Levels of economic growth and cross-province spread of the COVID-19 in China

Qiqing Mo,1,2,3 Xinguang Chen,2,4 Bin Yu,2 Zhenyu Ma

ABSTRACT

Background After the first COVID-19 case detected on 8 December 2019 in Wuhan, the Provincial Capital of Hubei, the epidemic quickly spread throughout the whole country of China. Low developmental levels are often associated with infectious disease epidemic, this study attempted to test this notion with COVID-19 data.

Methods Data by province from 8 December 2019 to 16 February 2020 were analysed using regression method. Outcomes were days from the first COVID-19 case in the origin of Hubei Province to the date when case was first detected in a destination province, and cumulative number of confirmed cases. Provincial gross domestic products (GDPS) were used to predict the outcomes while considering spatial distance and population density.

Results Of the total 70 548 COVID-19 cases in all 31 provinces, 58 182 (82.5%) were detected in Hubei and 12 366 (17.5%) in other destination provinces. Regression analysis of data from the 30 provinces indicated that GDP was negatively associated with days of virus spreading (β=−0.2950, p<0.10) and positively associated with cumulative cases (β=97.8709, p<0.01) after controlling for spatial distance. The relationships were reversed with β=0.1287 (p<0.01) for days and β=−54.3756 (p<0.01) for cumulative cases after weighing in population density and controlling for spatial distance.

Conclusion Higher levels of developmental is a risk factor for cross-province spread of COVID-19. This study adds new data to literature regarding the role of economic growth in facilitating spatial spreading of infectious diseases, and provides timely data informing antiepidemic strategies and developmental plan to balance economic growth and people’s health.

INTRODUCTION

The spread of infectious disease has often been associated with low economic development, poor sanitation conditions and unhygienic behaviours. This widely accepted notion may face challenges in understanding the epidemic of infectious diseases today in countries with rapid modernisation and urbanisation such as China. At the community level, the spread of a virus disease is determined primarily by the infectivity of a pathogen, in addition to its virulence. At macro-geographic levels, a factor riskier than the infectivity of a pathogen could be the rapid and high volume of population mobility across various spatial distances in urbanised societies. Current outbreak of the COVID-19 in China provides an opportunity to test the relationship between developmental levels and infectious disease spread.

COVID-19 is caused by a novel coronavirus SARS-CoV-2 (also known as 2019-nCoV). The first suspected COVID-19 case was detected on 8 December 2019 in Wuhan, the Capital City of Hubei Province. Wuhan is known as a transportation hub in China with a total population of 13 million, including 5 million rural-to-urban migrants and per capita gross domestic product (GDP) of 124 000 RMB (equivalent to US$17 700 with 7:1 exchange ratio). Rural migrants in Wuhan come from all parts of China to make money while contributing to the urban growth. Before official declaration of the COVID-19 as an outbreak on 20 January 2020, many of these migrants travelled back home for family reunion and for more than a week-long celebration of the Chinese New Year on 25 January, a traditional holiday with long history in China. This massive population movement usually within a short period of 1 week or 2 was made possible by the highly but unevenly paced development of air and land transportation systems.

After the first COVID-19 case was reported on 8 December 2019 in Wuhan, Hubei Province, it took a period of 43 days for China to declare it as an outbreak on 20 January 2020; however, it took only 12 days for the disease spread to the remaining 30 provinces of country. By 16 February 2020 when the analysis for this study was completed, a total of 70 548 COVID-19 cases were reported in China, including 58 182 (82.5%) cases in Hubei and 12 366 (17.5%) cases in other 30 destination provinces outside of Hubei. China, like many other countries in the world, has experienced rapid though unevenly paced economic growth. It has been documented that higher levels of economic growth are associated with longer life expectancy in countries across the globe, including China. However, little is known about the relationship between economic growth and the spread of infectious diseases. The COVID-19 epidemic in China provides a window of opportunities to examine the relationship. Hubei Province is the epicentre of COVID-19 and the COVID-19 epidemic in the other 30 destination provinces of China was considered as being originated at Hubei Province. In this study, we attempted to examine the relationship between levels of development and COVID-19 spread using an ecological approach to analyse data from the 30 destination provinces.
Cumulative COVID-19 cases in destination provinces
The cumulative number of detected and confirmed COVID-19 cases was used as another outcome variable. Data for this variable were derived also from the reported COVID-19 cases from Provincial Health Commissions. We used the cumulative cases up to 16 February 2020 for a period of 70 days since the first case was reported. This duration covered five incubation periods, assuming the incubation period of COVID-19=14 days. This variable was used to assess the volume of COVID-19 spread such that a large number indicating a higher volume.

