CEPR PRESS

325

Covid Economics Issue 23, 28 May 2020

Fast and local: How lockdown policies affect the spread and severity of covid-19

Jean-Philippe Bonardi,[1] Quentin Gallea,[2] Dimtrija Kalanoski[3] and Rafael Lalive[4]

Date submitted: 20 May 2020; **Date accepted:** 22 May 2020

Covid Economics 23, 28 May 2020: 325-351

We analyse whether the various types of lockdowns implemented around the world mitigated the surge in infections and reduced mortality related to the Covid-19, and whether their effectiveness differed in developing versus developed countries. Our data cover 184 countries from December 31st 2019 to May 4th 2020, and identifies when lockdowns were adopted, along with confirmed cases and deaths. We find that reducing movements within countries has been effective in developed economies – averting about 650,000 deaths – but not in developing ones, that countries that acted fast fared better, and that closing borders has had no appreciable effect, even after 50 days.

1 Professor, University of Lausanne – HEC Lausanne (Faculty of Business and Economics, Enterprise for Society Center (E4S).
2 PhD student, University of Lausanne – HEC Lausanne (Faculty of Business and Economics, Enterprise for Society Center (E4S).
3 Post-doctoral student, University of Lausanne – HEC Lausanne (Faculty of Business and Economics, Enterprise for Society Center (E4S).
4 Professor, University of Lausanne – HEC Lausanne (Faculty of Business and Economics, Enterprise for Society Center (E4S).

Covid Economics 23, 28 May 2020: 325-351

1 Introduction

The first death from the coronavirus, on January 11th 2020, was a 61-year-old man in China who had purchased goods from a seafood market. In the middle of May 2020, a few months later, over 300,000 deaths had been registered, and the health and economic effects of the covid-19 have turned out to be massive. There is a lot to learn, however, from looking at how governments around the world have responded to this crisis, and how it impacted the development of the disease. This is the purpose of this paper.

Throughout the first months of the spread of the virus, two alternative strategies have indeed emerged to fight the covid-19 pandemic. First, the so-called ‘herd immunity approach’, according to which the viral dissemination through the population was critical to develop collective immunity. From this perspective, the only public policy that had to be put in place was one in which patients at risk or infected had to be isolated and taken care of. The second major policy option that emerged from the crisis is the ’lockdown approach’, in which most of a country’s population had to stay at home to stop the virus dissemination, avoid over-crowding critical care hospital facilities and prevent the deaths of many people. China was the first large country to announce this type of lockdown policy on January 23rd, 2020. Even though the governments of some influential countries (such as the US or the UK) had originally chosen the herd immunity approach, things rapidly evolved and, within a few days in March, most governments had opted for the lockdown approach in a hurry. Now that some time has gone by, it is important to take a closer empirical look at the real impact of these lockdowns on the disease.

Here, we study the effect of lockdown policies, as well as their differences in terms of speed, strength and nature across countries on the increase of new cases and mortality (Flaxman et al. (2020)). Beyond the general question of whether lockdowns are effective or not, several other more subtle aspects can be informative for policy-making. One of them is to know whether there

CEPR PRESS

is a ‘speed premium’ in setting up lockdowns. With a virus growing exponentially, one could expect to observe an advantage for early movers. However, there might also be an option to wait, for instance because countries might learn from what happens to others. So, can we observe a speed premium in the Covid-19 case? Another interesting and politically sensitive issue is related to international border closures. Beyond internal lockdowns, most countries have been closing their borders, something that seem logical to handle a pandemic in a globalized world. But some countries did it right away, while others did it at the last resort. Did closing borders really matter to slow down the spread of the virus? Did the order of the national-international sequence have an impact?

In exploring these questions, endogeneity issues could be major hurdles in order to establish causality, in particular omitted variable bias, reverse causality and measurement errors. We address these issues explicitly in our empirical approach (see Section 3). The panel structure of our dataset, composed of 184 countries, allows us to control for country fixed effects and day fixed effects. Furthermore, we also control for the within-country evolution of the disease both by using a lagged outcome and by controlling for the number of days since the first case was reported in the country.

From an economics perspective, we also explore the underlying mechanisms that can explain why certain types of lockdown measures are more effective than others, and why these might work better in some places than others. The hypothesis driving our empirical investigation is that lockdowns to be effective have to drive down individuals’ opportunity costs of staying home. As long as these opportunity costs are high enough, one could expect that people might not abide by lockdown restrictions, especially since the cost for authorities of monitoring what individuals are doing should typically be quite high. This issue is of particular importance for the effectiveness of lockdown policies in developing countries. Indeed, in these countries where a large number of people earn their living in the underground economy and do not have

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

social insurance, this opportunity cost approach would predict that lockdown measures will be less effective than in developed countries. This is what our empirical analysis shows. We will return to this issue in the Discussion section.

A few papers have already studied the impact of non-pharmaceutical measures interventions (NPIs) on pandemics and more particularly on the covid-19 (Harris (2020); Hartl et al. (2020); Flaxman et al. (2020)). Chinazzi et al. (2020) and Kraemer et al. (2020) explore to what extent China's travel ban, human mobility, and control measures reduced the spread of the disease, and Maier and Brockmann (2020) finds that measures put in place in China before the lockdown contributed to slow down its viral dissemination. Additionally, Giordano et al. (2020) compare simulation results with real data on the covid-19 epidemic in Italy and show that restrictive social-distancing measures are effective, but their effectiveness could be further enhanced if combined with widespread testing and contact tracing. Hatchett et al. (2007) study cities in the United States and the non-pharmaceutical interventions they adopted to curb the spreading of the Spanish Influenza. Whereas these papers focus on one country, our analysis covers most countries in the world, which allows us to leverage the heterogeneity regarding how lockdowns were implemented. In some cases, in effect, lockdowns were strict and complete, while in others they were partial. In some cases, there was a curfew and in some others not; in some countries, borders were closed right away, whereas in some others bordure closure was the last measure to be taken. As we will see below, these differences matter.

