How Can Econometrics Help Fight the COVID'19 Pandemic?

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Abstract

The current pandemic is difficult to model – and thus, difficult to control. In contrast to the previous epidemics whose dynamics was smooth and well described by the existing models, the statistics of the current pandemic is highly oscillating. In this paper, we show that these oscillations can be explained if we take into account the disease's long incubation period – as a result of which our control measures are determined by outdated data, showing number of infected people two weeks ago. To better control the pandemic, we propose to use the experience of economics, where also the effect of different measures can be observed only after some time. In the past, this led to wild oscillations of economy, with rapid growth periods followed by devastating crises. In time, economists learned how to smooth the cycles and thus, to drastically decrease the corresponding negative effects. We hope that this experience can help fight the pandemic.

1 Formulation of the Problem

Need for a model. To properly control the pandemic, it is important to be able to predict the effect of different possible measures. For this purpose, we need a model that would predict how the number of infected and recovered people will change if we implement different measures.

The existing models do not work well. There are many mathematical models describing the spread of epidemics – and the effect of different measures on this spread. However, these models do not describe the current pandemic very well: indeed, these models usually predict smooth changes (see e.g., [1, 2, 3, 7, 10]), while for the current pandemic, the changes are heavily oscillating, even after we try to smooth this data by taking 5-day averages instead of daily data; see, e.g., Figures 1 and 2.
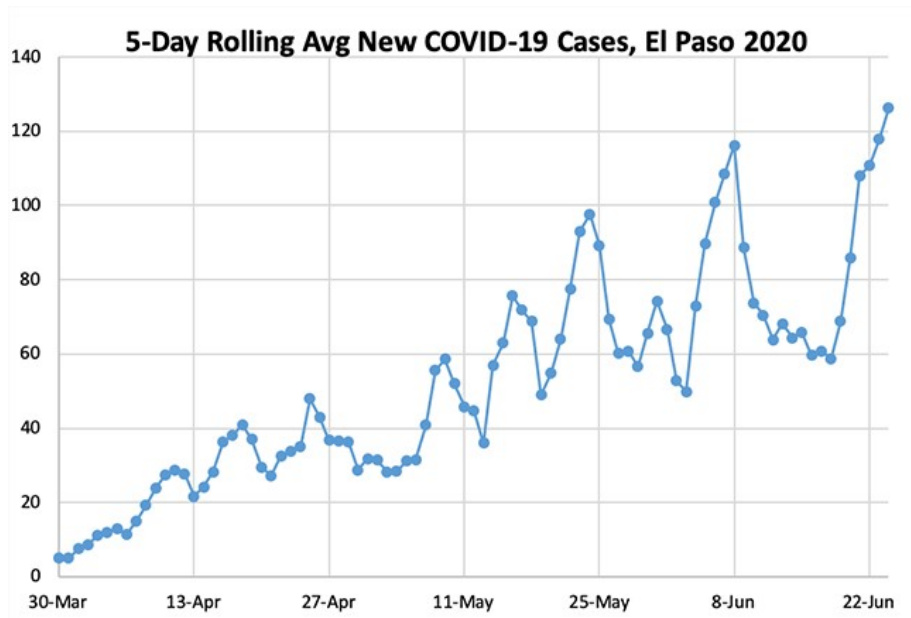
Figure 1: Typical COVID-19 Statistics

Oscillations in the first picture may be partly explained by the uneven progress of testing, but the second picture, describing the number of hospitalized people, show similar oscillations as well.

What can we do? In this paper, we provide a possible explanation for this oscillation, and we explain how the experience of econometrics can help.

2   Oscillations: Possible Explanation

Possible explanation: general idea. What distinguishes the current pandemic from all previous epidemics is the unusually long incubation period. It can take up to two weeks before the infected person shows any symptoms of the disease.

As a result, when we make a decision – e.g., to enforce or ease restrictions – we do not know the current number of infected people, we only know the number of sick people – which is proportional to the number of infected people two weeks ago. In other words, when we impose some restrictions – whether it is on the level of a city or on a level of individual family decisions – our decisions are based on outdated data.

