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

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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.[1] 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 risker 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).[2] The first suspected COVID-19 case was detected on 8 December 2019 in Wuhan, the Capital City of Hubei Province.[3] Wuhan is known as a transportation hub in China with a total population of 15 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).[4] 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,[3] it took a period of 43 days for China to declare it as an outbreak on 20 January 2020[5]; however, it took only 12 days for the disease spread to the remaining 30 provinces of country.[3 5 6] 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.[7 8] 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.

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METHODS

Data collection and variables

Total days for COVID-19 to penetrate a province

One outcome variable was the total days for COVID-19 to penetrate a province outside of Hubei; and it was computed as the difference between the date when first case was detected in origin of Hubei (ie, 8 December 2019) and the date when the first case was reported in a destination province. The computed days were used to measure the speed of COVID-19 spreading within a few days indicating quicker spreading. All the data were derived from the reported data by Chinese Provincial Health Commissions.[9 10]

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.[11] 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.[12 13] 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 Arc GIS (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 be associated with 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/km^2) 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.[14 15] 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:

, (1)

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 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:

, (2)

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:

, (3)

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 analysis were conducted with commercial software SAS V.9.4 (SAS Institute).

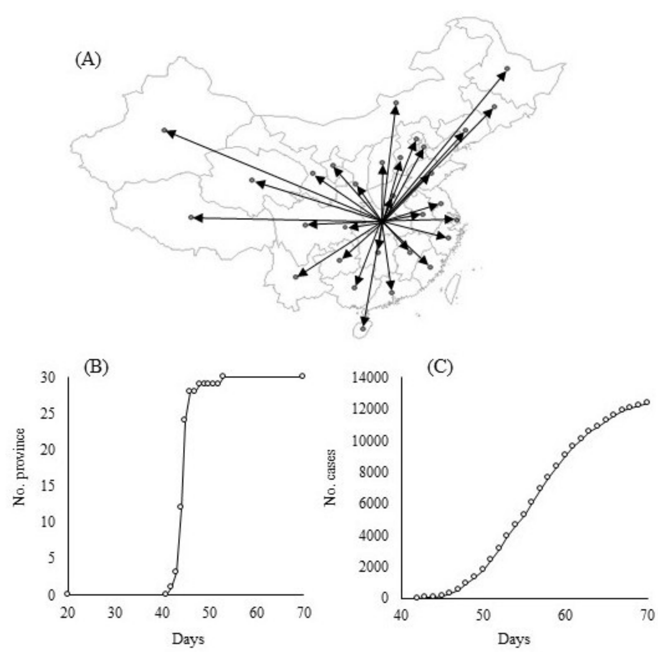

Figure 1 Spread of COVID-19 from Hubei to the remaining 30 destination provinces in China. (A) Geographic spreading, (B) speed of spreading and (C) volume of spreading. Days: total days from the first case in Hubei Province to the date when the first case was detected and reported in a destination province.

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/km^2) ranged from 0.03 to 38.48 with a median of 2.77; and spatial distances (100 km) ranged from 3.02 to 28.90 with a median of 8.98.

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 Up to February 16	2019 GDP (Trillion yuan)	Distance to Hubei (100 km)	Pop. density (100 persons/km^2)
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
Jiangxi	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
Heilongjiang	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	2.09
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 national data due delays in reporting by Inner Mongolia and Shaanxi Province.
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	N	Range	Mean (SD)	2	3	4	5
days	30	42–53	44.97 (1.88)	−0.49**	−0.48**	0.55**	−0.40*
Cases (n)	30	1–1322	412.27 (395.56)		0.69**	−0.53**	0.13
GDP	30	0.12–7.72	2.25 (1.94)			−0.42*	0.26
Distance	30	3.02–28.90	10.68 (6.26)				−0.22
Pop. density	30	0.03–38.48	4.68 (7.22)				

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 (n): 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/km^2). See detailed description in the text.
*p<0.05, **p<0.01.
GDP, gross domestic product.

