When can physical distancing be relaxed?

A health production function approach for COVID-19 control policy

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Abstract

Background

Physical distancing measures to control the COVID-19 pandemic come at a heavy short-term economic cost. But easing the measures too early carries a high risk of transmission re-escalations. To assess if physical distancing can be relaxed, a number of epidemic indicators are used, most notably the reproduction number R. Many developing countries, however, have limited capacities to estimate R accurately. This study aims to demonstrate how health production function can be used to assess the state of COVID-19 transmission and to determine a risk-based physical distancing relaxation policy.

Methods

The author establishes a short-run health production function, representing the cumulative number of COVID-19 cases, from the standard SIR model. Three zones defining the state of transmission are shown. The probability of meeting a policy target, given a production elasticity range, is computed. The method is applied to France, Germany, Italy, the UK and the US, and to Indonesia as an example of application in developing countries.

Results

As of June 30, 2020, France, Germany, Italy and the UK have arrived in the “green zone” where relaxation can be considered. The US is still in the “red zone” where physical distancing still needs to be applied. France, Germany and Italy can set a policy target of maximum daily-cases of 500, while the UK has to make do with a target of 1,100 daily-cases. France, Germany, Italy and the UK still exhibit a relatively high risk of their daily-cases failing to meet the policy target or even rising. Indonesia is still

in the “red zone”, so it comes as no surprise that the country’s daily-cases rose sharply after relaxation of physical distancing.

Conclusions

Short-run health production function can be used to assess the state of COVID-19 transmission and to determine a risk-based physical distancing relaxation policy. Given its simplicity and minimum data requirement, the approach is very useful for developing countries which are unable to have reliable estimates of the reproduction number *R*. Follow-up research from this study may include estimating an economically optimal date for relaxing distancing measures and application of this method to other epidemics.

Keywords:

COVID-19, physical distancing, pandemic control policy, state of transmission, health production function, production elasticity, developing countries.

Introduction

To control the rapid spread of the coronavirus disease 2019 (COVID-19) pandemic, many countries employ community-wide physical (social) distancing measures. These measures usually include border closing, movement restriction, school, workplace, and public-place closures, prohibition of gatherings, isolation and or quarantine. These measures constitute a pandemic control policy termed “large-scale public health restrictions” by the World Health Organization (WHO) [1].

The short-term economic costs of physical distancing, however, can be very high. At the macro level, a 6-weeks social distancing is estimated to lower the Gross Domestic Product (GDP) of 15 European countries by 4.3-9.2% [2]. Using an Effective Lockdown Index (ELI), a 14% contraction of the global GDP on a year-on-year basis has also been estimated [3]. At the micro level, physical distancing adversely affects household income. It is estimated that the US’ household income could decline by 4.6-25.6% [4].

At the global level, in June 2020 the International Monetary Fund (IMF) estimates that the COVID-19 pandemic and its containment policies could subdue the 2020 global economic growth to -4.9%, an 8.2% correction from its January 2020 projection [5]. In its June 2020 Economic Outlook, the Organisation for Economic Co-operation and Development (OECD) projects a 6% contraction of the world's economy in a single-hit scenario, and a 7.6% fall if there is a second wave of infections before the end of 2020 [6]. This contraction will cause higher global unemployment.

Notwithstanding the short-term economic costs, in the long-term the economic benefits of social distancing have been shown to outweigh the costs. Over a 30-year planning horizon using a 3% discount rate, effective social distancing produces economic net benefits of about US$ 5.2 trillion [7]. Evidence from the 1918 Flu Pandemic in the US also shows the economic benefits of social distancing as a non-pharmaceutical intervention (NPI). Cities that intervened earlier and more aggressively with an NPI had an increased economy after the pandemic [8].

If social distancing is not applied, the economic costs can be much higher. A two-sector analysis of the US Input-Output Table shows that without social distancing, the falls in output, capacity utilization and investment is around two-folds of those with social distancing [9]. If social distancing goes wrong, the economy could experience another severe hit [9]. If social distancing is "just slightly too relaxed", the net economic result would be worse than doing nothing [10].

