Modelling analysis of the economic impact from the decreasing population mobility of China's mainland during the pandemic

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Abstract. We extracted the data on population mobility from the Baidu Migration and the historical economic data from governmental statistics over the same period and Designing a model to quantitatively evaluate the impact of different measures taken in different stages by China in response to the COVID-19 on Chinese Mainland economy. The nominal GDPs in the Q1 of 2020 and 2021 predicted by us for Chinese Mainland are confirmed roughly by the official report.

The results suggest that the population mobility data may serve as a new indicator for the real-time economic prediction at different stages of the epidemic, and serve to evaluate the impact of the epidemic on other economies and the global as a whole. Our model is applicable to situations where population movement is greatly reduced due to sudden causes such as epidemics and natural disasters, with good real-time performance and accuracy.

Keywords: computational geometry, graph theory, Hamilton cycles

1 Introduction

The COVID-19 hit Wuhan, China on December 29, 2019 and has spread quickly across entire Mainland[1]. As of July 22, 2021 according to the statistics from Johns Hopkins University, the cumulative confirmed cases of and the deaths of the COVID-19 around the global have gone respectively beyond 190 millions and 4.12 millions. During the epidemic, lockdown is necessary for preventing the spread of the disease, but leads to very high cost[2], Chinese government adopt a series of large-scale public health interventions, such as inter- and intra-city travel restrictions, Staying Home Exercise, and Keeping Social Distancing[3]. These decisive measures have effectively reduced the spread of the COVID-19, but

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have also significantly reduced the cross-regional population mobility in Chinese Mainland[4], and while the sharp decline in the population mobility has result in a sharp decrease in economic activities. At the same time, the global epidemic has almost disconnected global supply chains, which has further caused heavy damages to the circulation of the import and export commodities, and also caused unemployment to rise and consumption capacity to decline, and thus aggravated the economy. Statistics based on Baidu Migration Data, the total inter-city emigration index on 346 cities in the Q1 of 2020 and 2021 were 18595 and 17383 respectively, which are separately 25.26% and 40.86% less than that in the same period of 2019 (24981), and the total intra-city activity intensity on 346 cities in the Q1 of 2020 and 2021 were 120462 and 160519 respectively, when compared with that of the same period in 2019, the former decreased by 12.47% and the later increased by 19%. (Figure 1).

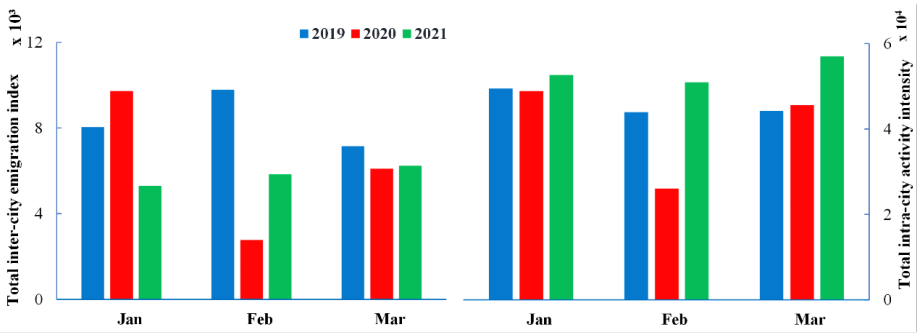

Fig. 1. The population mobility in the Q1 of 2019 ,2020 and 2021 in Chinese Mainland Data source: Baidu Migration website

The population mobility is an important indicator of a region's economic activities and has a strong positive correlation with the region's economic development level[5]. During the outbreak, scholars around the global have been paying attention to the inhibition effects of the epidemic prevention measures on the population mobility and the economy. Xu et al. analyzed the renewal of population flows and the resumption of an urban's transportation, production and life in China after the COVID-19 has been brought under initial control[6]. Giovanni et al. had a massive analysis on the mobility data in Italy to find how the lockdown strategies affect the economic conditions of individuals and local governments.