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 β=−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 hours. Likewise, the regression coefficient β=0.1287 (p<0.05) for spatial distance. This result

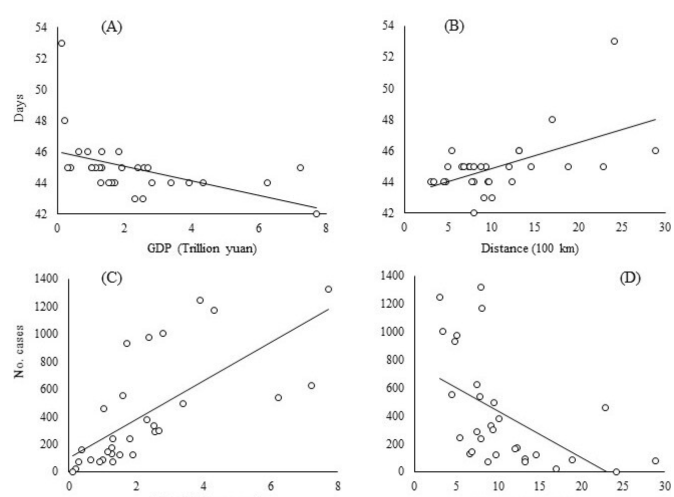

Figure 2 Relationships between days of COVID-19 spread and GDP (A) and spatial distances (B); and relationships of between cumulative COVID-19 cases with GDP (C) and spatial distances (D). GDP, gross domestic product.

Table 3 Results from regression analyses of the relationship between GDP and total days and cumulative COVID-19 cases

	Model 1: days		Model 2: cases		Model 3: cases	
Predictor	β	P value	β	P value	β	P value
GDP	−0.2950	0.0787	118.7409	0.0005	97.8709	0.0007
Distance	0.1287	0.0159	−19.3800	0.0451	−54.3756	0.0036
Pop. density	–	–	−0.4.8987	0.5200	–	–
Data-model fit						
F (p value)	8.41 (0.001)		10.66 (<0.001)		16.89 (<0.001)	
R^2	0.44		0.55		0.56	

Days: period from the first case reported in Hubei to the individual province reported case; cases: cumulative number of COVID-19 cases up to the date of the study; GDP: estimated GDP for 2019; distance: spatial distance (100 km) from a destination province to Hubei; pop. density: population density (100 persons/km^2). In regression model 3, population density was used as weight.

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

figure 2C,D suggests that GDP was positively associated with cumulative COVID-19 cases while spatial distance was negatively associated. Results from regression models 2 and 3 (table 3) indicate good data-model fits with regard to F-test and R^2. However, model 3 performed better than model 2 by including population density as weight rather than a covariate as indicated by F-test and R^2.

Based on the results from model 3, the β coefficient=97.8709 ($p<0.01$) for GDP, which means nearly 100 more COVID-19 cases were detected in a destination province with every trillion more in GDP. The β coefficient for spatial distance was −54.3756 ($p<0.01$), which means, fewer than 55 COVID-19 cases were detected in a destination province with every 100 km in spatial distance from a destination province to Hubei.

DISCUSSION AND CONCLUSIONS

Understanding the relationship between development levels and spread of an infectious disease is of great significance.[1 16] The present study is the first to investigate the issue with provincial level data, including GDP (for measuring developmental levels) and the spread of COVID-19 infection in China. Findings of this study advance our understanding of the spread of COVID-19, a pandemic declared by the WHO on 11 March 2020 (https://www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen). Study findings will inform medical and health professionals to prepare for medical treatment at the individual level, to take massive antiepidemic actions. Study findings will also inform decision-makers to form strategic plans balancing the development with population health at the macro level.

Findings of this current study suggest that after controlling the influences of spatial distance, 1 trillion GDP of a province in China will shorten the time of 3 hours for COVID-19 to spread from the origin to a destination province. For example, the GDP for Guangdong Province was 7.72 trillion in 2019, it was the first province with COVID-19 tested outside of Hubei. In another word, if the spatial distance is the same for all 30 destination provinces, the speed by which the COVID-19 spread from the origin of Hubei to Guangdong was 1 day (7.72×3 hours) sooner than the remaining 29 provinces.

Relative to speed of spreading, study findings on cumulative COVID-19 cases were more striking. After controlling for spatial distances and weighing in population densities, 1 trillion GDP was associated with approximately 100 (97.9) more COVID-19 cases. Taking Henan Province as an example. GDP for this province was about 4 trillion (3.91). Among the 1246 cumulative COVID-19 cases in the province, approximately 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.[17]

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.[1] 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.[18] 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.[19]

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.

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