2 Data

We compiled information regarding the lockdown policies undertaken by countries around the world. Using a web-scraping program, we extracted from LexisNexis all news headlines for each country from October 31st, 2019 to April 1st, 2020, and all per country information from US Embassy Covid-19 bulletin. We cross-checked the news headline data against the data

CEPR PRESS

from the US Embassy Covid-19 bulletin to ensure its validity. The final dataset allowed us to generate dates of implementation for several measures designed to stop the spread of the Covid-19, some being internal to the coutry and oriented towards the outside (See Figure 1). Two measures, *State of Emergency* and *Curfew*, significantly restrain movement of individuals within a country, and thus represent a form of total lockdown within a country. We combined *State of Emergency* and the *Curfew* into one measure, which we call *Total within country lockdown* (see Supplementary Material).

	Measures	Explanation	Example	Severity
INTERNAL MEASURES	***Curfew***	The effective date when a country announced a limit of the movement of individuals within a given time of the day.	*17th of March 2020:* Bosnia declares nationwide state of emergency over coronavirus.	
	State of emergency	The effective date when a country announced a state of emergency.	*21st of March 2020:* President Roch Marc Christian Kabore closed airports, land borders and imposed a nationwide curfew to curb the spread of the pandemic.	
	Within country regional lockdown	The earliest effective date when a region within a country announced that it will be entering a total lockdown	*12th of March 2020:* Quebec, Declares State of Emergency to Blunt Pandemic.	
	Partial selective lockdown	The earliest effective date when the earliest effective date when a country announced partial limitation of movement by implementing school closures, limiting the number of people permitted to gather in a group, and/or closure of religious institutions.	*16th of March 2020:* Cambodia Announces Nationwide School Closures as COVID Response Ramps Up.	
EXTERNAL MEASURES	***Selective border close stage 1***	The earliest effective date when a country closed borders towards any other significantly affected region or country in the world from Covid-19 (Wuhan, China, Iran, and Italy - individually or as a group).	*30th of January 2020:* Australia banned the entry of foreign nationals from mainland China.	
	Selective border close stage 2	The earliest effective date after *Selective border closure stage 1* when a country closed borders towards one or multiple other countries in the world significantly affected from Covid-19.	*27th of February 2020:* Fiji extended its travel ban and announced that travelers from Italy, Iran and the South Korean cities of Daegu and Cheongdo would be denied entry.	
	International lockdown	The effective date when a country closed its borders for all flights, rail, and automotive movement internationally.	*30th of March 2020:* Council of Ministers of Bosnia and Herzegovina issued a decision which bans entrance for all foreigners.	

Figure 1: Lockdown Policies Implemented Around the World

Note: The state of emergency is a situation in which a government is empowered to perform actions or impose policies that it would normally not be permitted to undertake, that is, restriction of movement of individuals and closure of non-essential and essential (if necessary) public and private entities.

We use the John Hopkins University data on the number of cases testing positively for Covid-19 infections (Dong et al. (2020)), as it seems to be the most complete and reliable source regarding reported cases and deaths. We focus here on the number of new infected cases (results on deaths in Supplementary Material), and that for three reasons. First, people who die from the virus got infected first. Hence, controlling the number of contaminated persons in-

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

evitably reduces the number of deaths. Second, a major objective for the public management of the pandemic, which is reflected in the "flattening the curve" argument, is to prevent hospitals from being overwhelmed by patients in need of intensive care. Hence, the number of people infected by the virus is a better indicator for the future burden on the healthcare sector than the number of patients who have already passed away. Finally, there is clearly a delay in how a lockdown measure can affect the number of deaths: the patient has to contract the virus, pass the incubation time, experience complications and then eventually die. This process is potentially long and might vary from patient to patient, which might make it harder to observe clear relationships. Our data, of course, represents a lower bound on the total number of people ever infected by the virus; but what is important for us here is to have a measure of the number of people who need medical attention. These people are symptomatic, and possibly quite well represented in our data. Measurement errors will affect our dependent variable, but our estimates should not be greatly affected by them (see Supplementary Material).

It is important to note that the data on the Covid-19 suffer from measurement errors. The dataset contains reported cases which are not equivalent to the total number of cases infected by the virus in the country. To observe reported cases, these have to be reported first. Hence, the person has to be tested, recorded and observed by the John Hopkins University team. However, those three conditions are not met for many individuals. First, the person has to be tested and in most countries, this person requires to have symptoms or even severe symptoms to be tested. When there is no systematic testing (which is the case for an overwhelming majority of countries), asymptomatic people or people contaminated but not experiencing symtoms yet (because of incubation time) are not observed. Second, the new case has to be recorded and transmitted to the authorities or some statistics institute. Some countries are suspected to under-report or modify the data[1]. Third, this information has to reach the sources watched by John

[1] Can China's COVID-19 Statistics Be Trusted? (last accessed: 14.04.20) https://thediplomat.com/2020/03/can-

Covid Economics 23, 28 May 2020: 325-351

Hopkins University. Hence, our data represents a lower bound on the total number of people ever infected by the virus. Yet, in our context, we need a measure of the number of people who will need medical attention. These people are symptomatic and possibly quite well represented in our data. Moreover, measurement errors affect our dependent variable, and our estimates should not be greatly affected by them.

A more worrying problem would be the presence of non-classical errors-in-variables. For example, if countries which under-report systematically the number of cases are countries with a lower quality health sector, potentially autocracies. However, as we use country fixed effects in our empirics, these time-invariant unobservables, which might generate measurement errors, are controlled for.

Governments relied on a variety of measures with different levels of strictness to mitigate the effects of Covid-19. On the one hand, many governments focused on what we call ”outside measures”, i.e. partially or totally restricting international movement from and to a given country for individuals of other countries (International Lockdown of the Country, Selective border closure stage 1 and Selective border closure stage 2). On the other hand, governments took ”inside measures”, which ranged from closing specific regions within the country (Within country regional lockdown), implementing partial selective lockdown on public and private institutions (Partial selective lockdown) to other stricter measure such as declaring a State of emergency or setting-up Curfews.