Once distancing measures are applied, given their high economic costs, the policy challenge facing governments is to determine when the measures can be relaxed without increasing the risk of transmission re-escalations. In this case, WHO recommends that COVID-19 transmission should come under control [1], based on a number of epidemic indicators, most notably the reproduction number R. Developed countries such as Germany use R as a benchmark to ease lockdown; its R prior to the easing was 0.8 [11]. The UK frequently releases its R and growth rate figures, which as of June 25, 2020 were 0.7-0.9 and -4% to -2%, respectively [12]. The UK government did not, however, solely rely on these indicators to ease lockdown measures.

For developing countries, estimating R can be very problematic. Many developing countries have very limited financial and research capacities to estimate R accurately on a daily basis. They have a relatively inferior health data collection system, making them unable to accurately estimate the basic reproduction number R_0 in the early stages of a pandemic. Fiscal tightness limits their ability to conduct large-scale test and tracing programs. With only a tiny fraction of the population is tested, the accuracy of any estimate of R is highly questionable.

In this study, the author proposes the use of short-run health production function as an additional approach to assessing the state of COVID-19 transmission. The author shows that with a minor adjustment, the cumulative number of COVID-19 cases can be constructed as a short-run total product function. One can then use the function to estimate the corresponding marginal and average products, the production elasticity and the relevant Bayesian probabilities to determine a risk-based pandemic control policy. This approach is very simple and straightforward, which can be performed easily by developing countries officials.

Methods

Since Grossman's seminal work [13], there have been a large body of research on health production function. These research use community or individual health status as the output variable, measured for example by morbidity [14], mortality or individual health status, with inputs such as health care, safe water and sanitation, habits (e.g. diet, smoking) and other relevant variables.

This study employs time as the health input variable. Because only one variable is used, we are dealing with a short-run health production function. The cumulative number of COVID-19 cases is employed as the health status output.

Now consider the Susceptible-Infected-Recovered (SIR) model, with $S(t)$, $I(t)$, $R(t)$, and t representing the susceptible, the infected, the recovered, and time, respectively. Defining $Y(t)$ as a twice-differentiable function given by the integral of $I(t)$ with respect to (w.r.t) time from t=0 to t=τ, it follows that for $\forall\tau > 0$, $Y(\tau)$ is the cumulative number of the infected or the cumulative number of cases from t=0 to t=τ. Thus, we have $Y(t)$ as a short-run health production function.

The main departure of $Y(t)$ from the standard short-run production function in economics is that it has no downward curve. This is because the cumulative number of cases does not decrease unless there is a change in the definition of cases or an incorrect recording of data. The corresponding marginal product of the infected (MY), the average product of the infected (AY), and the production elasticity of the infected w.r.t time t (εt) can then be derived from $Y(t)$. Note that εt is defined as the percentage change in $Y(t)$ for every one per cent change in t. This procedure is formally presented in Additional file 1.

Because the number of confirmed COVID-19 cases is reported daily, and recognizing that these data are the best available guesses of the true number of the infected, we can let dt = one reporting day. Thus, without any need to estimate the functional form of $Y(t)$, we can compute MY, AY, and εt directly from these data. Because $MY = I(t)$, that is the number of daily COVID-19 cases at time t, MY and $I(t)$ are used interchangeably. Note that $MY = I(t) \geq 0$. For reason of definition rigor [15], this study uses arc elasticity, even though estimates of both arc- and point-elasticity are presented

Because $Y(t)$ and $I(t)$ are time-series variables, to have clearer trends the author smooths out the data using 5-day exponential moving average (EMA), assuming an incubation period of 5 days as used by Kucharski et al [16]. The author uses 5-day EMAs as the bases of analysis.

