The First and Second Derivative Analysis of the Daily Cumulative Coronavirus Disease 2019 Cases in Representative European Countries

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Abstract: Coronavirus disease 2019(Covid-19) had spread all around the world in 2020. For most countries, their epidemic was still not stable. This study would analyze the epidemic of England and Ireland from different aspects to find the reason for which their infection numbers are still increasing. Moreover, this study would analyze them from three distinct geological strata, which are England, Ireland, and all countries in the Europe. The author uses the first and second derivative graph of cumulative confirmed cases from June 1st 2021 to August 3rd 2021. The data were collected from official websites that report daily confirmed cases. Moreover, the author analyzes three different strata (England, Ireland, and all countries in the Europe). There are 5929786 cumulative cases in England, 305527 cases in Ireland and 51805897 cases in all European countries until August 3rd, the change of F''(x) in England and all European countries could be demonstrated in three periods: Stable Period, Acceleration Period and Deceleration Period. Furthermore, the Ireland's epidemic only contained two Periods, which were Stable Period and Acceleration Period. The Acceleration Period could reveal the relaxation of restriction, which increased the number of confirmed cases, in both Ireland and England. Connecting to the local policy, the further vaccination that took place in England help them reduce the Acceleration rate of confirmed cases.

SCIENCE AND TECHNOLOGY PUBLICATIONS

1 INTRODUCTION

The coronavirus disease 2019(Covid-19), caused by severe acute respiratory syndrome coronavirus 2(Sars-Cov-2, which had a genetic relationship with the SARS disease happened in 2003 in China), took place in China already for one year, and it spread worldwide by mostly transportation, especially international flights. Although the first and earliest case happened on December 8th 2019, which was not exact since it was the recall of the first patient of Covid-19, the pandemic was carefully controlled by start some anti-epidemic actions, quarantine. In contrast, some other countries had more severe epidemic situations than Chinese. For instance, England was the country that had the 6th highest number of diagnosed cases and 7th highest number of deaths, These facts get attention globally. Until August 30th, there were 6698486 diagnosed cases in England alone, accounting for nearly 12.2 percent of all cases in Europe. The total confirmed cases in all European countries except England was 45876111(87.8%) cases. Moreover, Europe had total number of 51805897 cases, accounting for 25.4% of the world and ranking the 2nd of all continents. Europe was the second most dangerous continent since most European countries had high infection density. The diagnosed rate was approximately 7.35%, implying that there would be over 70 thousand confirmed cases, second only to North America (7.95%), where the majority of the cases were amassed.

England has started several anti-epidemic policies in order to control the pandemic like started lockdown in the UK began on 16th March 2020 and encouraged working from home on 15 April 2020. Some of these actions definitely had effects, but some anti-lockdown protests occurred, disturbing the controlling process (Poppy 2021).

In this essay, the author aims to explain the transmission of Covid-19 in England by explaining the second derivative model from June 1st to August 3rd. In order to achieve a precise result, the writer

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investigated the epidemic in different strata, including England, Ireland, and Europe Countries.

The result of this study would give suggestions to the England and Ireland in order to help them monitor the epidemic better by providing the trend of pandemic and predict the trend afterward. These pieces of evidence could help decision-makers control their countries' pandemics better. The research also enriches the field of pandemic study in European Countries.

2 METHOD

Database: The author gain the data of daily confirmed cases from only one source: Data from June 1st to August 3rd were derived from an official website that contains daily reported and officially finalized cases (Max 2021)(American Library Association 2021).

In order to gain the data for study, the author derives the daily data: (1) for England only, (2) for Ireland only and (3) for Europe Only. Details could be seen in Figure 1:

Date	England	Ireland	Europe
2021/6/1	4503232	261946	46723425
2021/6/2	4506335	262319	46772797
2021/6/3	4510598	263019	46831988
2021/6/4	4515779	263720	46892146
2021/6/5	4521922	264072	46933089
2021/6/6	4527577	264425	46972318
2021/6/7	4532802	264778	47001518
2021/6/8	4538399	265131	47041209
2021/6/9	4544374	265484	47085213
2021/6/10	4551694	265837	47132946
2021/6/11	4558933	266190	47186893
2021/6/12	4566893	266543	47229008
2021/6/13	4574447	266896	47265540
2021/6/14	4581779	267249	47296762
2021/6/15	4589400	267602	47337451
2021/6/16	4596994	267949	47375845
2021/6/17	4605807	268251	47416266
2021/6/18	4616629	268644	47461450
2021/6/19	4626915	269037	47506973
2021/6/20	4636993	269321	47544343
2021/6/21	4646068	269495	47577829
2021/6/22	4656538	269793	47621491
2021/6/23	4668043	270097	47665159
2021/6/24	4683989	270477	47718029
2021/6/25	4700694	270920	47769788
2021/6/26	4716066	271260	47823226
2021/6/27	4734011	271589	47868500
2021/6/28	4748645	271931	47912419
2021/6/29	4771369	272336	47973615
2021/6/30	4791628	272784	48034605
2021/7/1	4817316	273296	48108117
2021/7/2	4845029	273744	48185151
2021/7/3	4871818	274306	48259947
2021/7/4	4896274	274641	48322118
2021/7/5	4920174	275038	48381460
2021/7/6	4947286	275571	48477670
2021/7/7	4975916	276104	48566867
2021/7/8	5007966	276735	48656283
2021/7/9	5040413	277316	48763397
2021/7/10	5075967	277892	48874377
2021/7/11	5107803	278464	48956663
2021/7/12	5139169	279053	49036443
2021/7/13	5173995	279790	49145267
2021/7/14	5210616	280784	49281040
2021/7/15	5252691	281954	49418833
2021/7/16	5301335	283331	49562162
2021/7/17	5353307	284510	49700127
2021/7/18	5407437	285689	49827668
2021/7/19	5455309	286760	49936673
2021/7/20	5495990	288020	50092220
2021/7/21	5542859	289208	50237598
2021/7/22	5586740	290594	50379049
2021/7/23	5626772	291939	50533187
2021/7/24	5662838	293065	50634571
2021/7/25	5694462	294341	50774967
2021/7/26	5723422	295455	50863516
2021/7/27	5748331	296816	51004170
2021/7/28	5771732	298117	51127809
2021/7/29	5797451	299618	51266873
2021/7/30	5828343	301045	51400668
2021/7/31	5857661	302143	51535158
2021/8/1	5883451	303495	51628775
2021/8/2	5907614	304379	51719669
2021/8/3	5929786	305527	51805897

Figure 1: The number of cumulative confirmed cases of COVID-19 in England, Ireland, and all European Countries from June 1st to August 3rd.

To find the second derivative model, the author firstly derived the cumulative diagnosed cases table, which was denoted as F(x)

$$F(x)=\sum_{a=1}^{t} x(a) \quad (1)$$

where x(a) represent the daily confirmed cases in day a(a=1,2,3...t)

According to this, the author gained the first derivative F'(x). Since F'(x) means the velocity that the growth of cumulative cases, everyday's F'(x)s were different. The author gain F'(x) from

$$F'(x)=\sum_{a=1}^{t+1} x(a) - \sum_{a=1}^{t} x(a) \quad (2)$$

by subtracting the daily cumulative cases, the rate of change of confirmed cases could be obtained. In addition, since F'(x) is gained, the author found F''(x):

$$F''(x)=F'(xa+1)-F'(x) \quad (3)$$

where F''(x) means the rate of change of the growth rate, or the acceleration of confirmed cases.

The bigger F'(x), the faster daily cases increased, whereas if F'(x) = 0, it means that the diagnosed cases did not change during that day. In the cumulative model, the rate of growth of confirmed cases would always be non-negative since it grew almost every day.

When F''(x) is bigger than 0, it means that the speed of increasing the number of diagnosed cases is accelerating, whereas the negative F''(x) value means the rate of change in daily new cases is decelerating. If the F''(x) = 0, it means the F'(x) does not change during that time, and it further means the number of cumulative confirmed cases is evenly increasing, decreasing or stop growing. F''(x) always be represented as a straight line on the F(x) graph.

3 ANALYSIS

3.1 First Derivative Analysis

The first derivative graph of cumulative cases of three different strata is presented in figure 2. From June 1st to June 30th, the infection rate in England did not fluctuate very much, which illustrates very slow growth of epidemic. However, in July, the rate of change of reported cases increased to its peak in these three months. The highest F'(x) value reached 54130 cases per day on July 17th. This may be a result from the new policy posted by the prime minister on June 14th, which delayed England's lockdown easing by four weeks. Moreover, on July 5th, the prime minister set out a plan to ease Covid-19 restrictions in England (Sarah 2021. Because of these policies, the infection rate grew rapidly. After the peak, the infection rate declined on July 27th, and after a few days increasing, it went down again at the end of July

Unlike England, the F'(x) lines of Ireland showed another picture, For the Ireland graph, since Ireland is isolated from most countries and its lockdown policy, the number of infections did not grow very much during this time. It only experienced its peak on June 28th because Ireland reach its highest rate of vaccination throughout the whole epidemic. The rate of vaccination reached 110673 new vaccinations per day. Because of this, the number of contact among people increased, which caused a short period of increase in confirmed cases.

