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Health Expenditures and the Effectiveness of Covid-19 Prevention in International Comparison

Abstract

In the beginning of the COVID-19 pandemic, governments had to rely on Non-Pharmaceutical Interventions in their struggle against the spread of the virus. The stringency of the lockdowns differed across space and time as governments had to adjust their strategy dynamically to the country-specific development of the crisis. We examine the effectiveness of lockdowns with a focus on the role of health care based upon both the between and the within-variation of our panel-data. The within-variation over time allows us to control for unobserved heterogeneity through fixed-effects. The results reveal that lockdowns had significant effects on the mortality rates associated with COVID-19. Marginal effects are estimated conditional on the state of the health care system before the crisis. Lockdowns were more efficient in countries with well-supported health care systems. Marginal effects turn insignificant when per capita health expenditure dips below the mean. We can show that both results are driven by economic development. Per capita GDP is highly correlated with public health expenditure but it is not a perfect substitute.

JEL-Codes: I100, I130, I140.

Keywords: Covid-19, health expenditures, lockdown.

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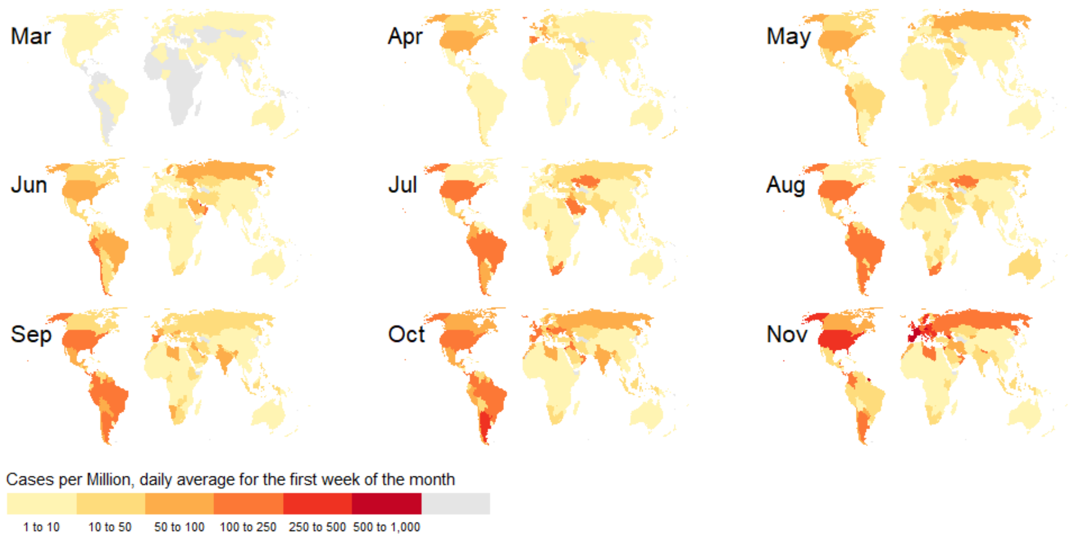
1. Introduction

The global spread of COVID-19 developed into the most serious threat to both health and economic welfare since World War II. The virus first attracted public interest in the beginning of 2020 when the World Health Organization sent out a global warning about an outbreak of a new virus that soon turned into a global pandemic. Figure 1 illustrates this rapid development of COVID-19 in the first nine months of the crisis.

Figure 1: *Global transmission of COVID-19 (March to November 2020)*



Source: Figure is constructed based on data of "*Our World in Data*". Each plot depicts averages of observations in the first week of the month for new COVID-19 cases per 1 mill. inhabitants. Light-yellow areas specify countries with a low transmission rate (< 10 new cases /1 Mill.). Darker coloured areas are associated with higher transmission rates. Dark red areas present 500 to 1000 new cases per one million inhabitants.

In February 2020, the pandemic was restricted to very few locations in Asia but - within a couple of weeks - the virus has reached almost every country in the world. The depicted color progressions reflect the rapid growth of transmissions and mortality rates but some countries are exceptional. For instance governments in Asia were quite successful in repelling the virus. China, one of the major pandemic hot-spots in the beginning of the crisis, managed to suppress all outbreaks until today. Its monthly average rate of infections per 1 Million residents always dipped below the value of 5. In comparison, countries in Europe, South, and North America reported extremely high transmission rates going up to more than a 1000 new cases per 1 Million residents.

This rapid development and the lack of vaccines forced governments to rely on Non-Pharmaceutical Interventions (NPIs) as school and workplace closing, stay at home orders, restrictions on gatherings and specific rules on wearing protective gear. The economic and social costs caused by these interventions were huge. Thus, assessing the efficiency of past lockdowns and identifying ways of improving their efficiency is an important task for future research from all provenances.