Pandemic control inferences from $Y(t)$, MY, AY, and εt

Figure 1 illustrates the pandemic control inferences that can be drawn from $Y(t)$, MY, AY, and εt for $I(t) \geq 0$. The curves shown are the standard short-run total, marginal and average products where the marginal product is equal or greater than zero. The inferences depend on whether three crucial periods determining the state of transmission, i.e. t_1, t_2, or t_3, have been reached. They are described as follows:

1. Before t_1 is reached, MY=$I(t)$ has not peaked and is still rising, and $\mathcal{E}t$>1. Policy makers need to apply physical distancing measures to stop the rise, and to bring the number of daily cases down. This state is represented by the “red zone” in Figure 1.
2. At t_1, MY reaches its peak, which corresponds to the inflection point Y_1. From t_1 to t_2, $I(t)$ declines. Naturally, policy makers start to think if distancing measures can be relaxed. But at this state of transmission, MY>AY and $\mathcal{E}t$>1. Relaxing the measures is not recommended. This state is represented by the “yellow zone” in Figure 1.
3. At t_2, AY reaches its peak and $\mathcal{E}t$=1. From t_2 to t_3, both MY and AY decline, $MY \leq AY$, and $0 \leq \mathcal{E}t \leq 1$. Relaxation of distancing measures can be considered at this state of transmission, depicted by the “green zone” in Figure 1.
4. At t_3, MY=$I(t)$=0. No more daily COVID-19 cases are recorded; $Y(t)$ reaches its steady-state.

At a given time t, the question is then “is now the right time to relax the measures?” To answer this and to showcase inferences #2 and #3, the author assumes that policy makers rationally adopt risk-based decision-making. They need to assess the probability of near term’s daily COVID-19 cases being equal to or below a given daily-cases target of I^*. This probability is conditional on $\mathcal{E}$t because the condition $\mathcal{E}t \leq 1$ must be satisfied. I^* may be set in accordance to the number of daily-cases that a health system can handle, or be determined arbitrarily based on, say, a socio-political process. A rational policy maker will only relax distancing measures if the probability is high. A more cautious one might add another target such as “constant or declining number of daily-cases”.

Results

To test this approach, the author initially analyses COVID-19 cases in France, Germany, Italy, the UK and the US. The analysis only needs data on the cumulative (or the daily) number of COVID-19 cases and their recording dates, which for these countries are obtained from Coronavirus Statistiques [17]. The method is then applied to Indonesia’s COVID-19 data [18] as a developing country example, given the author’s familiarity with its health data collection system. The data covers a period from the first day a confirmed case is recorded until June 30, 2020.

The state of COVID-19 transmission

Descriptive statistics of the data are given in Table 1. Figure 2 presents the 5-day EMA curves of *Y(t)*, *MY=I(t)*, and *AY*. See Additional file 2 for the corresponding curves from original data.

(Table 1 and Figure 2 can be placed here)

From France's, Germany's, Italy's and the UK's curves in Figure 2, it is obvious that *Y(t)*, *MY*, and *AY* have the curvature of short-run total, marginal, and average products, respectively. With regard to the state of transmission, these countries have all reached t_1 with Italy being the earliest one and the UK the latest one..

The US on the contrary has not reached t_1. It appeared to reach t_1 on April 25, but the EMA data show new heights of *I(t)* on June 26-27. As this study covers data until June 30, 2020, the author has no adequate data to consider June 26-27 as the US' t_1. On May 21 the US reported a sharp drop in *I(t)*, making its *MY* falling below its *AY*. But because its *AY* is still rising and the sharp fall is not sustained on the days after, the fall is considered a statistical outlier. All these explain why currently *Y(t)* in the US has yet to exhibit the standard total product curve.

With regard to t_2, Germany reached it on April 20. France and Italy reached it a few days later, while the UK almost a month later. On May 6 France recorded a large jump in its daily cases, resulting in *MY>AY*. But France's *AY* has been declining from April 22-24, and its *MY* is lower than its *AY* from May 7 to June 30. So the May 6 jump is seen as an outlier.

With regard to t_3, none of the countries studied has suppressed their *I(t)* to zero. So, none of them has arrived at the steady-state of *Y(t)*.

Production elasticities

Table 2 presents the arc production elasticity (Ɛt) for these countries. Point elasticity values are also presented for comparative purpose. In general, arc elasticities are larger than point elasticities for all countries. Italy has the smallest Ɛt, with a mean of 1.45. This means that for every one per cent change in time, Italy has 1.45 per cent additional COVID-19 cases. The US exhibits the largest Ɛt with a maximum value of 9.07.