The first derivative graph for the whole of Europe has an extremely different epidemic pattern from the other two. It fluctuates numerous times during these two months. After June 26th, it started to grow rapidly, and it reached its peak on July 19th and another people on July 22nd which is a little later than England. Contrasting to all European countries, the England and Ireland showed a much flatter pattern, telling the researchers and decision makers that other countries in the Europe show strengthen their countries' anti-epidemic policies.

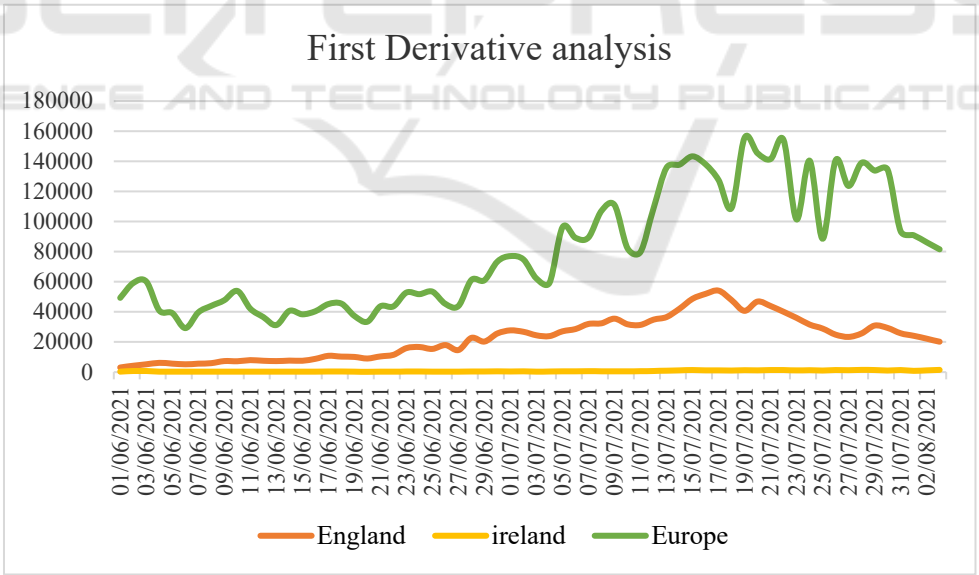

Figure 2: Epidemic curve of the first derivative of cumulative COVID-19 cases from June 1st to August 3rd in England, Ireland and Europe.

3.2 Second Derivative Analysis

Figure 3 illustrates the second derivative graph for different strata.

From the second derivative graph of England, presented in figure 3, the author concludes that during these two months, England epidemic experienced three different period, which is categorized by the rise or fall of F''(x).

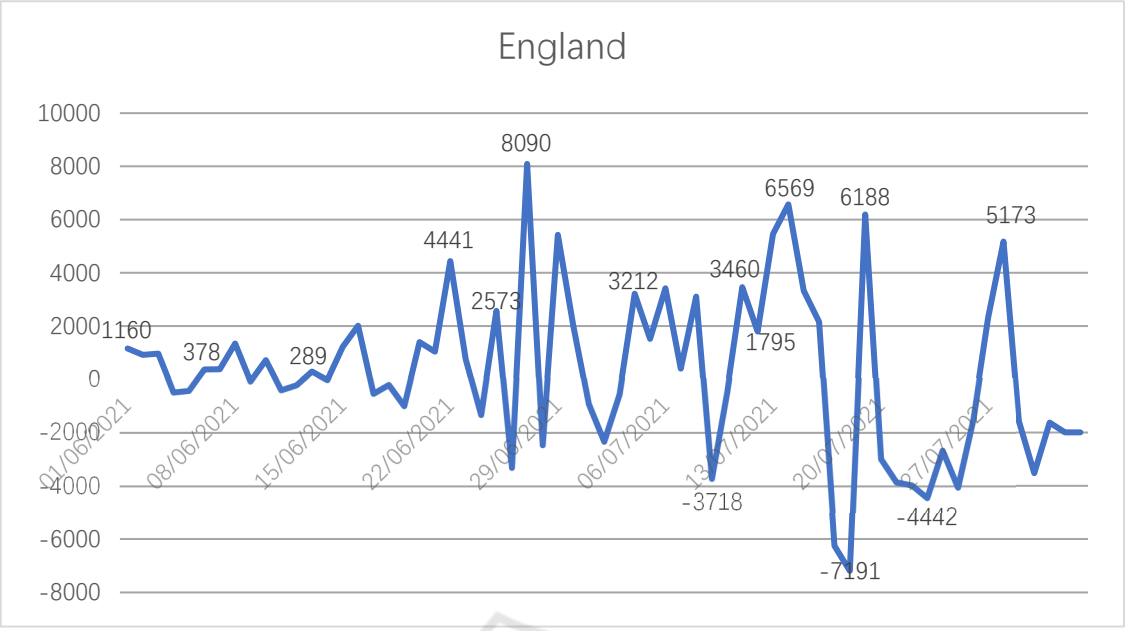

Figure 3: Second Derivative Curve of cumulative COVID-19 cases from June 1st to August 3rd in England.