GDP, as a representative indicator to measure the national macroeconomic development, reflects the final results of all production activities of a country or a region within a certain period of time. Using scientific and effective methods to predict accurately GDP is the main basis for formulating the strategic objectives of economic development. At present, many models predicting GDP have been developed. Most models are based on time series data to find out the charac-

teristics, trends and development rules of the data, so as to effectively predict the GDP of current quarter. Time series prediction method has the defect of prediction error because it does not consider the influence of external factors for the time series. When a major event such as the COVID-19 occurs, large fluctuations in economic indicators will be unavoidable, which makes these forecasting methods become unreliabl[7].

Based on the population mobility data and GDP data of 31 provinces in the Q1 of 2019, 2020 and 2021, we established multiple regression models to predict the GDP of each province in the Q1 of 2020 and 2021, and use real values to test and evaluate the model's Effectiveness, so as to further evaluate the actual impact of different epidemic prevention measures on Chinese Mainland's economy.

2 Methods

2.1 Data sources

The Baidu Migration, a Location Based Services (LBS) provider, provides a large-scale dataset by an application tracking in real time the movements of mobile phone users and publishes the data[8]. These location-based data include the population migration and tourism activities between provinces and cities, which are time-sensitive and continuous, and provide the exact data needed by the accurate analysis of the population movement trend that changes dramatically during the epidemic[9]. In this research, the population mobility and traffic intensity data on intra-city, inter-city, intra-province and inter-province ranging from January 1 to March 31 in 2019, 2020 and 2021 in Chinese Mainland is obtained from the Baidu Migration (http://qianxi.baidu.com). This platform describes the travel population of each city or province with the immigration indicators and the emigration indicators. The intensity of intra-city population movements in each city is the ratio of the number of people travelling within a city to the number of residents in the city[10].

The GDP and the population size data in the Q1 of 2019, 2020 and 2021 by provinces and municipalities are from National Bureau of Statistics of China (http://www.stats.gov.cn/) and its affiliates.

2.2 Feature Selection

At the province level, we checked the relationship between the GDP in the Q1 of 2019 among the total emigration index of travelers leaving for other provinces, the total emigration index of travelers leaving from other provinces, the total inter-city migration index within a province, the total activity intensity of cities in a province, the population size; the determined coefficients were 0.7362, 0.4724, 0.6873, 0.4411 and 0.6981, respectively. which shows that there is a high linear correlation between the population mobility index and the GDP, and this index thus can be used to predict the GDP. We choose some population mobility index with higher determined coefficient for modeling, at the same time, we

further checked the revenues of the express business in each province, and found that the determined coefficient is 0.5612.

In the initial selection of indicators, we constructed a small collection of indicators through stepwise regression to summarize the predictors and participate in the final modeling. The total emigration index of travelers leaving from the i^{th} province to other provinces on the j^{th} day is denoted as PEI_{ij} ($i = 1, 2, \ldots, 31$; $j = 1, 2, \ldots, 90$ for 2019, 2021 and $j = 1, 2, \ldots, 91$ for 2020). The emigration index of travelers leaving from a district in the k^{th} city of the i^{th} province to other districts in the same city on the j^{th} day is denoted as CEI_{kij} ($k = 1, 2, \ldots, m$; m is the total number of cities in the i^{th} province). $Ratio_{kij}$ represents the ratio of the number of travelers leaving from the k^{th} city of the i^{th} province to other cities in the same province to the total number of travelers leaving from the k^{th} city on the j^{th} day. PEI_{ij}, CEI_{kij} and $Ratio_{kij}$ are all given in the Baidu Migration.