Finally, to study the existence of heterogenous effect between developed and developing countries we use the Human Development Index (henceforth HDI) produced by the UN (Programme (2020)). The HDI is a composite index defined as the geometric mean of normalized indices ($\in [0; 1]$) for Life expectancy, Education and GNI. Note that the median in our sample

chinas-covid-19-statistics-be-trusted/. China's data, in fact, reveal a puzzling link between covid-19 cases and political events (last accessed: 14.04.20) https://www.economist.com/graphic-detail/2020/04/07/chinas-data-reveal-a-puzzling-link-between-covid-19-cases-and-political-events.

CEPR PRESS

Covid Economics 23, 28 May 2020: 325-351

is 0.745. We define developing countries as the ones with an index up to 0.699, which refers to Low and Medium human development using the United Nation codebook definition, while above 0.699 will be defined as developed countries (the exact list of countries can be found in the Supplementary Material).

Our final dataset is composed of 184 countries, of which 108 had implemented at least one of the measures at the time we collected the data, observed over 127 days, from the 31st of January 2019 to the 4th of May 2020. We adopt a calendar time definition where the 31st of December 2019 is the starting date, as it is the first day when a country other than China undertook measures to mitigate the Covid-19 dissemination [2]. Figure 2a shows the number of measures taken, and the number of confirmed cases, and deaths, by time since the first measure has been taken. Governments initially adopted "inside" measures, during the period end of January and early February 2020 (20 to 40 days after Taiwan), and moved to outside measures later on. Figure 2b shows measures and confirmed cases by days since the first case is recorded in a country. Countries implement measures during the first three weeks after the first case has been recorded, when the average number of cases is still low.

3 Methods

Our main results are based on models of the growth rate in the total number of confirmed cases in a country (see Supplementary Material for alternative approaches, including the ones about the number of deaths). The growth rate in the number of cases, or new infections, captures whether the lockdown measures reduced the spread of the disease Avery et al. (2020). The underlying mechanism to curb the development of the virus should be the reduction in the number of contacts between people who can be infected and those who are currently infected.

[2]Taiwan Centers for Disease Control (CDC) implemented inspection measures for inbound flights from Wuhan, China in response to reports of an unidentified outbreak. – 31st of December 2019.

CEPR PRESS

Covid Economics 23, 28 May 2020: 325-351

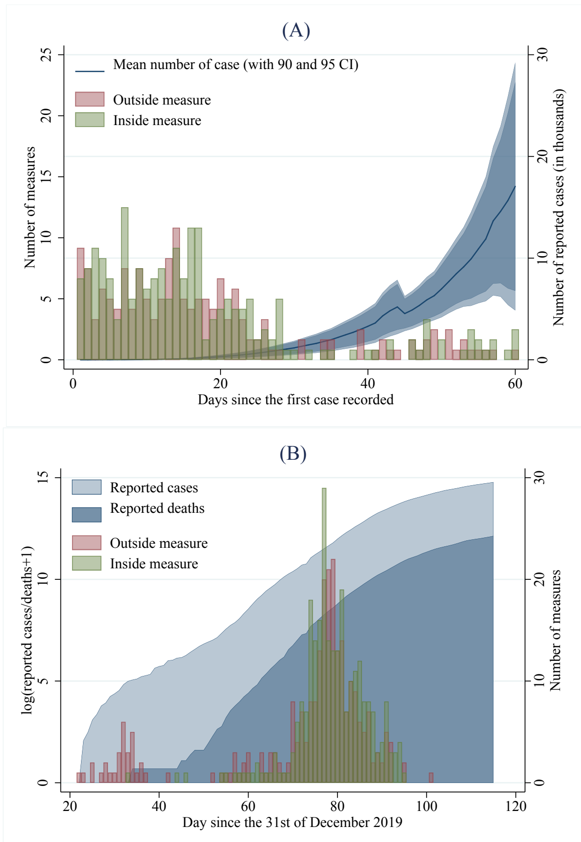

Figure 2: Evolution of Measures, Cases, and Deaths

Note: This Figure displays the distribution of lockdown measures over the beginning of 2020 and the beginning of the outbreak in each country. We exploit this visible variability to quantify the effect of each measure on the growth rate of the virus. "Outside" measures are those that restrict movements out of or into the country, while "Inside" measures are those restricting movements within a country. Both graphs exclude China. (A) Lockdown measures restricting movements within countries or towards the outside take place mostly during the 30 days after the first case is reported in the country, while some measures are taken up to 60 days after the first case. The blue line represents the mean number of reported cases by countries with 90% and 95% confidence intervals. (B) The earliest measures were taken in January with restriction of travel to or from specific locations (outside measure), while most of the measures were taken in March (from day 60 to day 91). The blue areas represent the number of reported death and number of reported cases for the world in log.

Covid Economics 23, 28 May 2020: 325-351

Successful lockdown measures are expected to restrict the movements of both the susceptible and the infected Kermack and McKendrick (1927); Maier and Brockmann (2020); Tian et al. (2020).

The panel structure of our data allows us to control quite extensively for the risk of omitted variable bias. First, the countries fixed effects allow to control for unobservables fixed over time at the country level (quality of the healthcare system, age distribution of the population, population density, geographical location, number of neighbouring countries, climate conditions, etc.). Those factors vary over time, but we could expect that they do not significantly vary over the period of interests (a few months). Second, the days fixed effects control for time-varying unobservables affecting the world in the same way (global evolution of the virus (early-stage vs. pandemic), global lockdown, etc.). Finally, the fixed effects also address the measurement errors by controlling for numerous factors that could correlates with the quality of the reporting and the spread of the virus. The countries fixed effects allow to exploit within country variation: if some policies or unobserved country characteristics affect the rate of case reporting (constant bias over time), this does not affect the within-country variation that we exploit.

The second main difficulty to measure the effect of governmental measures on the evolution of the disease comes from reverse causality. Indeed, the spread of the disease in the country influences the timing and the extent of the lock-down measures enforced by the government. To address the timing issue, we either control for the number of days since the first case was reported in country i or we control for the lagged dependent variable (auto-regressive model of order 1). Furthermore, the country fixed effects also serve to address the potential reverse causation of the extent of the measure taken (partial vs. complete lockdown, within vs. outside oriented measures). For example, a country who suffered from several initial "starting points" might require a complete lockdown compared to a country where the initial infections are all geographically concentrated (partial lockdown might be more appropriate).