Level of development
Developmental level of a destination province was measured using the GDP (trillion RMB Yuan) of the province in 2019. GDP data were obtained from the National Bureau of Statistics of China. The source provided GDP data only for the first three quarters of 2019, we thus estimated the annual GDP of 2019 by inflating the data and used as a proxy measure. GDP provided a monetary measure of all final goods and services produced by these provinces, and it is a commonly used measure of developmental levels in research. We used it in this study to predict the speed and volume of COVID-19 spread from Hubei to the destination provinces within China.

Spatial distance
Spatial distances (100 km) from the geographic centre of individual provinces to Hubei were estimated using the software ArcGIS (V.10.0) with geographic data. This variable was used as a covariate in regression to assess the relationship between GDP and COVID-19 spreading. Spatial distance is a factor known to influence the spread of any infectious diseases, including COVID-19.1

Population density
Population density is associated with community spreading of any infectious diseases. To better assess the relationship between GDP and the volume of COVID-19 spreading, population density (100 persons/km²) was included. Population data for the 30 destination provinces were obtained from the 2019 National Bureau of Statistics of China, and geographic area data were obtained from website. Population density of a destination province was thus calculated by dividing its population with its geographic area. As an ecological modelling analysis, we used this variable in two different ways. In one regression model, this variable was used as a covariate, assuming linear and independent association; in another model, this variable was used as weight without any assumptions.

Statistical analysis
To assess the relationship between GDP and total days for COVID-19 to spread from the origin Hubei Province to the other 30 individual destination provinces; we first plotted the two variables. Informed by the plot, a linear regression model was used to quantify the relationships:

\[y = ax + b\]

where represents total days from the date when the first case was reported in Hubei to the date when the first case was reported in destination province; represents GDP of the same province; represents the spatial distance of ith destination province to Hubei as a covariate; and = residuals (1, 2 ... 30).

A slightly different approach was used to assess the relationship between GDP and cumulative numbers of COVID-19 cases. We first plotted the two variables to visually assess the relation between the two. In the first step of regression analysis, we include spatial distance and population density both as covariates assuming independent influence of the two variables:

\[y = ax + bx + c\]

where represents the cumulative COVID-19 cases, = population density, and the rest were the same as in equation 1.

In the second step of regression analysis, population density was used as weights with no assumption of linear and independent effect:

\[y = ax + bx + c\] where = population density weights. In this model, provinces with higher population density were weighted more than provinces with lower population density in assessing the impact of GDP.

Statistical inference was made at p<0.05 level (two-sided) for all modelling analysis. Data processing and statistical analyses were conducted with commercial software SAS V.9.4 (SAS Institute).

Figure 1 Spread of COVID-19 from Hubei to the remaining 30 destination provinces in China. (A) Geographic spreading, (B) speed of spreading and (C) volume of spreading. Days: total days from the first case in Hubei Province to the date when the first case was detected and reported in a destination province.
RESULTS
Spread of the COVID-19 within China
It took 43 days for China to declare the COVID-19 as an outbreak since the first case in Hubei on 8 December, 2019; however, it took only 12 days for the epidemic to penetrate all remaining 30 provinces within China (figure 1A,B).

Consequently, the cumulative number of COVID-19 cases in the destination provinces increased rapidly from one case on 19 January (42 days from the first case in Hubei) to 12.368 on 16 February (70 days of the COVID-19 epidemic in China) (figure 1C).

Table 1 indicates that total days ranged from 42 to 53, in another word, it took only 12 days to spread the virus from the origin of Hubei to all remaining 30 provinces within China. Other results include cumulative COVID-19 cases ranged from 1 to 1322 with a median of 256; GDPs (trillion RMB Yuan) ranged from 0.12 to 7.72 with a median of 1.66; population densities (100 persons/km²) ranged from 0.03 to 38.48 with a median of 2.77; and spatial distances (100 km) ranged from 0.12 to 7.72 with a median of 1.66; population densities. See text for detailed description. There were two extra cases in total in the table than the origin of Hubei to all remaining 30 provinces within China.

Correlation between the key variables
Results in table 2 indicate that the total days from the first COVID-19 case in Hubei to the first case in a destination province were negatively correlated with GDP (r = -0.48, p < 0.01) and population density (r = -0.40, p < 0.05), and positively correlated with spatial distances (r = 0.55, p < 0.01). The cumulative cases were positively correlated with GDP (r = 0.69, p < 0.01) and negatively correlated with spatial distances (r = -0.53, p < 0.01).

