behaviour and public health, need to be further investigated. In particular, comparative studies on how cities with metro systems in different regions impact on economic, social and environmental development also need to be conducted. Furthermore, as metro systems in non-provincial capital cities in China's coastal region have undergone rapid development in recent years, policies on metro development in non-provincial capital cities in China's inland region and central-western regions require further exploration, taking into account economic, transport and environmental development.

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