CEPR PRESS

Covid Economics 23, 28 May 2020: 325-351

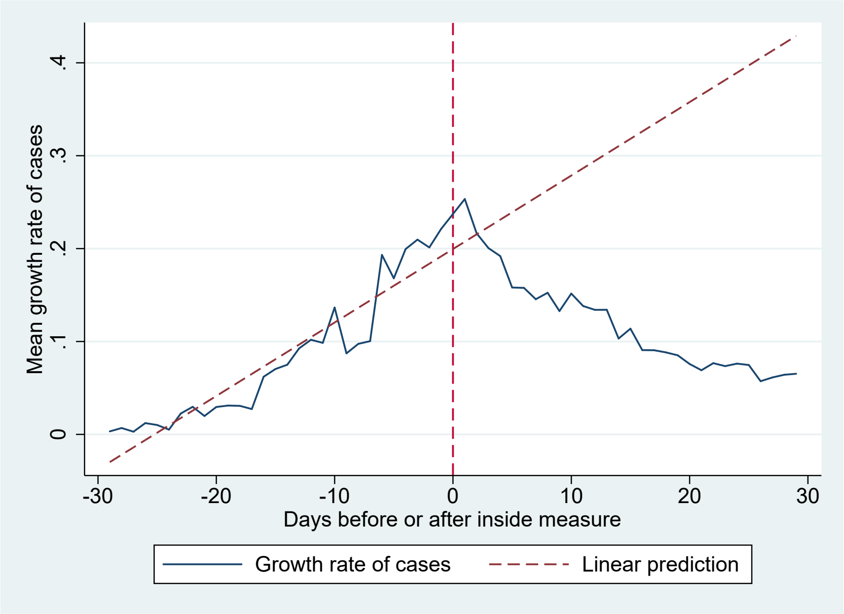

Figure 3: Empirical Illustration

Notes: This graph reports the average growth rate of confirmed cases in the interval 30 days before, and after an inside measure was taken. The graph also shows a prediction of the growth rate based on fitting a linear model to the data before the measure was introduced.

One crucial empirical challenge is to find an adequate specification to capture the development of the growth rate of cases. Figure 3 reports the average growth rate of confirmed cases in the interval 30 days before, and after an inside measure was taken. Before the measure is introduced, the growth rate of cases is high and this eventually leads to its adoption. There is a sharp decrease in the growth rate after the measure has been implemented. The graph also shows a prediction of the growth rate based on fitting a linear model to the data before the measure was introduced. This is an illustration of how the growth rate of cases might have developed in the absence of the measure.

3.1 Baseline model: Number of days after the measure was taken

This approach allows to assess the change of trend after the country took the measure.

Model (1): First difference:

$$log(cases+1)_{it} - log(cases+1)_{i(t-1)} = \tag{1}$$
$$\beta_0 + \beta_1 Measure_{it} + \beta_2 DaysAfterMeasure_{it} + \beta_3 First_{it} + FE_i + FE_t + \epsilon_{ct}$$

with i for country and t for the day. $cases_{it}$ is the total number of people who were infected by the virus in country i on or before calendar day t. $Measure_{it}$ is an indicator variable taking the value 1 from the day the measure was taken (onset). $DaysAfterMeasure_{it}$ is the number of days since the measure was taken. $First_{it}$ records the number of days since the first confirmed case in country i at calendar time t. FE_i and FE_t are countries and days fixed effects. ϵ_{ct} is a error term clustered on the country level.

Model (2): AR(1) (auto-regressive model of order 1):

$$log(cases+1)_{it} = \beta_0 + \beta_1 Measure_{it} + \beta_2 DaysAfterMeasure_{it} \tag{2}$$
$$+\beta_3 log(cases+1)_{i(t-1)} + FE_i + FE_t + \epsilon_{ct}$$

Model (3) is identical as Model (1) but we use an AR(1) instead of a first difference.

3.2 Baseline model: Time trend interaction

This approach allows to assess the global change of trend when a measure is taken

Model (3): First difference:

$$log(cases+1)_{it} - log(cases+1)_{i(t-1)} = \tag{3}$$
$$\beta_0 + \beta_1 Measure_{it} + \beta_2 Days_t \times Measure_{it} + \beta_3 First_{it} + FE_i + FE_t + \epsilon_{ct}$$

with i for country and t for the day. $Measure_{it}$ is an indicator variable taking the value 1 from the day the measure was taken (onset). $Days_t$ is the number of days since the 31st of December

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

2019 (beginning of the sample). $First_{it}$ the number of days since the first case was reported in the country. FE_i and FE_t are country and day fixed effects. ϵ_{ct} is a error term clustered on the country level.

The parameter β_1 estimates the growth rate on calendar day 0, which is 31^{st} of December 2019. The parameter β_2 estimates the change in the growth rate as a function of the number of days since day 0.

Model (4): AR(1) (auto-regressive model of order 1):

$$\begin{aligned} log(cases+1)_{it} &= \beta_0 + \beta_1 Measure_{it} + \beta_2 Days_t \times Measure_{it} \\ &\quad + \beta_3 log(cases+1)_{i(t-1)} + FE_i + FE_t + \epsilon_{ct} \end{aligned} \tag{4}$$

Model (4) is identical as Model (3) but instead we use an AR(1) instead of a first difference.

3.3 Parallel with SIR model

Our estimates can also be interpreted in the context of the Susceptible-Infected-Recovered (SIR) model Kermack and McKendrick (1927). Individuals are either susceptible to the infection, S_τ, or infected, I_τ, so there can be at most $S_\tau \times I_\tau$ potential contacts between infected and susceptible (the SIR model assumes that recovered individuals play no direct role in new infections). The disease is then transmitted at rate β_τ from the infected to the susceptible individuals, so every period τ there are $\beta_\tau S_\tau I_\tau$ new cases reported infected. The total number of cases until day t is $\sum_{\tau=0}^{t} \beta_\tau S_\tau I_\tau$, and the growth rate of cases is equal to $\beta_{t+1} S_{t+1} I_{t+1}$. Our model provides an estimate of how this growth rate changes as measures are introduced. These changes happen for mainly two reasons. The transmission rate β_τ can decline because the number of actual contacts decreases, and the number of infected individuals decreases thereby creating fewer potential contacts. Our estimates provide the overall effect.