For each province, the total emigration index of travelers leaving from the ith province to other provinces in the Q1 of 2019 can be calculated by Equation 1.

$$x_{li} = \sum_{j=1}^{90} PEI_{ij}, \quad (i = 1, 2, \ldots, 31) \tag{1}$$

The total inter-city emigration index within a province in the Q1 of 2019 can be calculated by Equation 2.

$$x_{ij} = \sum_{j=1}^{90} \sum_{k=1}^{m} CEI_{kij} \cdot Ratio_{kij}, \quad (i = 1, 2, \ldots, 27) \tag{2}$$

For each municipality, its x_{2r} ($r = 28 =$ "Beijing", $29 =$ "Chongqing", $30 =$ "Shanghai", $31 =$ "Tianjin") can be described with the mean x_{2i} of 27 provinces and adjusted by the population:

$$x_{2r} = \frac{\sum_{i=1}^{27} x_{2i}}{\sum_{i=1}^{27} \frac{x_{5i}}{27}} \times x_{5r},$$
$$(r = 28 = \text{"Beijing"}, 29 = \text{"Chongqing"}, 30 = \text{"Shanghai"}, 31 = \text{"Tianjin"}) \tag{3}$$

- x_3: the population size of each province in 2019, represented with the population at the end of 2018.
- x_3': the population size of each province in 2020, represented with the population at the end of 2019.
- x_4: the revenue of the express business of each province in the Q1 of 2019 and 2020.
- Y: the nominal GDP (RMB) of each province in the Q1 of 2019 and 2020.
- x_1', x_2', x_3', x_4' and Y' of 2020 correspond to x_1, x_2, x_3, x_4 and Y of 2019, respectively.

3 Model design

The dynamics in social production can be reflected through the population migration and the inter-city traffic conditions, and the results obtained by modeling analysis also indicate a strong linear correlation existing between these indicators and GDP. From this, we will construct respectively the multiple linear models with no constants to forecast each province's GDP of the Q1 of 2020 and 2021, which is shown as Equation 4 and Equation 5.

$$\hat{Y}_1 = c_1 \times x_1' + c_2 \times x_2' + c_3 \times x_3' + c_4 \times x_4' \tag{4}$$

$$\hat{Y}_2 = c_1' \times x_1'' + c_2' \times x_2'' + c_3' \times x_3'' + c_4' \times x_4'' \tag{5}$$

x_1'', x_2'', x_3'', and x_4'' of 2021 correspond to x_1, x_2, x_3, and x_4 of 2019, respectively.

$\hat{Y}_1$: The predicted nominal GDP of each province in the Q1 of 2020.

$\hat{Y}_2$: The predicted nominal GDP of each province in the Q1 of 2021.

We use data from China's Mainland during the epidemic period as a sample set, and import the real-time population mobility data which listed in **??** into the above model, and construct the regression models of GDP forecast in the Q1 of 2020 and 2021 are constructed as follows:

$$\hat{Y}_1 = 3.9047 \times x_1' - 0.1151 \times x_2' + 0.9726 \times x_3' + 22.7975 \times x_4' \quad (n = 31, R^2 = 0.8862, P < 10^{-7}) \tag{6}$$

$$\hat{Y}_2 = 9.6667 \times x_1'' - 0.3544 \times x_2'' + 0.6984 \times x_3'' + 17.8208 \times x_4'' \quad (n = 31, R^2 = 0.8841, P < 10^{-7}) \tag{7}$$

4 Results and analyses

4.1 The predicted values of GDP for the Q1 of 2020 and 2021

By feeding the regression models with the corresponding population mobility data in the Q1 of 2020 and 2021, we got the predicted GDPs for each province in 2020($\hat{Y}_1$) and 2021($\hat{Y}_2$). The predicted GDPs in the Q1 of 2020 and 2021 for each province are listed in Table 1.