How this explains oscillations: a quantitative explanation. Once the severity of a situation becomes known, we impose several restrictions trying to
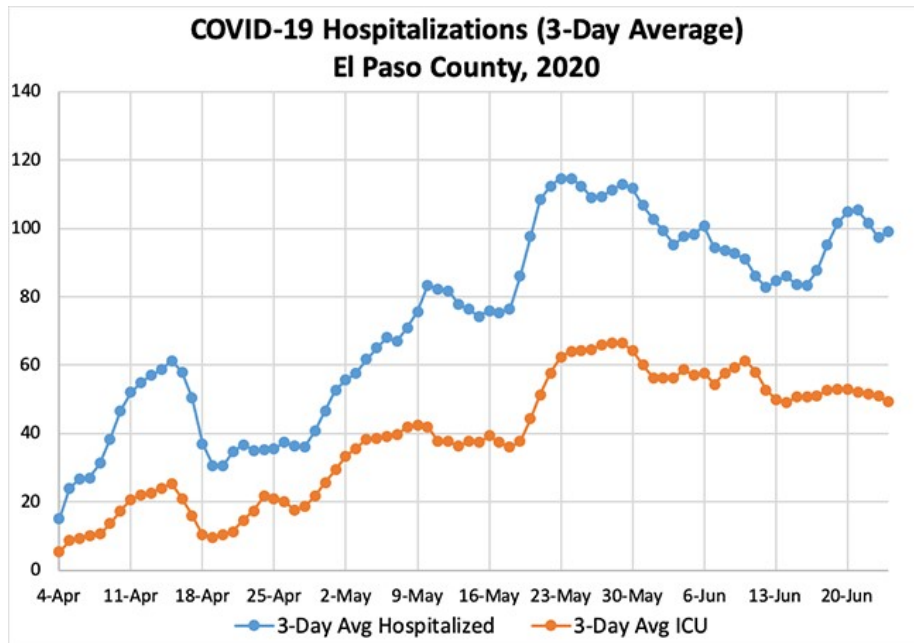
Figure 2: Typical COVID-19 Statistics (cont-d)

cut down the number of new infections. If the number of newly sick people does not go down – or even continue to grow – more and more severe restrictions are placed, until the numbers start going down.

Once the numbers go down, a natural idea is to ease the restrictions, all the way to completely eliminating them. Since the virus is still there, this inevitably leads to some people getting infected. If we had a good idea of how many new people get infected, we could implement appropriate measures and slow down the spread of the pandemic. However, we do not have that information, we only have the information about the number of infected people two weeks ago – when this number was small. So, for two following weeks, we are under the false impression that the situation has improved, while in reality, in the absence of needed restrictions, the epidemic grows exponentially – and we only impose restrictions two weeks later, when the epidemic has already grown a lot. So, more severe restrictions are re-introduced, etc. – and this cycle repeats again and again.

A simple quantitative model explaining such oscillations. Let us introduce a simple quantitative model that explains such oscillations.

In the absence of any restrictions, each infected person infects, on average, a certain number $r > 1$ of new people during a certain period of time (e.g., a week). So, the number $x(t + 1)$ of people newly infected during the next

period of time is proportional to the previous number $x(t)$, with the coefficient of proportionality r:

$$x(t+1) = r \cdot x(t). \tag{1}$$

In this case, we have the exponential growth typical for the starting period of each epidemic: because of the equation (1):

- for $t = 0$, we get $x(1) = r \cdot x(0)$;

- for $t = 1$, we get $x(2) = r \cdot x(1)$; substituting the above expression for $x(1)$ into this formula, we get $x(2) = r \cdot (r \cdot x(0)) = r^2 \cdot x(0)$;

- for $t = 2$, we get $x(3) = r \cdot x(2)$; substituting the above expression for $x(2)$ into this formula, we get $x(3) = r \cdot (r^2 \cdot x(0)) = r^3 \cdot x(0)$.

In general, we get $x(t) = r^t \cdot x(0)$.

What if we impose restrictions? The restrictions decrease the number of newly infected people. The severity of restrictions – and thus, their effect – is proportional to the observed data, and the observed data reflects the number of newly infected people 2 week ago, i.e., the value $x(t - t_0)$, where t_0 is the incubation period (in our case, two weeks). Let us denote the proportionality coefficient by k. Then, in the first approximation, we can replace the equation (1) with the following one:

$$x(t+1) = r \cdot x(t) - k \cdot x(t - t_0). \tag{2}$$

We said that this is only the first approximation, since two important corrections are needed.