CEPR PRESS

Covid Economics 23, 28 May 2020: 325-351

4 Results

4.1 Baseline model: Effectiveness of lockdown measures

We start by presenting how government measures reduce the growth of infections as a function of the time since the measure has been implemented compared to countries which have not implemented any measure yet. Panel (A) and (B) of Figure 4 shows the marginal effects of our baseline model (see Supplementary Material for the equation estimated and the regression tables). Lockdowns are implemented when confirmed cases increase strongly and affect infections only with a delay since the incubation period of the illness is several days. Restrictions within the country are more efficient than measures towards the outside at curbing the spread of the virus (the effect kicks-in quickly and triggers a steeper reduction). Panel (A) and (B) of Figure 4 highlight this results. On average, after 25 days, countries who took internal measures experienced a reduction of the growth rate compared to the other countries. After fifty-days the growth rate is lowered by 7.5%. On the other hand, the aggregation of measures towards the outside does not have a statistically significant effect after fifty-days. We aggregated the measure in two categories to highlight this main results. When we look at the subcategories of governmental measures defined in Figure 1 we obtain a similar split between within country measures and measures towards the outside (See Figure 1 panels (C) to (H) and (III) to (VIII)).

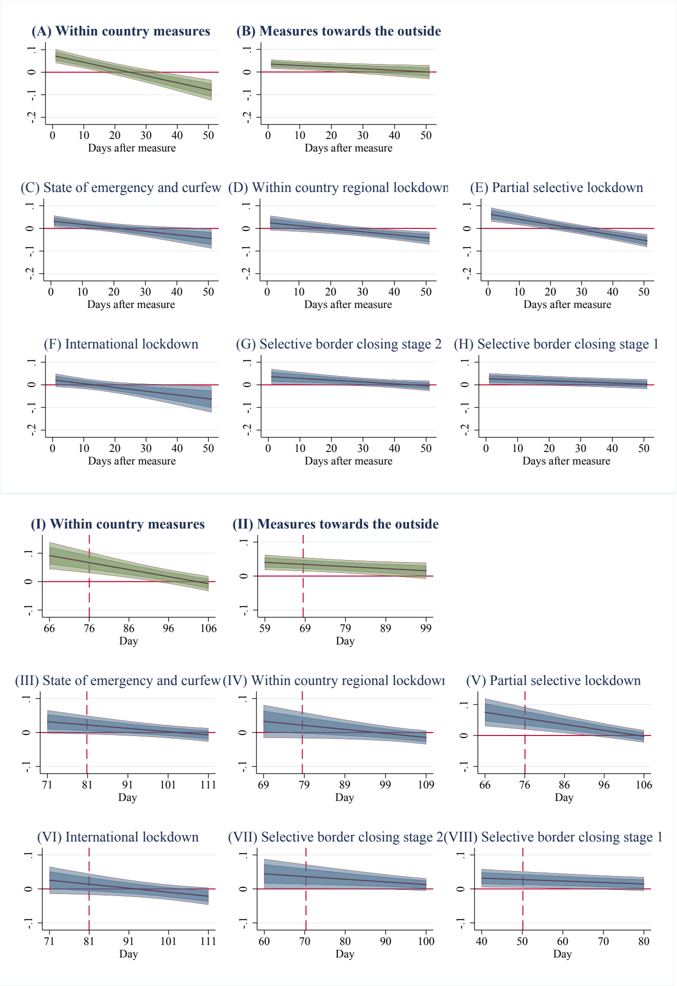

Figure 4: Baseline model (days after the measure): Marginal effects (Cases Confirmed)

Note: Marginal effects computed with our autoregressive model or order 1. 90% and 99% confidence intervals are shown in different shade of blue or green. The vertical dashed line shows the average day where the measure was taken in the sample. The model shows: i) the effectiveness of numerous lockdown measures that governments implemented across countries to mitigate the viral dissemination (statistically significant effect and number of days before the rate of the disease is reduced compared to countries who did not implement the measure), ii) the strength of the effect (steepness of the slope). The corresponding results for deaths are in the Supplementary Material. Panel (A) to (H) show the impact of a measure on the growth rate of infections as a function of time since the measure was implemented. Panel (I) to (VIII) show the impact of a measure on the growth rate of infections as a function of time since the 31st of December 2019 (Day).

CEPR PRESS

Panel (I) and (II) of Figure 4 shows when each type of lockdown measure was adopted on average since December 31st 2019, and when the various measures became effective. Overall, this second approach provides a similar picture: within country measures have a clear impact, while the efficiency of outside measures remain questionable. Restrictions inside countries have been implemented on average on the 16th of March 2020 (76th day) and the average reduction was expected to be observed around the 13th of April (day 103). On the other hand, outside-oriented measures were taken on average on the 9th of March 2020 and their efficiency still had not materialized on the 13th of April (day 100).

Our baseline model thus strongly suggests that lockdown measures focused on blocking relationships among people within a country (inside measures) prevail over measures aimed at blocking international relationships. To explore this point in more depth, we also estimated a model including both measures: inside and outside (c.f: Supplementary Material). With this model, we can observe the effect of one type of measure while taking into account the effect of the other. This model weakens even more the evidence that outside measures had an effect. Results for the fatality growth rate point in the same direction, even though lockdowns measures took more time to have an impact. As discussed earlier, this delay was expectable (See Supplementary Material). We use estimates for deaths to quantify the number of prevented deaths. We find that, world-wide, internal measures have prevented about 650,000 deaths, this is more than three times the actual number of deaths. Internal measures have thus been successful at preventing many pre-mature deaths.

4.2 Quantifying Prevented Deaths

We use model (2) to compare the evolution of the total number of deaths with and without a measure. The model has two parameters which help assess this, β_1 which indicates by how much more the number of deaths grows in a country that has implemented a measure, and β_2

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

which describes the gradual slowing down of the growth rate in deaths due to the measure.