We predicted with the model that nominal GDP of China in the Q1 of 2020 is RMB 20,579.09 billion, which dropped by 7.56% from RMB 21,560.6 billion in the same period of 2019 at comparable prices. Similarly, the nominal GDP in the Q1 of 2021 is predicted to be RMB 22,187.38 billion, which increased by 6.57% than that in the same period of 2020 and decreased by 0.28% than that in the same period of 2019 at comparable prices. The result is confirmed

Table 1. The population mobility data in the Q1 of 2021 and the predicted nominal GDP in the Q1 of 2020 and 2021 for each province

Province	x_1''	x_2''	$x_3'' \times 10^4$	$x_4'' \times 10^9$	$\hat{Y}_1 \times 10^9$	$\hat{Y}_2 \times 10^9$
Anhui	501.6	854.1	6393.1	45.0	8779.9	9813.5
Fujian	200.2	350.4	3990.0	80.6	5977.9	6033.5
Gansu	126.2	591.7	2658.7	8.3	3106.4	3014.3
Guangdong	820.8	1014.3	11570.2	534.8	23339.8	25186.3
Guangxi	289.2	652.1	4981.2	24.8	6297.8	6486.3
Guizhou	258.9	306.9	3635.5	14.0	4744.5	5182.0
Hainan	76.9	499.1	948.8	6.9	1277.3	1351.9
Hebei	528.7	279.1	7624.4	76.2	10649.5	11693.8
Henan	549.7	556.0	9681.2	69.8	12235.7	13122.4
Heilongjiang	82.0	210.5	3775.1	16.3	4318.0	3645.1
Hubei	313.5	886.0	5957.3	52.8	7124.8	7818.6
Hunan	382.7	337.0	6947.9	34.9	8719.5	9055.0
Inner Mongolia	153.8	243.0	2550.5	11.9	3227.5	3394.1
Jilin	84.4	246.2	2703.5	15.6	3284.8	2895.1
Jiangsu	776.1	649.9	8104.5	180.6	13519.6	16150.1
Jiangxi	302.1	544.4	4693.0	31.3	6123.2	6561.9
Liaoning	140.6	249.3	4370.3	36.3	5437.8	4969.5
Ningxia	52.7	194.5	697.7	3.7	900.4	994.7
Qinghai	34.1	73.6	610.4	2.1	728.6	767.3
Shaanxi	230.7	449.8	3892.8	26.4	5015.0	5259.9
Shandong	423.6	704.4	10113.2	98.4	12859.1	12662.1
Shanxi	191.0	383.5	3745.2	19.5	4578.2	4673.9
Sichuan	432.6	1604.4	8407.8	59.3	10726.4	10542.0
Tibet	13.3	105.0	352.5	0.8	395.1	352.0
Xinjiang	42.8	82.1	2537.8	7.7	2725.8	2295.1
Yunnan	189.3	294.6	4879.1	19.8	5734.2	5485.4
Zhejiang	614.4	485.7	5875.0	261.5	12112.1	14530.2
Beijing	375.9	1053.9	2162.8	73.1	5459.2	6073.0
Chongqing	285.6	1529.0	3137.7	24.4	4301.6	4845.5
Shanghai	481.2	1188.3	2438.5	368.7	9475.6	12503.8
Tianjin	191.3	764.4	1568.7	32.2	2615.8	3248.0

Data source: Baidu Migration website and National Bureau of Statistics of China

roughly by two official reports released separately in April of 2020 and April of 2021, in which the two nominal GDPs are RMB 20,650 billion and 24,931 billion respectively.

With the GDP data of each province in the Q1 of 2020 and 2021 published by the National Bureau of Statistics, we conducted a correlation analysis over the predicted results, and the analytical results are shown in Figure 2.