Figure 2A,B suggests a negative relationship between GDP and total days when the COVID-19 spread from Hubei to all destination provinces, and a positive relation between total days of spreading and spatial distances.

Results from multivariate regression model 1 in table 3 indicate a good data-model fit with F = 8.41 (p = 0.001). The regression model explained 44% of the total variances. The regression coefficient β̂ = -0.2950 (p < 0.10) for GDP. This result suggests that for every trillion of GDP, the time for COVID-19 to spread will shorten by 0.295 days or 7.29 hours. Likewise, the regression coefficient β̂ = 0.1287 (p < 0.05) for spatial distance. This result

Table 1 Days from the first case of Hubei to individual reported case, cumulative COVID-19 cases, GDP, and spatial distance to Hubei, and population density

| Province | Days from first case | Cumulative cases | 2019 GDP | Distance to Hubei | Pop. density |
|----------|---------------------|-----------------|----------|------------------|-------------|
|          | Up to February 16   | (Trillion yuan) | (100 km) | (100 persons/km²) |
| Total    | 53                  | 12.368          | 67.61    | 320.30           | 140.25      |
| Guangdong| 42                  | 1322            | 7.72     | 7.95             | 6.30        |
| Beijing  | 43                  | 381             | 2.31     | 10.10            | 12.82       |
| Shanghai | 43                  | 331             | 2.54     | 9.19             | 38.48       |
| Zhejiang | 44                  | 1171            | 4.32     | 8.02             | 5.63        |
| Henan    | 44                  | 1246            | 3.91     | 3.02             | 5.75        |
| Hunan    | 44                  | 1006            | 2.80     | 3.42             | 3.26        |
| Jiangsu  | 44                  | 930             | 1.72     | 4.82             | 2.78        |
| Chongqing| 44                  | 551             | 1.61     | 4.49             | 3.77        |
| Shandong | 44                  | 541             | 6.23     | 7.79             | 6.53        |
| Sichuan  | 44                  | 495             | 3.39     | 9.57             | 1.73        |
| Yunnan   | 44                  | 171             | 1.30     | 12.34            | 1.26        |
| Tianjin  | 44                  | 125             | 1.53     | 9.75             | 13.81       |
| Anhui    | 45                  | 973             | 2.38     | 5.03             | 4.53        |
| Jiangsu  | 45                  | 626             | 7.22     | 7.46             | 7.85        |
| Hainan   | 45                  | 457             | 1.03     | 22.92            | 0.83        |
| Fujian   | 45                  | 290             | 2.56     | 7.53             | 3.25        |
| Hebei    | 45                  | 301             | 2.68     | 9.40             | 4.03        |
| Guangxi  | 45                  | 238             | 1.32     | 7.95             | 2.69        |
| Hainan   | 45                  | 162             | 0.39     | 12.05            | 2.75        |
| Shanxi   | 45                  | 129             | 1.27     | 6.60             | 2.38        |
| Liaoning | 45                  | 121             | 1.91     | 14.61            | 2.99        |
| Guizhou  | 45                  | 146             | 1.15     | 6.81             | 2.05        |
| Jilin    | 45                  | 89              | 1.00     | 18.84            | 1.44        |
| Ningxia  | 45                  | 70              | 0.30     | 8.77             | 1.04        |
| Shaanxi  | 46                  | 240             | 1.83     | 5.42             | 1.88        |
| Gansu   | 46                  | 90              | 0.64     | 13.24            | 0.58        |
| Inner Mongolia | 46 | 72 | 1.33 | 13.21 | 0.21 |
| Xinjiang | 46                  | 75              | 0.91     | 28.90            | 0.15        |
| Qinghai | 48                  | 18              | 0.20     | 16.95            | 0.08        |
| Tibet    | 53                  | 1               | 0.12     | 24.15            | 0.03        |

Days from first case: total days from the first case of COVID-19 in Hubei Province to the date when a case was detected in a destination province; distance to Hubei: calculated spatial distance with GIS data; pop. density: population density. See text for detailed description. There were two extra cases in total in the table than the origin of Hubei to all remaining 30 provinces within China. GDP, gross domestic product.