We base our simulation on countries that have implemented inside measures, as those are shown to be effective. We consider the average time, T, from the day when a measure has been implemented, 0, until the end of our analysis period. For countries that implemented the measure, the increase in the number of deaths between the day they implemented the measure until the end of the observation period is:

$$g_1 = \prod_{t=0}^{T} exp(\hat{\beta}_1 + \hat{\beta}_2 \times t)$$

where $\prod$ is the product of its arguments. The counterfactual growth in the number of deaths is

$$g_0 = \prod_{t=0}^{T} exp(\hat{\beta}_1) = exp(\hat{\beta}_1 \times T)$$

The ratio of $(g_0 - g_1)/g_1$ provides information on how many deaths were prevented per actual death that occurred. In our context, this ratio is 3.11 so somewhat more than three deaths were prevented per every death that unfortunately occurred. We then use the average number of cases in countries that implemented the measure, $\bar{d} = 209'799$, to calculate the total number of prevented deaths, which is $\bar{d} * (g_0 - g_1)/g_1 = 652'254$. A total of over 650,000 deaths were prevented, or a bit more than three prevented deaths per actual death.

4.3 Did early lockdown movers fare better?

In this section, we explore whether early reactions by governments influenced the spread of the Covid-19. We define an early reaction with respect to the calendar date when a measure is implemented, and define early to be in the first quartile of the countries implementing the measure (See Supplementary Material.) Figure 5 shows the marginal effects for the impact of moving early, and provide a consistent picture: the growth rate number of days to observe a reduction of the growth rate is similar for countries that adopted an outside measure and reacted early compared to others, and the slope for early movers is flatter (lower intercept). Note, however, that reaching the zero growth rate at the same moment but at a lower rate implies that the rate was lower to start with, which is in line with the famous idea of "flattening the curve" and thus with the overall objective assigned to lockdown policies. We focus our analysis on inside measure as they proved to be more efficient throughout our analysis. Panels (A) and (B) of Figure 5 show that the countries adopting the inside measure later reached the baseline growth after 36.3 days for the countries which did not react early, while early movers reached the baseline growth rate in 23.4 days. Panel (E) of Figure 5 show that countries who took inside measure late did so on average on the 18th of March 2020 (day 78) and could expect the growth rate to slow down around mid-April. Panel (F) of Figure 5 show that countries who took inside measure late did so on average on the 6th of March 2020 (day 68) and could expect the growth rate to slow down around the end of March.

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

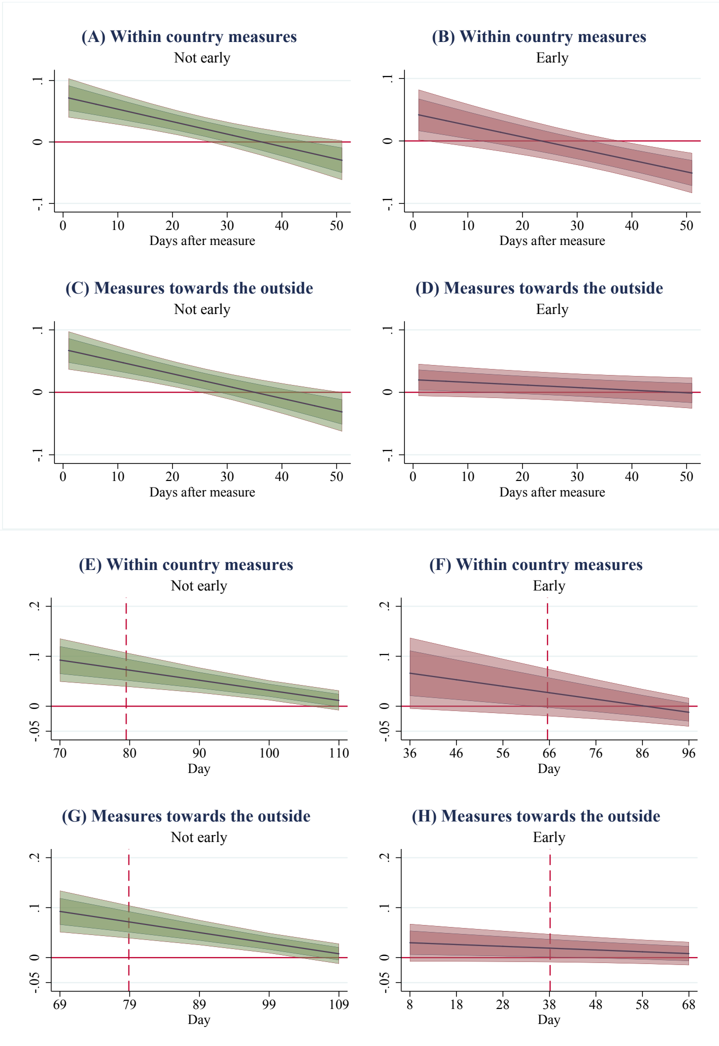

Figure 5: Sequence model: Marginal effects (Cases Confirmed)

Note: “Early” is defined as a measure adopted in the first quartile of the sample. Marginal effects computed with our autoregressive model or order 1. Panel (A) to (B) show the impact of a measure on the growth rate of infections as a function of time since the measure was implemented. Panel (C) to (D) show the impact of a measure on the growth rate of infections as a function of time since the 31st of December 2019 (Day). 90% and 99% confidence intervals are shown in different shade of blue. The vertical dashed line shows the average day where the measure was taken in the sample. The corresponding results for deaths are in the Supplementary Material.

Covid Economics 23, 28 May 2020: 325-351

4.4 Developing versus developed countries

This section explores whether the impact of lockdowns is different in developed and developing countries. Figure 6 shows the marginal effect of all the different types of measures for developed and developing countries[3]. A clear pattern appears in this Figure: lockdown measures have no statistically significant effects in developing economies, while the effects for developed economies are statistically significant. Most of the explanatory variation from our baseline model therefore comes from lockdown imposed in developed countries. Obviously comparing those results to the marginal effects of the baseline model, they are stronger as we are pinning down the group who benefit the most from the lockdown measures. For developed countries, within countries lockdowns have an effect after 20 days on average and the reduction after 50 days is 7.8% on average.

[3]We define developing countries as the ones with an Human Development index up to 0.699, which refers to Low and Medium human development using the United Nation codebook definition while above 0.699 will be defined as developed countries.