(Table 2 can be placed here)

The UK's Ɛt has a mean of 2.20, larger than France's, Germany's and Italy's. With a much lower coefficient of variation (CV), the UK's Ɛt is much less dispersed around its mean value. These results reflect the UK's persistently higher daily COVID-19 cases, and its inferior ability to suppress both $I(t)$ and Ɛt compared to France, Germany and Italy.

Probability of a policy target

The next analysis is not relevant for the US because it has yet to reach t_1. Now let's assume that based on the latest $I(t)$ records, France, Germany and Italy set the policy target I^* arbitrarily at 500 daily-cases. Table 3 presents the probability of $I(t+1) \leq I^*$, given a range of Ɛt.

(Table 3 can be placed here)

For Ɛt>1 (the "yellow zone"), the probability of $I(t+1) \leq 500$ is zero for these countries. This means, even though France, Germany, and Italy have reached t_1, they have a zero chance of supressing their near term's daily-cases below or equal to 500. After reaching t_1, with Ɛt>1 they only have a probability of greater than zero if I^* is set higher than 500. For example, France will have a probability of 0.04 if I^* is set at 1,507.1. This explains why relaxation is not recommended in this transmission state.

If a country reaches t_2, they have $0 \leq \mathcal{E}t \leq 1$. As shown in Table 3, the probabilities of $I(t+1) \leq 500$ are 0.47, 0.37, and 0.50 for France, Germany and Italy, respectively. If policy makers aim at having a larger probability, they need to set a lower elasticity range. Table 3 presents the probabilities if the range is set at $0 \leq \mathcal{E}t \leq 0.5$ and $0 \leq \mathcal{E}t \leq 0.2$. For $0 \leq \mathcal{E}t \leq 0.2$, France has a probability of 0.71 (five out of seven cases), Germany 1.00 (nine out of nine cases) and Italy 1.00 (30 out of 30 cases).

If $I(t+1) \leq I(t)$ is put as an additional target, the probabilities return lower values, except for $\mathcal{E}t>1$ where the probabilities are again zero. For $0 \leq \mathcal{E}t \leq 0.2$, Germany and Italy have a probability of 0.33 (three out of nine cases) and 0.67 (20 out of 30 cases), respectively. Against expectation, France's probability of 0.29 (two out of seven cases) is lower than its probability in the $0 \leq \mathcal{E}t \leq 0.5$ range. France's erratic data on May 6, May 28, May 30, June 2 and June 24-25 cause this irregularity, and an EMA longer than 5 days is needed to smooth out the data.

The UK shows similar results but with a much higher I^* of 1,100. This is because for $I^*< 1,100$ the UK has no or only few records that meet the threshold. For example, the UK has no records that meet $I^*=500$ because currently this level is unattainable. For $I^*=1,100$ the UK has seven data records, returning a probability of 0.41 at $0 \leq \mathcal{E}t \leq 0.5$ and 0.75 at $0 \leq \mathcal{E}t \leq 0.4$. If the $0 \leq \mathcal{E}t \leq 0.2$ range is used, the probability becomes zero because the UK's lowest elasticity is 0.34. For the $I(t+1) \leq I^*$ and $I(t+1) \leq I(t)$ policy target, at $0 \leq \mathcal{E}t \leq 0.4$ the UK's probability is 0.50 (two out of four cases).

Application to a developing country: Indonesia

In January and February 2020 Indonesia denied that the country has a COVID-19 case. When the central government finally announced the "first" COVID-19 case on March 2, opportunity to estimate R_0 more accurately has been wasted. Consequently, Indonesia has no reliable estimates of R to assess its state of transmission.

On the other hand, the results from France, Germany, Italy and the UK show that short-run health production function and elasticity can be used to assess the state of transmission. As shown by Table 1 and Figure 2, Indonesia has not reached t_1. It means, the country is still in a transmission state where physical distancing needs to be applied to bring down the number of daily-cases. Yet on June 1 Indonesia began to relax physical distancing in some of its provinces in order to "save" the economy. Unsurprisingly, Indonesia's daily-cases rose to a new height of 2,657 on July 9.