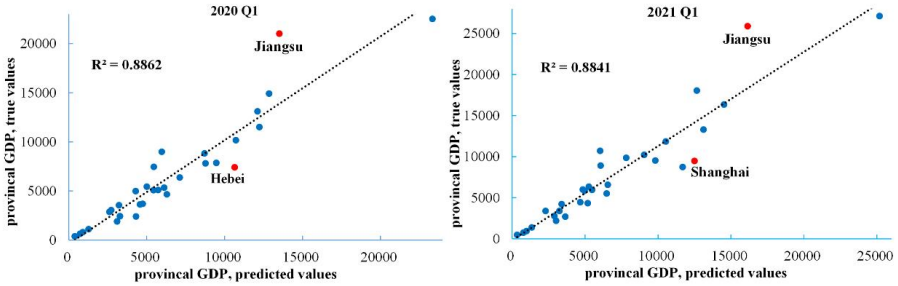

Fig. 2. The true and the predicted GDP values of 31 provinces

The deterministic coefficients between the predicted GDPs for 2020, 2021 by the regression equation and the corresponding real GDPs are respectively 0.8862 and 0.8841, as shown in Figure 2 from which the effectiveness of our model is further verified.

At the same time, we can find provinces whose predicted value is significantly lower than the true value, such as Jiangsu (red dot in Figure 2). These provinces above the trend line maintain a low population flow rate. The higher economic growth shows that their economic structure is more reasonable and diversified. The opposite is true for provinces below the trend line such as Hebei and Shanghai.

4.2 Comparison of the proposed model and related models

We compare the proposed method with ARIMA, ES and Quadratic ES, and the results are shown in Table 2.

Table 2. Comparison of GDP Forecast Results with Different Methods

Models	**2020**				**2021**			
	Predicted /True (billion)	**RMSE**	**MAE**	**MAPE (%)**	**Predicted /True (billion)**	**RMSE**	**MAE**	**MAPE (%)**
Proposed	20,579 / 20,650	1822.8	1162.0	19.75	22,187 / 24,931	2506.5	1523.0	17.61
ARIMA	26,726 / 20,650	2625.9	2036.1	31.62	28,262 / 24,931	1455.5	1163.3	16.67
Simple ES	25,893 / 20,650	2301.9	1734.6	26.06	25,880 / 24,931	2499.9	2373.9	25.28
Quadratic ES	27,947 / 20,650	3106.9	2397.2	36.79	29,619 / 24,931	1991.9	1568.1	21.58

We chose the data of the Q1 of 2020 and 2021 as the research sample because of the greater impact of the epidemic and the significant seasonal factors such as the Spring Festival. RMSE and MAPE of the predicted results were 1822.82, 2588.59 and 19.75%, 17.93%, respectively, which are better than other models.

From the comparison of methods, it can be seen that under the severe impact of the epidemic, the effect of using traditional time series forecasting method to predict GDP is not ideal, and the multiple linear regression model established by the real-time population mobility data can be more accurate predictive effect, which can be used as an effective method for macroeconomic forecast when major event occur.

Due to the international flights data is unobtainable, the international population mobility is not considered in our research, which may be one reason for the higher predicted value for some provinces in this paper.

4.3 Different economic policies to deal with different epidemic changes

Controlling the epidemic situation and maintaining economic growth are the biggest challenges facing all countries in the world. Taking Chinese Mainland as an example, we studied the different economic impact of different epidemic control measures adopted by China under different epidemic conditions, some suggestions are provided here. Here we take the 40-day data of China's Spring Festival travel rush as an example, because this is the time when China's population mobility the most and economic activities are the most active each year, but it is also the time when the epidemic has the greatest impact. The comparison of population mobility data show in Figure 3.

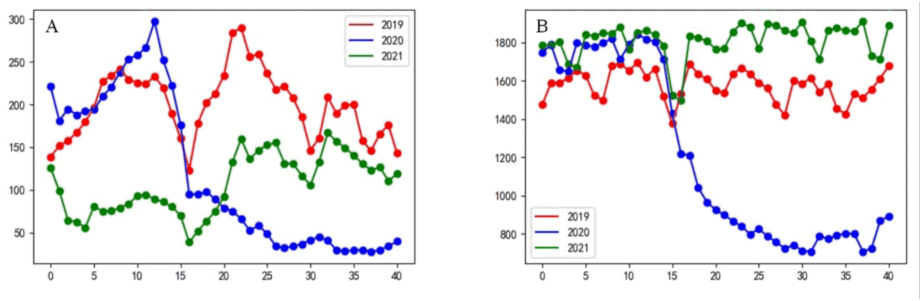

Fig. 3. Comparison of 40-day population mobility of Spring Festival travel rush from 2019 to 2021