The first period was called Stable Period (From June 1st 2021 to June 22nd 2021). During this time, the variation of F''(x) did not exceed 2000 cases/day2. The situation was seemingly good to England, until the lockdown was delayed by the Prime Minister on June 14th. After that day, the average change of infection rate became extreme and intense.

The second period was called Acceleration Period (From June 23rd 2021 to July 15th 2021). F''(x) became much less stable than Stable Period. After 4 days, F''(x) began to fluctuate, reached its peak on June 27th. The graph shows the relatively increasing tendency from June 23rd to July 15th. This result tells researchers and those decision makers in the UK that delaying the lockdown time definitely negatively influenced the England pandemic.

The Last period was called Deceleration Period (From July 16th 2021 to August 3rd 2021), which shows a decreasing trend of F''(x). Some anti-epidemic actions occurred during the period. Further vaccination started in this period. Until July 16th, there was already 35745635 people who had taken the second vaccination (UK Health Security Agency 2021)(Johns Hopkins University 2021). This event definitely decrease the growth of infection rate. Furthermore, from these data, the author knew three important information: first, the future tendency of F''(x) would be more stable and stay between ±2000 if England continues to maintain the same situation, or more people be vaccinated. Second, if more people be quarantined, or England continues lockdown, another decline wave would occur after an incubation period, which would last for 14 days. Third, the actions that took place in England after Acceleration Period led to the decline of F''(x). Though less evidence could support this fact, a longer time of observation is needed to confirm this information.

The tendency of F''(x) of Ireland was showed in figure 3. Even though Ireland was the nearest country to the England, the graph of F''(x) of Ireland is very distinct from England's. It only had two periods: Stable Period and Acceleration Period. There was no Deceleration Period during these two months. Additionally, the lengths of these periods were far different from England's. In Ireland, the Stable Period only lasted for 18 days (From June 1st 2021 to June 17th 2021). After that, later days were considered as Acceleration Period (From June 18th 2021 to August 3rd 2021). The main reason for which Ireland's epidemic during these two months did not have Deceleration Period was because of the relaxation of restriction around the end of July and the beginning of August. According to Tully, the co-chairman of the Behavior Change Group at Northern Ireland's Public Health Agency, he said: "We've also seen an increase in the number of contacts between people here as well, slightly higher than the rest of the UK." (Chris 2021). This fact had negatively affect Ireland's epidemic. Moreover, since there were more serious control and anti-epidemic actions in Ireland than there were in England, so less fluctuation as shown in the graph.