Potential inter-dependencies between the public health care system and the efficiency of lockdown measures is the focus of this study. Causal effects are identified based upon a fixed-effects panel data regression approach that allows including a large set of heterogeneous countries. We argue that the higher lockdown efficiency in countries with high per capita health expenditures is emerging through various channels: *i*) a better health system likely magnifies the pass-through from infections to mortality rates, *ii*) a higher per capita health expenditure may also be a reflection of a higher priority given to health issues. People in countries with high evaluation for health issues may be more inclined to follow lockdown regulations imposed by the government. *iii*) A low per capita health expenditure in developing countries likely reflects these countries' inability of providing more than basic health care. According to the arguments discussed above, the pass-through from infections to mortality rates due to the lockdown are supposed to be much lower. Moreover, the majority of people in developing countries may have very little scope for prioritizing lockdown rules.

Per capita health expenditure captures all these channels at once. It is likely driven by per capita GDP when comparing developing and developed countries. Yet, it is a much more precise measure for the channels discussed above as the link between per capita GDP and per capita health expenditures is not perfect. We can show that the link diverges in countries at the upper end of the per capita GDP distribution. Figure 2 highlights this observation by correlating GDP and health expenditure. The correlation becomes lower when GDP per capita is relatively high.

The figure shows that per capita GDP seems to be an important determinant for health expenditure but it is not a perfect substitute.

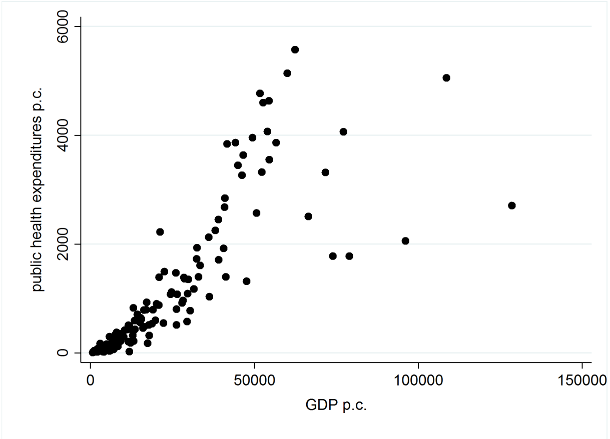


Figure 2: *Correlation GDP p.c. and public health care expenditures p.c.*

In summary, detection and retracement is likely more efficient in countries that pay more attention to their public health care system. Yet, higher health expenditure may also be a reflection of a larger share of the elderly. We account for the latter by disentangling health expenditure using a simple regression approach, which allows us to neutralize the impact of the share of health expenditure associated to the higher share of the elderly.

Our results indicate that there is a trade-off between the stringency of the lockdown and the prevailing health expenditures. Less stringent lockdowns in countries with higher health expenditures had a similar impact on mortality as more stringent lockdowns in countries with lower health expenditures. This trade-off is more of an issue for developed countries with high per capita GDP. We show that the effects of lockdown interventions were insignificant in developing countries with per capita health expenditure below the mean.

Our analysis is structured as follows: The next section reviews the related literature, chapter two presents the data employed as well as the steps taken to clean the data. In chapter three, some stylized fact plots characterize the relations of interest. Subsequently, we introduce our empirical strategy in chapter four. The results of the analysis are discussed in chapter five. Chapter six concludes and gives some political implications.

1.1. Literature review.

Lockdown policies. Our study contributes to a growing strand of literature on the effectiveness of social-distancing measures. Numerous studies simulate and study the course of a pandemic based upon the Susceptible-Infected-Recovered (SIR) model (e.g. Alvarez et al. (2020) Atkeson (2020), Eichenbaum et al. (2020), Farboodi et al. (2020), Krueger et al. (2020)). These contributions highlight the trade-off between social distancing, health risk and its interplay with economic outcomes. Overall, these models suggest that lockdown measures are highly effective in reducing infection rates. Interventions are even more effective when rigorously applied in a very early stage of the pandemic.[1] Simultaneously, more stringent social distancing measures help preventing a breakdown of the national health care system. In summary, social distancing is an effective instrument for reducing infection rates but - from a political perspective - people sometimes argue that the cost of economic inactivity must be balanced against the cost of human lives.[2]

These theoretical insights are supported by various empirical studies. One strand of literature investigates the effects of lockdown rules during the "Spanish flu", 1918 - 1920 (e. g. Correia et al. (2020), Barro et al. (2020), Bootsma and Ferguson (2007), Hatchett et al. (2007), Markel et al. (2007)). Overall, these studies find that imposing strict lockdown measures in the beginning of the pandemic reduced mortality rates significantly.[3] More recent studies confirm the effectiveness of social-distancing measures in the current COVID-19 pandemic, whereby some studies focus on specific geographic areas (e.g. Born et al. (2020), Fang et al. (2020), Friedson et al. (2020)), and others conduct cross-country analyses (e.g. Bendavid et al. (2021), Flaxman et al. (2020), Hsiang et al. (2020)). Bendavid et al. (2021) compare health outcomes of countries

[1] The models additionally account for test strategies to identify susceptible, infected and recovered individuals, as well as quarantine rules. These instruments of monitoring and identification complement social distancing strategies and promote their effectiveness.