First, if the number of new cases is very small, i.e., smaller than some small threshold x_0, then no restrictions will be imposed. So, the effect of restrictions should be proportional not to the actual value $x(t - t_0)$, but rather to the excess of this value in comparison with x_0, i.e., to $\max(x(t - t_0) - x_0), 0)$. Thus, the equation takes the following form:

$$x(t+1) = r \cdot x(t) - k \cdot \max(x(t - t_0) - x_0, 0). \tag{3}$$

Second, no matter how severe are the restrictions, we cannot fully eliminate the virus, so the number $x(t + 1)$ cannot go below the small value x_0. In other words, if the right-hand side of the formula (3) is smaller than x_0, the new value $x(t+1)$ will still be equal to x_0. So, instead of the right-hand side of the formula (3), we should take the largest of this right-hand side and x_0. Thus, we arrive at the final equation describing our model:

$$x(t+1) = \max(x_0, r \cdot x(t) - k \cdot \max(x(t - t_0) - x_0, 0)). \tag{4}$$

This equation describes the effect of control when we have already realized that there are infected people in the community: we will do that after time t_0, when the first infected people get sick.

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So, for $t \geq t_0$, we have equation (4), while for $t < t_0$, we use the uncontrolled equation (1).

This model indeed leads to oscillations. Let us show, on a simple example, that the above formulas (1) and (4) indeed leads to oscillations.

In this example, we start with:

- the simplest number infected persons – one: $x(0) = 1$;

- the simplest value $x_0 > 1$: $x_0 = 2$;

- the simplest value r for which the infection grows if not controlled: $r = 2$;

- the simplest value $k > r$: $k = 3$; we need to have $k > r$ to make sure that the control is effective; and

- the actual incubation period $t_0 = 2$ weeks.

Then, we have the following dynamics:

- at first:
$$x(0) = 1;$$

- to get the value $x(1)$, we use equation (1) with $t = 0$, getting :
$$x(1) = 2 \cdot x(0) = 2;$$

- to get the value $x(2)$, we use equation (1) with $t = 1$, getting:
$$x(2) = 2 \cdot x(1) = 4;$$

- to get $x(3)$, we already need to use equation (4), which leads to:
$$x(3) = \max(2, 2 \cdot 4 - 3 \cdot 0) = \max(2, 8) = 8;$$

- for $x(4)$, we get
$$x(4) = \max(2, 2 \cdot 8 - 3 \cdot 0) = 16;$$

- for $x(5)$, we get:
$$x(5) = \max(2, 2 \cdot 16 - 3 \cdot (4 - 2)) = \max(2, 32 - 6) = 26;$$

- for $x(6)$, we get:
$$x(6) = \max(2, 2 \cdot 26 - 3 \cdot (8 - 2)) = \max(2, 52 - 18) = 34;$$

- for $x(7)$, we get:
$$x(7) = \max(2, 2 \cdot 34 - 3 \cdot (16 - 2)) = \max(2, 68 - 42) = 26;$$

finally, the number of new cases started decreasing;

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- for $x(8)$, we get:

$$x(8) = \max(2, 2 \cdot 26 - 3 \cdot (26 - 2)) = \max(2, 52 - 72) = 2;$$

  we think we won;

- for $x(9)$, we get:

$$x(9) = \max(2, 2 \cdot 2 - 3 \cdot (34 - 2)) = 2;$$

- for $x(10)$, we get:

$$x(10) = \max(2, 2 \cdot 2 - 3 \cdot (26 - 2)) = 2;$$

- for $x(11)$, we get:
$$x(11) = \max(2, 2 \cdot 2) = 4;$$

  the number of infected people starts growing again, but we do not know it yet;

- for $x(12)$, we get:
$$x(12) = \max(2, 2 \cdot 4) = 8;$$

- for $x(13)$, we get:
$$x(13) = \max(2, 2 \cdot 8) = 16;$$

- for $x(14)$, we get:

$$x(14) = \max(2, 2 \cdot 16 - 3 \cdot (4 - 2)) = \max(2, 32 - 6) = 26;$$

  finally, we notice the growth and start taking measures.

Then, the loop repeats again: we get $x(15) = x(6) = 34$, $x(16) = x(7) = 26$, $x(17) = x(8) = 2$, and we get oscillations with period $T = 9$.

3   How Econometrics Can Help: Idea

General idea. The current pandemic is not the only case when we can only see the delayed effect of each measure. Such situations are typical in economics. Whatever measures we implement in economics, be it a change in taxes of tarifs, a change in the interest rate, etc. – these measures do not immediately affect the Gross Domestic Product (GDP), unemployment level, or any other important economic characteristic, the effect is usually delayed.

The delayed character of economics is, in our opinion, one of the main reasons for the economic cycles. These cycles are easy to explain, For example, if one year, there is a lot of demand for some agriculture crop, its price goes up, so next year, everyone switches to this crop and the resulting production becomes much larger than the demand. So the price goes down, and many farmers lose money.