Covid Economics 23, 28 May 2020: 325-351

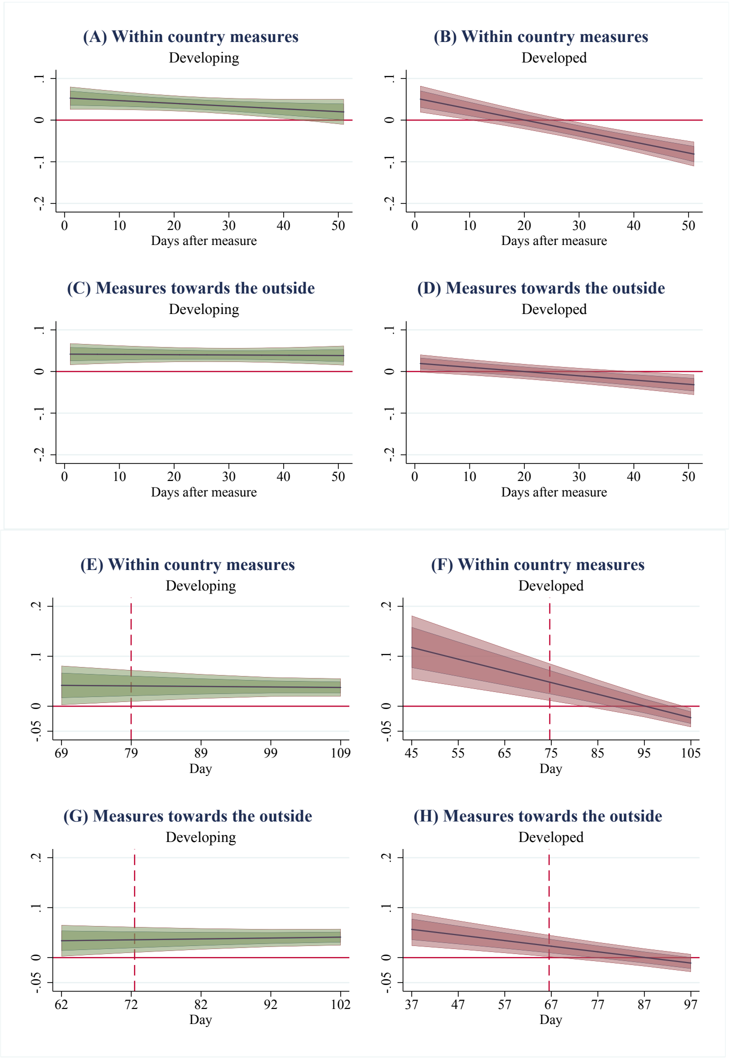

Figure 6: Developing versus developed countries model: Marginal effects (Cases Confirmed)

Note: Developing countries are the one with an Human Development index up to 0.699 which refers to Low and Medium human development using the United Nation codebook definition while above 0.699 will be defined as developed countries. Marginal effects computed with our autoregressive model or order 1. Panel (A) to (B) show the impact of a measure on the growth rate of infections as a function of time since the measure was implemented. Panel (I) to (I) show the impact of a measure on the growth rate of infections as a function of time since the 31st of December 2019 (Day). 90% and 99% confidence intervals are shown in different shade of green/blue. The vertical dashed line shows the average day where the measure was taken in the sample.

CEPR PRESS

Covid Economics 23, 28 May 2020: 325-351

5 Discussion

Studying the lockdown measures adopted in the context of the Covid-19 crisis in 184 countries, our paper delivers several important public policy insights for how pandemics should be faced. From these insights, one can also derive ideas about how individuals behave during lockdowns and thus how pandemics can be faced.

The first key insight from our study is that lockdowns are indeed effective measures to stop both the growth of new cases and of the number of deaths. This result is in line with observations from previous pandemics. In his review of the evidence about the 1918 Inluenza, Garrett (2008), for instance, compares the cases of Philadelphia, where public officials let a large parade take place during the pandemics, and St. Louis. He wrote: "Officials in St. Louis (a comparable city to Philadelphia at the time), however, responded quickly to the influenza by closing nearly all public places as soon as the influenza had reached the city. As a result, influenza mortality rates were much lower than in Philadelphia" Garrett (2008). With the covid-19 episode so far, lockdown measures have prevented many deaths -our estimates are that about 650,000 deaths have been averted- or more than three deaths were prevented for every death that occurred.

Contrary to common belief, however, our analysis suggests that the most extreme measures such as total lockdowns and immediate border closures are not necessarily the most effective actions to respond to a pandemic, even without considering the economic impact of these lockdowns. Let's analyse these in turn. First, our empirics show that partial or regional lockdowns are as effective as stricter measures such as those related to declaring a state of emergency or implementing curfews. Since partial measures are likely to be less damaging to the economy than stricter lockdowns, their overall impact can be considered as superior. This analysis should of course be confirmed by a joint study of the economic and health impact of the virus, but the fact that partial internal measures are effective at stopping the spread of the disease and at pushing down mortality is an important result by itself. So, why is this the case? One possible explanation is that partial and selective lockdowns are enough to push down the opportunity costs for people of going outside –as schools, stores or local businesses are closed- and taking the risk of being infected. Total lockdowns might thus be superfluous. In a similar manger, one could speculate that partial lockdowns might be strong enough as signals for people not only to stay home but also to quickly adopt sanitary measures or avoid group activities that might spread the disease fast. In other words, our results point to the fact that people might adjust their behaviors quite significantly as partial measures are implemented, which might be enough to stop the spread of the virus at lower economic costs. This questions pure epidemiological models, which typically made projections about the diffusion of the covid-19 without taking into account the adjustments made by rational individuals.