Discussion

This study demonstrates how short-run health production function is employed to assess the state of COVID-19 transmission, using only data on the cumulative number of cases and the recording dates. The data are processed in a relatively simple way in Microsoft Excel. To view how the calculations are done, see Additional files 3-8. This simple approach can be performed at minimal costs in developing countries. Needless to say that the accuracy of the results depends data quality.

This study also show that relaxing physical distancing measures can only be considered when the state of transmission is in the "green zone". In this zone the probability of maintaining a relatively low number of near term's daily COVID-19 cases, at a given elasticity range, is relatively high. In the "yellow zone" the probability is zero or near zero.

As of June 30, 2020, France, Germany, Italy, and the UK have all arrived at the "green zone". With a policy target of 500 daily-cases, France, Germany, and Italy need to have a very low elasticity of 0.2 to return a probability larger than 0.7. At a higher elasticity, their probability can fall below 0.5. If the policy target includes "keeping a constant or declining number of daily-cases", their probabilities are below 0.5, except for Italy. In other words, France and Germany still have a high risk of their daily-cases rising.

The UK must make do at a higher target of 1,100 daily-cases, and yet, the probability of meeting the target is relatively lower. The UK also has a higher risk of its daily-cases rising. The US and Indonesia are still in the "red zone", hence, physical distancing measures need to be applied in these countries.

Conclusions

Short-run health production function can be used as an additional method to assess the state of transmission and to determine a risk-based physical distancing relaxation policy. Given its simplicity and minimum data requirement, the approach can be very useful for developing countries which -- for various reasons -- are unable, or miss the opportunity, to estimate R_0 thoroughly and accurately. Indonesia is used as an example, and the results explain why the country's daily-cases rose sharply after relaxation of physical distancing.

Follow-up research from this study may include estimating the functional forms of the short-run production curves, examining elasticity conception that best explains an epidemic, estimating an economically optimal date for relaxing distancing measures, the cost-benefit analysis of relaxation at different states of transmission, and application of this method to other epidemics.

Abbreviations

COVID-19: Coronavirus disease 2019; WHO: World Health Organization; GDP: Gross Domestic Product; ELI: Effective lockdown index; IMF: International Monetary Fund; OECD: Organisation for Economic Co-operation and Development; NPI: Non-pharmaceutical intervention; SIR: Susceptible-Infected-Recovered; EMA: Exponential moving average; CV: Coefficient of variation.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study are included in this published article and its supplementary information files.

Competing interests

The author has no competing interests.

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Author's contributions

The author designed, wrote and approved the study by himself.

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Tables and figures

Table 1. **Descriptive statistics**

	France	Germany	Italy	The UK	The US	Indonesia
Recording dates	Feb 21-June 30	Feb 24-June 30	Feb 19-June 30	Feb 27-June 30	Feb 24-June 30	March 2-June 30
Number of recording days (t)	131	128	133	125	128	121
Cumulative number of cases, Y(t), on June 30, 2020						
Orignal data	164,801	194,259	240,578	312,654	2,634,432	56,385
EMA	163,789	193,382	240,227	310,946	2,551,686	53,961
Number of daily-cases, My=I(t), 5-day EMA						
Mean	1,290	1,559	1,862	2,570	20,578	461
Standard deviation	1 288	1,637	1,762	1,810	11,182	358
Coefficient of variation	100%	105%	95%	70%	54%	78%
Maximum value	4,986	5,834	5,773	6 048	Not applicable	Not applicable
Date of maximum value	March 31	April 5	March 28	April 11	Not applicable	Not applicable
Average product of the infected, AY, 5-day EMA						
Mean	1,227	1,597	2,001	1,902	11,794	182
Standard deviation	647	813	914	1,138	7,484	134
Coefficient of variation	53%	51%	46%	60%	63%	74%
Maximum value	1,917	2,481	2,923	2,997	Not applicable	Not applicable
Date of maximum value	April 22-24	April 20	April 22-24	Mey 18-19	Not applicable	Not applicable