In the past, the oscillations were wild, and the cycles were really devastating, with huge unemployment and low GDP during the crisis period. At present, economists learned to smooth these cycles – i.e., to control the corresponding delayed systems; see, e.g., [5, 6, 9].

We hope that this experience will help control the current epidemic as well.

Why use experience of economies and not of some other time-delay systems. Economies are not the only systems in which the effect of a control measure appear only with some delay. There are other systems of this type, e.g., in engineering, in ecology, etc.; see, e.g., [4, 8]. In this paper, however, we concentrate on the experience of economic systems: while engineering time-delay systems are somewhat exotic and not yet well-studied, economy is what we all understand, what we all experience, in which there is a lot of experience of successful and unsuccessful control.

What exactly we can learn from economics. One of the ideas that economists have learned – and that the econometric models confirm – is that we need to keep some control of the economy even when this economy sounds healthy.

One of the main reasons why in the past, economy regularly went through disastrous crisis cycles is that control was only applied when it became clear that the situation has become critical – by which time it was too late (because of the delay effect) to prevent the crisis from happening. Now, we are smarter. Even when the economy is growing and all the signs are good, we know that there is a possibility of "overheating" that could potentially lead to a crisis. So, we impose restrictions, slowing down the growth – and thus, either avoid the crisis altogether or at least make the effects of the crisis less painful.

Thus, a natural idea is to use the same approach to fighting the epidemic: instead of completely easing restrictions when the situation become good, we need to keep some restrictions – this will hopefully help us fight the epidemic.

Let us describe this idea in some detail.

4 How Econometrics Can Help: Details

Main idea: in detail. In the previous section, we have shown that if we control the epidemic based only on the current number of sick people – which reflects the number of infected people two weeks ago – we are bound to have oscillations instead of the desired end to the epidemic:

- at first, we cut down on the number of new cases, but

- then, we ease the restrictions, and the number of infected people starts to rise again.

Once we have reached the long period of low number of newly sick folks, if we completely eliminate the restrictions, we may have a new outburst – that we

will not notice for 2 weeks, during which time it may again become catastrophic. So, to avoid the new outburst, we need to keep some restrictions, even when the number of cases stays very low.

How to formalize this idea. In the previous section, we assumed that the control is proportional to the excess of the number of new cases over the minimum x_0 – so that when this number becomes equal to x_0 or smaller than x_0, we do not apply any control.

Instead, we need to keep the pressure going even in this case. So, in addition to the control $k \cdot \max(x(t - t_0) - x_0, 0)$, which is proportional to the difference

$$x(t - t_0) - x_0,$$

we should also apply an additional constant control c, for some appropriate constant c selected so as to prevent the outburst.

In this case, instead of the equation (4), we have a formula

$$x(t + 1) = \max(x_0, r \cdot x(t) - (k \cdot \max(x(t - t_0) - x_0, 0) + c)). \qquad (5)$$

This indeed helps. In the above numerical example, to avoid the second outburst, it sufficient to take $c = 2$. If we apply this additional control from the very beginning, then, when we start with $x(0) = 1$, we will get the following:

- first, we get
$$x(1) = \max(2, 2 \cdot 1 - 2) = 2;$$

- after that, we get
$$x(2) = \max(2, 2 \cdot 2 - 2) = 2;$$

and after that we have $x(3) = x(4) = \ldots = 2$: no outburst.

We get the exact same result is we start applying the additional control value c not from the very beginning, but after some time. For example, in the above simulation, if we apply this additional control $c = 2$ at moment $t = 10$, at which the number of newly sick people $x(t - t_0)$ becomes smaller than or equal to the threshold, we will avoid the repetition of the loop. Indeed, in this case, we will have:

- for $x(11)$, we get:
$$x(11) = \max(2, 2 \cdot 2 - 2) = 2;$$

- for $x(12)$, we similarly get:
$$x(12) = \max(2, 2 \cdot 2 - 2) = 2;$$

and so on, the numbers never increase above the desired threshold x_0.

Important comment. As we have mentioned earlier:

- an important part of the control comes from the officially introduced measures, like wearing masks and keeping social distance;

- however, a significant part of the control comes from people following these measures, and, in general, exercising caution.

It is easy to impose measures of different levels of severity, but it is difficult to control people's behavior. No matter what measures we impose, if people see that for some period of time, the number of new cases remains low, they will ease their self-control. To compensate for that, we need to impose stricter official measures.

This sounds counter-intuitive: we impose stricter measures when the situation becomes better. However, this is the only way to keep the overall pressure constant and thus, to avoid the new increase in the number of cases.

Acknowledgments

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