From the end of January to the end of March in 2020, the epidemic is the most serious period. The government has to take measures such as closing cities and stopping public transportation. As a result, the flow of population has almost stopped, the national supply chain has been seriously damaged, and production

in many regions has come to a standstill. After the epidemic was basically controlled, the government took a series of measures to boost the economy, such as continue to actively enlarge the domestic demand and releasing the consumption demand being suppressed for the epidemic, and together with implement the proactive fiscal policy and the moderately loose monetary policy. Finally, China's GDP reached RMB 101.5986 trillion in 2020, an increase of 2.3% over the previous year.

In 2021, the epidemic situation in China under control, but the world epidemic situation is still in crisis. In order to reduce the risk of the spread of the epidemic, the Chinese government divides the whole country into high, medium and low-risk areas according to the severity of the epidemic, and advocates not to travel across regions when it is not necessary during the Spring Festival holiday. Such a policy effectively prevents the cross regional spread of the epidemic, and effectively ensures the supply of living materials, various consumption items and social services for residents in the region. Our analysis also shows that in the first quarter of 2021, the inter-city migrate index is lower than that in the same period of 2019 and 2020, but the intensity of intra-city activities is significantly increased. Finally, the GDP growth in the Q1 compared with the same period in 2019 is 10.3% and the number of newly local diagnosed cases in a quarter is only 2119, which shows the effectiveness of this policy.

5 Conclusions

The population mobility is an important indicator of a region's economic activities, and provides an important reference and a view for evaluating the impacts of the epidemic on other economies and the global as a whole, and also presents a new indicator for the real-time economic prediction by the end of the epidemic.

This paper extracted the data on population mobility from the Baidu Migration and the historical economic data from governmental statistics to design models, which are used to predict GDP and quantitatively evaluate the impact of different measures taken in different stages by China in response to the COVID-19 on Chinese mainland's economy. The main conclusions are as follows:

1. We predicted with the model that nominal GDP of China in the Q1 of 2020, 2021 are respectively RMB 20,579.09 billion and 22,187.38 billion, the result is confirmed roughly by official reports.

2. The deterministic coefficients between the predicted GDPs for 2020, 2021 by the regression equation and the corresponding real GDPs are respectively 0.8862 and 0.8841, the RMSE, MAE and MAPE of the predicted results are better than other prediction models.

3. Changes in population mobility during epidemic were regional and phased. In the Q1 of 2020, the population mobility indicators of Hubei, Heilongjiang and Inner Mongolia all decreased significantly. In the Q1 of 2021, inter-provincial population mobility declined, while intra-provincial population mobility increased significantly. The normalization of epidemic prevention and control will intensify the differentiation of regional economic growth, guide enterprises to adjust

their location behavior, and accelerate the digital transformation of the regional economy.

4. The different control measures adopted by the government have different effects on population mobility, and these effects are also reflected in economic changes to the same extent. Under the strictest control measures adopted in the Q1 of 2020, the population mobility of inter-provinces and intra-provinces decreased by 35.45% and 12.47% respectively compared with the same period in 2019, resulting in a decline of 6.8% in GDP. In the Q1 of 2021, the above two indicators were drop by 12.47% and increased by 16.64%, separately than that in the same period of 2019.

In different periods of the development of the epidemic, it is necessary to select different prevention and control measures suitable for each country's situation in the blocking and mitigation strategies, and to minimize the impact on social and economic activities on the premise of preventing the deterioration of the epidemic.

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