Table 2 Range, mean, SD and inter-correlation of COVID-19 spread days, cumulative COVID-19 cases, GDP, population densities and spatial distances

| Variable | Cases | Days | GDP | Pop. density |
|----------|-------|------|-----|--------------|
|          | 30    | 42–53| 44.97 (1.88) | 0.49** |
|          |      |      | -0.48** | 0.55** |
|          |      |      | -0.40** | 0.48** |
| Days     |      |      | -0.49** | 0.48** |
| Region   | (n)   |      |       |              |
|          | 30    |      |       |              |
| Guangdong| 30   | 1–322| 412.7 (35.56) | 0.69** |
|          |      |      | -0.53** | 0.13        |
| Beijing  | 30   | 0.12– | 2.25 (1.94) | -0.42* |
|          |      | 7.72  |       | 0.26        |
| Distance | 30   | 3.02– | 10.68 (6.26) | -0.22 |
|          |      | 28.90 |       |              |
| Pop. density | 30 | 0.03– | 4.68 (7.22) |
|          |      | 38.48 |       |

Days: number of days from the first COVID-19 case in China to the date when a COVID-19 case was detected in a destination province; cases: cumulative COVID cases; GDP: 2019 GDP (trillion RMB Yuan); distance: spatial distance (100 km) between a destination province and Hubei; and pop. density: population density (100 persons/km²). See detailed description in the text.

*p<0.05, **p<0.01.
GDP, gross domestic product.

Figure 2 Relationships between days of COVID-19 spread and GDP (A) and spatial distances (B); and relationships of between cumulative COVID-19 cases with GDP (C) and spatial distances (D). GDP, gross domestic product.
suggests that it took 0.1287 more days or 3 hours for COVID-19 to spread to a destination province for every 100 km increase in spatial distance.

Relationship between GDP and cumulative COVID-19 cases

The positive relationships between GDP and COVID-19 cases from the origin to a destination province. For example, the GDP from the origin to Guangdong was 7.72 trillion in 2019, or 382 (3.91×97.9=382) were associated with GDP. Likewise, the 2019 GDP for China was 67.6 trillion. This means economic growth is statistically related to a total 6619 (67.6×97.9=COVID-19 cases. It will cost a big fortune to treat these extra infections.

The positive relationships between GDP and COVID-19 spread suggest another conclusion: higher levels of economic growth present a risk for the spread of infectious diseases. This conclusion extended the traditional understanding that poverty is the primary cause of the spread of infectious diseases. Publicised messages in all forms of media repeatedly suggest that COVID-19 is highly contagious with high virulence and infectivity because it spread to broad geographic regions within and outside of China in a short period. However, findings from our analysis indicate that attributing the quick spread of COVID-19 to its virulence and infectivity is only partially true. The COVID-19 spreading would never be so quicker and so widely without high levels of economic growth and urbanisation. It is the development-related urbanisation and massive population movement that ‘carry’ the virus to penetrate geographic, judiciary and national boundaries a period as short as minutes or hours.

Findings of this study provide evidence supporting the need to strengthen the current infrastructure of preparedness for outbreak control, prevention and treatment of any infectious diseases. This is particularly true for provinces in China with high and rapid growing GDP. More funding should be allocated for training professionals in the field of public health and medicine for infectious disease control, prevention and treatment along with economic growth.

While economic growth and urbanisation can improve quality of life; they also create many opportunities to facilitate the spread of infectious diseases in addition to distance travelling. Decision makers at the population level must include infectious disease control and prevention as a key part of their plans and strategies for economic development.

What is already known on this subject

- Low developmental levels are often associated with infectious disease spreading. With rapid modernisation and urbanisation, economic growth has been improved; but little is known about the relationship between economic growth and the spread of infectious diseases.

What this study adds

- We presented an evidence that high levels of economic growth is in fact a risk factor for the spread of COVID-19. Contrast to the commonly accepted notion, higher gross domestic products is associated with higher speeds of disease spreading and the total number of infected cases.
- More advanced provinces need to be better prepared for infectious disease outbreak and balance their strategic plan for economic growth and development while considering people’s health.
This study has limitations. The cumulative cases in the destination provinces may not be accurate because the COVID-19 detection and test were not conducted by the same national team but local professionals and repeatedly revision of the standard protocols for diagnosis. Second, GDP was a proxy of but not equal to levels of development. Caution is needed to interpret the results. Third, other factors that may affect COVID-19 infection and spread at the population levels are not included, such as facemask use, social distancing, performance of COVID-19 test and quarantine of the suspected subjects. Finally, this study is an ecological modelling analysis with aggregated data at the provincial level. The observed relationship between economic growth and COVID-19 is more statistical than causal. Despite the limitations, this study is the first to assess economic development COVID-19 spread within China. Information derived from this study will be useful not for China but also for other countries in the world that are fighting for the COVID-19 epidemic.