[2] Greenstone and Nigam (2020) evaluate the effect of social distancing rules for the US. Using the age-specific value of a statistical live, the benefit of moderate lockdown measures that reduce mortality and relieve pressure on the health care system due to COVID-19, aggregate to 8 trillion USD.

[3] Bootsma and Ferguson (2007) also find that an early installment of the restrictions did not protect cities from a second or even third wave but cumulative deaths associated with the flu were significantly lower.

that implemented very strict measures to those of the more reluctant countries South Korea and Sweden, two countries that imposed less rigorous lockdowns. Overall, social distancing restrictions reduce infection numbers and deaths but the authors do not find a significant difference in lockdown efficiency.

Potential interplay between lockdown policies & public health care. The hypothesized link between the health care system and the efficiency of pandemic interventions is supported by the literature. Wealthier countries with higher per capita spending in public health care were likely better prepared due to the higher budgets available for medical equipment, prophylaxis and for conducting R&D (e.g. Bloom and Canning (2004), Ghobarah et al. (2004)).[4] But, despite this academic evidence on the importance of having a superior health system, Gmeinder et al. (2017) find that OECD countries in 2015 spent less than 3% of their overall health expenditures into pandemic prevention. This number is lower than the amount spent for administration in these countries.

Another strand of literature identifies inequality and a lack of equal opportunities for access to the health care system and the role of private versus public health care as major determinants for the course of the pandemic (e.g. Ahmed et al. (2020), Assa and Calderon (2020), Galea and Keyes (2020)). A larger private health sector may improve treatment for individuals with private health insurance but it likely has adverse effects during a pandemic: Assa and Calderon (2020) identify a positive effect of increased health care privatization on COVID-19 cases and deaths. Other studies analyze the effect of health care privatization on the control of Tuberculosis, an infection disease that mainly appears in low and middle income countries. Overall, these studies support the findings of Assa and Calderon (2020): Public health expenditures significantly reduce the number of Tuberculosis cases and deaths, while private health expenditures are either ineffective or even harmful for the control of Tuberculosis epidemics (e. g. Austin et al. (2016), Basu et al. (2012), Chengsorn et al. (2009), Reta and Simachew (2018)).[5]

[4]Ghobarah et al. (2004) argue that countries characterized by higher per capita public health expenditures tend to invest more in prevention, and thereby, have lower levels of individuals suffering from chronic diseases.

[5]Identified reasons for this result are worse equipment and regulations, breach of medical instructions

The coexistence of public and private health sectors can cause inequality in accessibility to health care, which is another source of inefficiency for the effectiveness of lockdown interventions. Ahmed et al. (2020) and Galea and Keyes (2020) argue that individuals with no or only limited access to health care more likely evade these lockdown regulations. If individuals have to pay for doctor visits or if they are not covered by insurance in case of illness, they are more inclined to continue working at odds with official lockdown guidelines.[6] A public health care system that provides equal access and insurance to all fosters security, and thereby supports the effectiveness of lockdown measures.

2. Data Description

COVID-19 data

The main pillar of our analysis are various COVID-19 indicators collected by Roser et al. (2020)[7]. We use information on country-specific COVID-19 related deaths and infections as main outcome variables. Information is available for 187 countries going back to December 2019 but most countries did not report cases until March 2020. All variables are updated on a daily basis.

Countries with inconsistent data for our preferred outcome variable, which is daily COVID-19 related deaths per one million inhabitants, were dropped from the sample. Inconsistencies are for example negative values and incomprehensible changes of daily new infections and deaths per one million residents or a high number of missing values.

The remaining 142 countries cover both developed and emerging economies.[8] The influence of potential outliers in the data is neutralized by taking weekly averages. The choice of the outcome variable is motivated by the fact that the number of COVID-19 related deaths is more reliable than the number of infections. The latter highly depends

and partially lower qualified personnel in private facilities.

[6]Less qualified individuals have lower earnings on average and their risk of dismissals is also higher. These occupations are also more likely associated with social interaction compared to high-skill intensive occupations.

[7]The data can be obtained at the *Our World in Data* platform.