Table 2. **The elasticity of production**

	France	Germany	Italy	The UK	The US	Indonesia
Are elasticity of production, 5-day EMA						
Mean	1.83	1.67	1.45	2.20	2.91	2.83
Standard deviation	1.80	1.76	1.44	1.62	2.10	0.72
Coefficient of variation	99%	106%	99%	74%	72%	25%
Maximum value	6.08	5.92	4.32	5.97	9.07	5.82
Minimum value *)	0.17	0.17	0.08	0.34	0.96 (outlier)	1.84
Point elasticity of production, 5-day EMA						
Mean	1.62	1.48	1.30	1.99	2.61	2.60
Standard deviation	1.55	1.52	1.23	1.42	1.76	0.56
Coefficient of variation	96%	103%	95%	71%	68%	22%
Maximum value	4.91	5.14	3.82	5.27	7.62	4.10
Minimum value *)	0.16	0.16	0.08	0.34	0.94 (outlier)	1.78

Note: *) It excludes minimum values in the beginning of transmission.

Table 3. **Probability of a policy target**

	France	Germany	Italy	The UK	The US	Indonesia
Policy (daily-cases) target, I*	500	500	500	1 100	This analysis is not applicable for the US	This analysis is not applicable for Indonesia
Probability of I (t+1) ≤ I*, if:						
εt > 1	0.00	0.00	0.00	0.00		
0 ≤ εt ≤ 1	0.47	0.37	0.50	0.17		
0 ≤ εt ≤ 0.5	0.63	0.46	0.63	0.41		
0 ≤ εt ≤ 0.2 (0 ≤ εt ≤ 0.4 for the UK)	0.71	1.00	1.00	0.75		
Probability of I (t+1) ≤ I* <u>and</u> I (t+1) ≤ I(t), if:						
εt > 1	0.00	0.00	0.00	0.00		
0 ≤ εt ≤ 1	0.29	0.26	0.35	0.15		
0 ≤ εt ≤ 0.5	0.38	0.32	0.44	0.35		
0 ≤ εt ≤ 0.2 (0 ≤ εt ≤ 0.4 for the UK)	0.29	0.33	0.67	0.50		