Acknowledgements Qinglian Qin, a graduate student at School of Public Health, Guangxi Medical University, provided assistance in data processing and analysis. This study would take longer time to complete without her assistance.

Contributors QM conducted data collection, data management, the analysis and drafted the manuscript. XC designed the study and conducted data management, revised the manuscript. BY undertook the statistical analysis and revised the draft. ZM designed the study and wrote the protocol, references management and revised the manuscript. QM conducted data collection, data management, the analysis and drafted the manuscript. XC designed the study and conducted data management, revised the manuscript. BY undertook the statistical analysis and revised the draft. ZM designed the study and wrote the protocol, references management and revised the manuscript.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Map disclaimer The depiction of boundaries on this map does not imply the official position, stance, or opinion of BMJ or any member of its authorities. This map is provided without any warranty of any kind, either express or implied.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. The data in our study were public available and collected from official websites.

This article is made freely available for use in accordance with BMJ’s website terms and conditions for the duration of the covid-19 pandemic or until otherwise determined by BMJ. You may use, download and print the article for any lawful, non-commercial purpose (including text and data mining) provided that all copyright notices and trade marks are retained.

Orcid id Zhenyu Ma http://orcid.org/0000-0002-7984-1827

References

1. Nelson KE, Williams CM. Infectious disease epidemiology: theory and practice 2014.
2. Lai C-C, Shih T-F, Ko W-C, et al. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease 2019 (COVID-19): the epidemic and the challenges. Int J Antimicrob Agents 2020;55:105924.
3. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med 2020;382:1199–207.
4. Hubei Provincial Bureau of Statistics. Statistical yearbook of Wuhan, 2019. Available: http://tjj.hubei.gov.cn/sj/pdf/tjj/ggzywh/201911/15020191104653556795480.pdf [Accessed 10 Mar 2020].
5. Chen X, Yu B. First two months of the 2019 Coronavirus Disease (COVID-19) epidemic in China: real-time surveillance and evaluation with a second derivative model. Glob Health Res Policy 2020;5:7.
6. Yu B, Chen X, Rich S. Dynamic of the COVID-19 epidemic in Wuhan, Hubei and China: A second derivative analysis of the cumulative daily diagnosed cases during the first 85 days. The Lancet 2020.
7. Zhang L, Cao S, Xu L. Study on the relationship of economic social factors and human health status. Chinese Health Economic 2014;2:54–5.
8. He L, Tang P. The relationship between life expectancy and economic growth: a review of the literature research. Social Security Studies 2017.
9. Health Commission of Guangdong Province. COVID-19 epidemic update, 2020. Available: http://wjw.gd.gov.cn/xxgzbfl/index/ [Accessed 17 Feb 2020].
10. National Health Commission of the People’s Republic of China. COVID-19 epidemic update, 2020. Available: http://www.nhc.gov.cn/xcs/yqtb/list_gbd.shtml [Accessed 17 Feb 2020].
11. National Bureau of Statistics of China. Provincial GDP, 2019. Available: http://data.stats.gov.cn/search.htm?si=2019%E5%89%84%20%E5%80%84%E7%9C%81% 20GDP [Accessed 18 Feb 2020].
12. Chen X, Lee C-WJ, Li J. Government assisted earnings management in China. Journal of Accounting and Public Policy 2008;27:262–74.
13. Lepenies P. The power of a single number: a political history of GDP 2016.
14. National Bureau of Statistics of China. Total population, 2019. Available: http://data. stats.gov.cn/search.htm?si=省份总人口 [Accessed 04 Mar 2020].
15. Baidu. Introduction for every Chinese Province, 2020. Available: https://baike.baidu. com/item/%E4%88%AD%E5%80%8A%E7%9C%81%E6%A6% 82%E5%86%92/15285626#2 [Accessed 04 Mar 2020].
16. Smith KM, Machalaba CC, Selfman R, et al. Infectious disease and economics: the case for considering multi-sectoral impacts. One Health 2019;7:100080.
17. Du L. Economic loss and economic burden of SARS, and economic benefit of health investment. Chinese Health Economics 2003;22:1–3.
18. Coker RI, Hunter BM, Rudge JW, et al. Emerging infectious diseases in Southeast Asia: regional challenges to control. Lancet 2011;377:599–609.
19. Zhang Y. Study on urban and rural medical and health resources allocation balance in China. Medicine Society 2016.