The third striking result of our analysis is that taking inside-country measures matters much more than implementing outside-oriented ones. Blocking borders, in particular, is the least effective policy at curbing the development of the virus, unless it follows effective internal measures. Even in a globalized world, internal policies are the name of the game. This result is in sharp contrast to current political discussions in the US and elsewhere, which often focus on border closure instead of putting the emphasis on within-country lockdowns. Again, why is this? One interpretation, in line with what was discussed above, could be that internal measures are effective at reducing opportunity costs for people of going out during a partial lockdown, whereas outside measures do not have this effect. Here again, what might drive the success of lockdown measures might be their ability to trigger a strong adjustment in individuals' behaviors. Whereas internal measures might have a significant effect, for instance, on the opportunity cost of staying home, it is likely that outside-oriented measures do not change much on that front for many individuals. This reasoning might also explain why outside measures matter only once internal ones have been implemented, an a result we obtained in a post hoc analysis

Covid Economics 23, 28 May 2020: 325-351

Covid Economics 23, 28 May 2020: 325-351

available from the authors upon request. Outside-oriented measures might thus deliver some added benefits in terms of further limiting interactions, but only when individuals have already adjusted their daily behaviours.

In order to push our idea of opportunity cost further, we splited our sample and explored differences between developed and developping countries. Our working hypothesis there was that the opportunity costs of abiding to lockdown rules and staying home are much higher in developing econoimes in which many people make a living in the informal sector and do not have any safety net. In agreement with our hypothesis, we do find that internal lockdown policies have a significant effect on both the number of cases and on the number of fatalities, whereas this is not the case in developing countries. We cannot firmly conclude from our analysis that lockdowns are not effective in developing countries, as the disease in these countries appeared later and we might thus lack observations and statistical power. However, our results so far indicate that lockdown measures would be have to be coupled with other policies, which could push opportunity costs down, to really impact the spread of the disease in developing markets.

Last, our empirical results suggest that there is somewhat of a speed premium for policy-making in the context of a pandemic, especially regarding the objective of 'flattening of curve' to avoid overwhelming intensive care hospital facilities.

In sum, and despite the fact that extreme measures have often been taken by countries in panic situations and for emergency purposes, there are clear learning outcomes from this first large pandemic of modern times: developing organizational structures and decision-making processes favouring fast reaction, agility and targeted lockdowns should be priorities. For similar reasons, these features should help in case we enter into a 'lockdown-release-lockdown' era, a hypothesis that cannot be ruled out in early May 2020 with the apparently low prevalence rate of the coronavirus across countries. One obvious caveat of our study, in that respect, is that the long-term efficiency of lockdown measures will only be known when these lockdowns have been lifted and when we have had time to observe whether the coronavirus has not surged again Bonardi et al.. If we are right that one key aspect of internal lockdown measures is to have pushed individuals to adjust their daily behaviors, there might hope in that regards nonetheless.

Covid Economics 23, 28 May 2020: 325-351

References

Avery, C., Bossert, W., Clark, A., Ellison, G., and Ellison, S. F. (2020). Policy implications of models of the spread of coronavirus: Perspectives and opportunities for economists. Working Paper 27007, National Bureau of Economic Research.

Bonardi, J.-P., Bris, A., Brülhart, M., Danthine, J.-P., Jondeau, E., Rohner, D., and Thoenig, M. The case for reopening economies by sector. Section: Economy.

Chinazzi, M., Davis, J. T., Ajelli, M., Gioannini, C., Litvinova, M., Merler, S., Pastore y Piontti, A., Mu, K., Rossi, L., Sun, K., Viboud, C., Xiong, X., Yu, H., Halloran, M. E., Longini, I. M., and Vespignani, A. (2020). The effect of travel restrictions on the spread of the 2019 novel coronavirus (covid-19) outbreak. *Science*.

Dong, E., Du, H., and Gardner, L. (2020). An interactive web-based dashboard to track covid-19 in real time. *The Lancet infectious diseases*.

Flaxman, S., Mishra, S., Gandy, A., Unwin, H., Coupland, H., Mellan, T., Zhu, H., Berah, T., Eaton, J., Perez Guzman, P., et al. (2020). Report 13: Estimating the number of infections and the impact of non-pharmaceutical interventions on covid-19 in 11 european countries.

Garrett, T. A. (2008). Pandemic economics: The 1918 influenza and its modern-day implications. *Federal Reserve Bank of St. Louis Review*, 90(March/April 2008).

Giordano, G., Blanchini, F., Bruno, R., Colaneri, P., Di Filippo, A., Di Matteo, A., and Colaneri, M. (2020). Modelling the covid-19 epidemic and implementation of population-wide interventions in italy. *Nature Medicine*, pages 1–6.

Harris, J. E. (2020). The coronavirus epidemic curve is already flattening in new york city. Technical report, National Bureau of Economic Research.

Hartl, T., Wälde, K., and Weber, E. (2020). Measuring the impact of the german public shutdown on the spread of covid19. *Covid economics, Vetted and real-time papers, CEPR press*, 1:25–32.

Hatchett, R. J., Mecher, C. E., and Lipsitch, M. (2007). Public health interventions and epidemic intensity during the 1918 influenza pandemic. *Proceedings of the National Academy of Sciences*, 104(18):7582–7587.

Kermack, W. O. and McKendrick, A. G. (1927). A contribution to the mathematical theory of epidemics. *Proceedings of the royal society of london. Series A, Containing papers of a mathematical and physical character*, 115(772):700–721.

Kraemer, M. U., Yang, C.-H., Gutierrez, B., Wu, C.-H., Klein, B., Pigott, D. M., du Plessis, L., Faria, N. R., Li, R., Hanage, W. P., et al. (2020). The effect of human mobility and control measures on the covid-19 epidemic in china. *Science*.

Maier, B. F. and Brockmann, D. (2020). Effective containment explains subexponential growth in recent confirmed covid-19 cases in china. *Science*.

Programme, U. N. D. (2020). http://hdr.undp.org. *Human Development Index (HDI). Available On-Line: http://hdr.undp.org/en/content/human-development-index-hdi*.

Tian, H., Liu, Y., Li, Y., Wu, C.-H., Chen, B., Kraemer, M. U., Li, B., Cai, J., Xu, B., Yang, Q., et al. (2020). An investigation of transmission control measures during the first 50 days of the covid-19 epidemic in china. *Science*.

Supplementary materials

Data and main variables

Empirical strategy

Additional figures S1 to S9

Regression tables S1 to S38

References *(1 - 2)*

Covid Economics 23, 28 May 2020: 325-351