Figure 1: The relationship between Y(t), MY=I(t), and AY

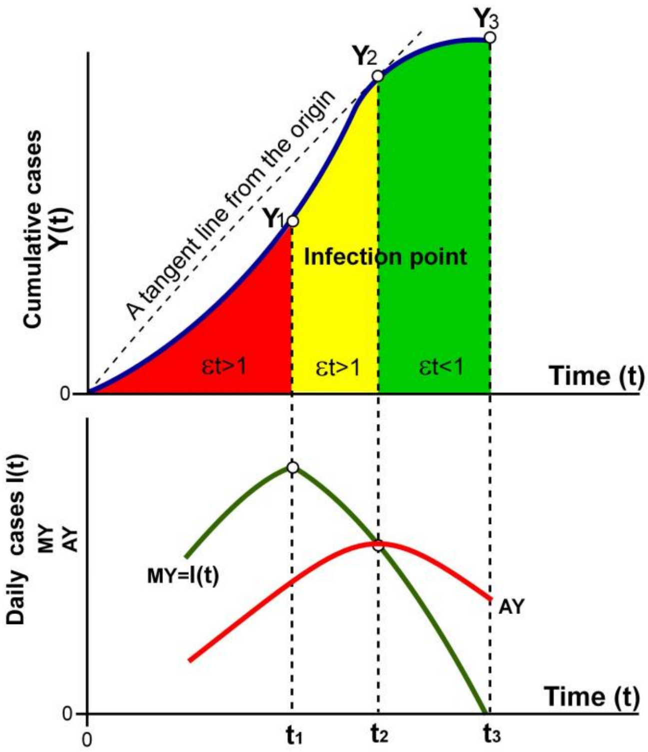
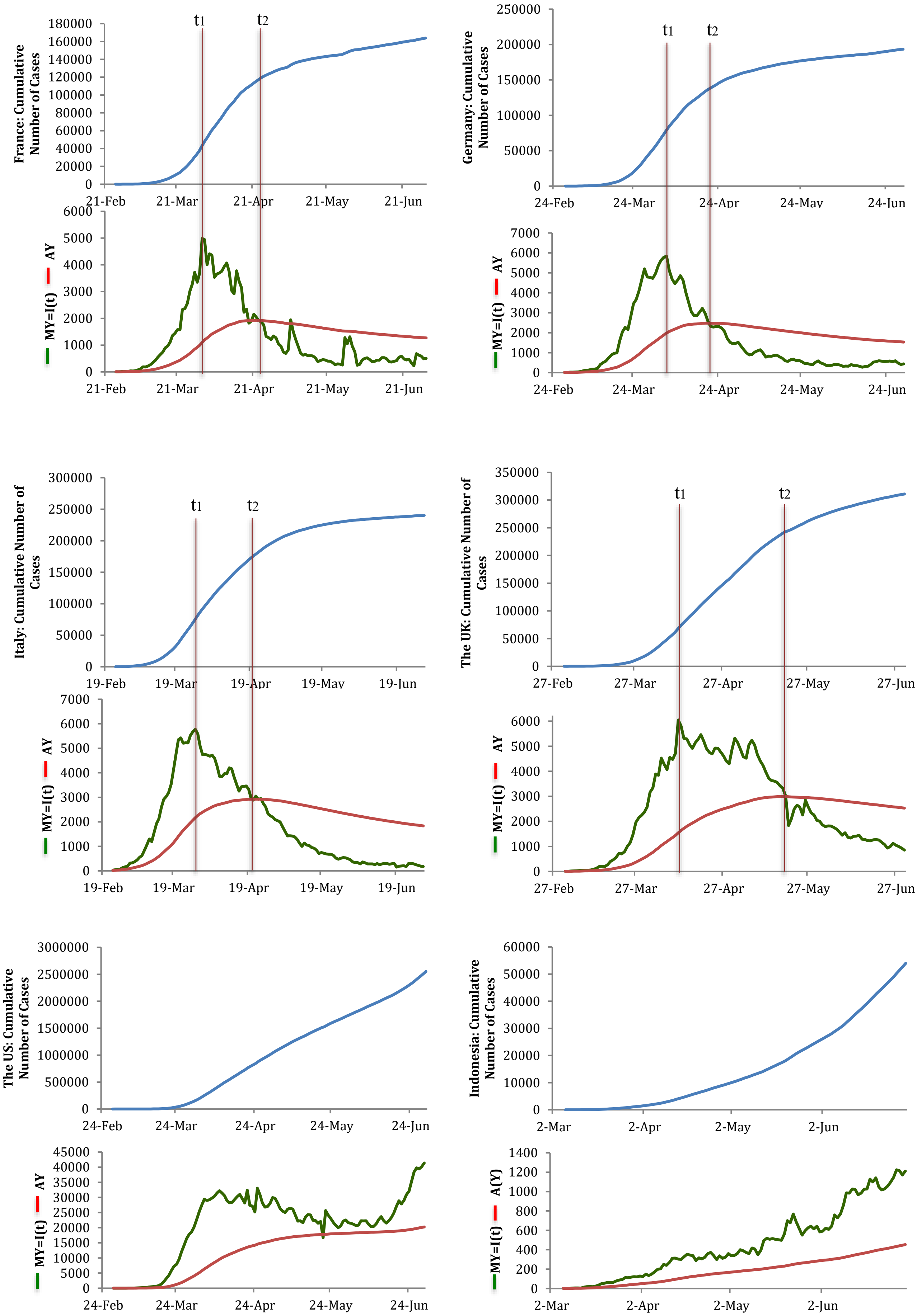


Figure 2: Cumulative number of cases, daily-cases, and average product of the infected



Additional files

File name: Additional file 1; **Forma**t: .docx; **Title**: Cumulative number of COVID-19 cases as a short-run health production function; **Description of data**: a formal mathematical presentation of the method used in this study.

File name: Additional file 2; **Forma**t: .docx; **Title**: Figures; **Description of data**: *Y(t)*, *MY=I(t)* and *AY* curves from the original data.

File names: Additional_file_3 to 8_country name. **Forma**t: .xlsx; **Title**: Country name_COVID-19; **Description of data**: All data collected and processed in this study, including the calculation formula of each cell.