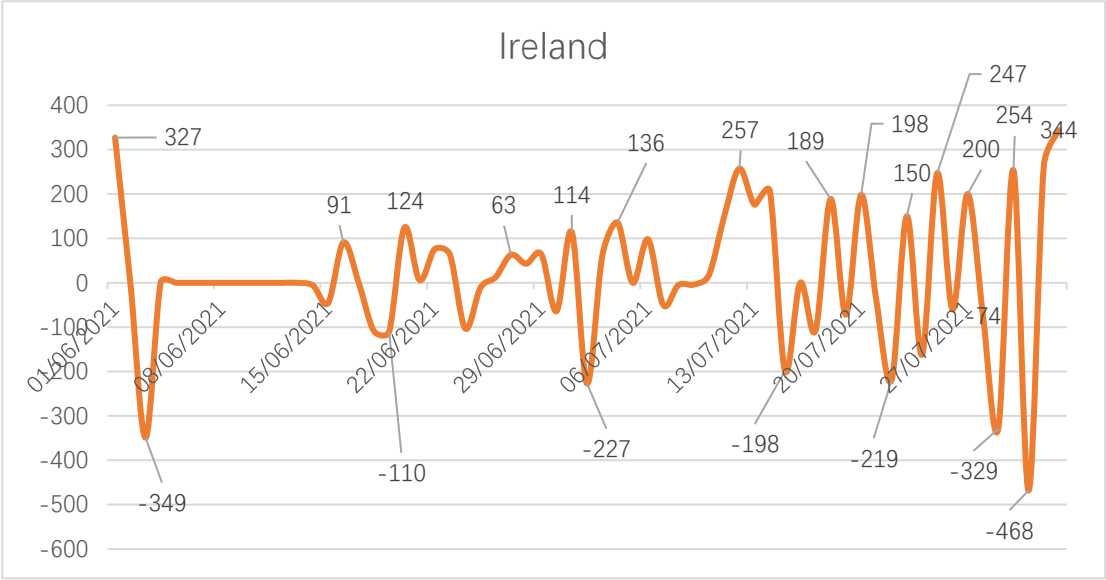

Figure 4. Second Derivative Curve of cumulative COVID-19 cases from June 1st to August 3rd in Ireland.

The trend of F''(x) of all European countries was showed in Figure 4. Unlike Ireland, the tendency of all European countries is more similar to England's. Because England had the most infections at the time, any change in England's infection would affect the tendency of all European countries more than others. It has three comparable periods to England: the Stable Period (June 1st to July 3rd), the Acceleration Period (July 4th to July 21st), and the Deceleration Period (July 22nd to August 3rd).Its Stable Period was 11 days longer, and it had 5 days shorter Acceleration Period and 6 days shorter Deceleration Period.

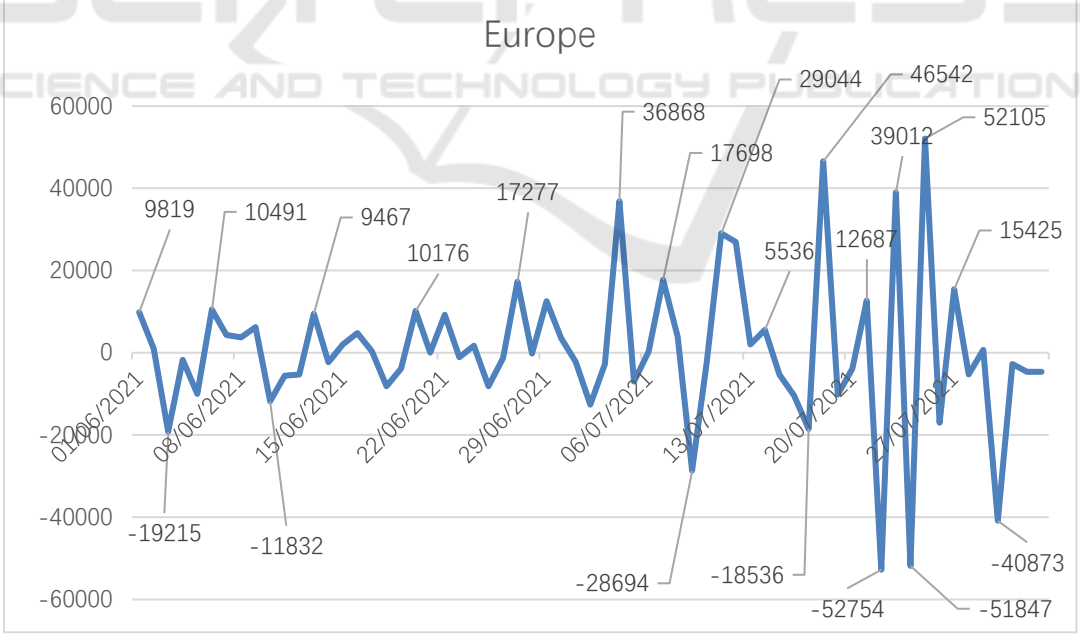

Figure 5. Second Derivative Curve of cumulative COVID-19 cases from June 1st to August 3rd in Europe.

4 CONCLUSION

This first and second derivative analysis illustrates that the main reason for the increase in the number of infections was the relaxation of restriction, and that caused the rise of contact among people. The fact that all European countries' F''(x) tendency had the unequal length of different periods from England infer that other countries in Europe had more stable epidemics than England. Furthermore, the result of this study could help those decision makers make more reasonable policies to control the pandemic.

This study, of course, has several limitations. First, the main study region is England and Ireland, which means that the author did not pay too much attention to other countries. As the Covid-19 had spread to other countries, more studies are needed to help scientists and medical staff to monitor the pandemic. Second, fluctuations Ireland's epidemic was too small that is hard to compare with other countries, so it may be more effective to use other countries' information, such as Russia, to compare with England. Finally, the study period is relatively shorter than the whole epidemic, and since the derivative graph is very sensitive to the change, two monthly analyses may not elaborate the big picture comprehensively. Therefore, longer time research is needed in order to confirm the tendency for each country.

SCIENCE AND TECHNOLOGY PUBLICATIONS

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