[8]A complete country list can be found in Table A.1 in the appendix.

on the testing strategy of a country and this strategy may have changed over time with the availability of tests. The definition of counting COVID-19 related deaths may also differ across countries but frequent changes in this definition over time are less likely. The former problem of cross-country differences can be addressed by including country fixed-effects.

We follow Hsiang et al. (2020) in assuming that the development of infections over time can be characterized by a susceptible-infected-recovered (SIR) model:

$$\frac{dI_t}{t} = (S_t\tau - \rho)I_t \quad . \tag{1}$$

Variable I_t is the number of infected individuals at time t and τ labels the transmission rate. The parameter ρ specifies the removal rate, which is the proportion of infected individuals recovering or dying each day, and S is the share of individuals that is susceptible to the infection. Without herd-immunity, the parameter S approaches the value one, which changes equation (1) to $\frac{dI_t}{t} = (\tau - \rho)I_t$. Solving the differential equation gives:

$$\frac{I_{t2}}{I_{t1}} = e^{g(t_2 - t_1)} \tag{2}$$

Taking logs transforms equation (2) to a growth rate, which is applied in our analysis:

$$ln(I_t) - ln(I_{t-1}) = g(t_2 - t_1) \tag{3}$$

Moreover, we also assume that the development of infections translates into the development of COVID-19 related deaths. Thus, the dependent variable can be constructed as the difference of the weekly (w) COVID-19 deaths in logs.

Lockdown data

To examine the effectiveness of COVID-19 interventions, we draw on data provided by the Coronavirus Government Response Tracker. Hale et al. (2020b) define different categories of closures and containment as well as economic and health measures that allow tracking governmental responses to COVID-19 on a daily basis around the world. The restrictiveness of COVID-19 related policy measures is captured by the *Stringency Index* provided by Hale et al. (2020a). This index lumps together all individual information on school and workplace closing, cancellation of public events, restriction on gatherings, closure of public transport, stay at home orders as well as restrictions on internal and international movements and public information campaigns. These categories are summed up to an aggregate measure, which is standardized so that the range of values goes from 0 (no lockdown measures) to 100 (strictest lockdown measures). Hence, the Stringency Index provides information on the variation in international governmental responses to the pandemic course. More details can be found in Table A.8 in the Appendix.

Health system related data

The second main variable of interest is the prevailing state of the health care system. The use of the term prevailing can be explained by our focus on the situation shortly before the start of the pandemic. We are interested in how good countries were prepared to the crisis. Information about short-term adjustments of health expenditures during the pandemic is neither available nor needed for the question at hand. Changes during the pandemic are endogenous adjustments for which the causality goes from the dependent variable to the variable of interest. The World Health Organization (WHO) provides information about health care, health expenditures and health conditions for 194 member countries. We build our analysis upon *Domestic General Government Health expenditures per capita in PPP in $ (GGHE)* observed for the year 2018. The relevance of the public health expenditure in contrast to private health care is taken into account by calculating the ratio between both variables.

Additionally, we use the *health care access & Quality Index*[9] of GBD 2015 Healthcare

[9]The health care access & Quality Index based on 32 causes of death that are avoidable if treated immediately and effectively. Estimates are age- and risk-standardized. The index ranges between 0 and 100, whereby 0 describes the worst, and 100 the best health care access and quality. For our analysis we re-scale the index to a range that goes from 0 (worst) to 1 (best). It is available for 195 countries in a time span between 1990 and 2015. For more detailed information see GBD 2015 Healthcare Access and Quality

Access and Quality Collaborators (2017) in another robustness check. Unfortunately, this variable is available for the year 2015 at the latest but we argue that this indicator was fairly stable in the years between 2015 and the recent crisis.

A potential endogeneity bias may emerge out of the higher requirement for health expenditure in a country with a high population share of elderly people. These countries have higher mortality rates and therefore a higher demand for health care expenditure. Controlling for the share of the elderly in the regression is appropriate for its bias on the lockdown efficiency but the interaction effect with health expenditure would still be biased. We tackle this problem by applying a simple decomposition exercise, which predicts $HEALTH_i$ based upon the outcomes from a regression. Health expenditure in country i is explained by a constant, its per capita GDP, its size in terms of population and its share of the elderly. We fit

$$HEALTH_i = C + \alpha_1 GDP_i + \alpha_2 POP_i + \alpha_3 ELD_i + \epsilon_i \tag{4}$$

to the cross-section data and predict age adjusted health expenditure by setting $\alpha_3 = 0$.[10]

Further controls

Further controls for potential macroeconomic characteristics as GDP per capita, openness or demography of the population are taken from the Penn World Table 9.1.[11] These variables are country-specific and therefore drop out in the fixed-effects approach. However, macroeconomic determinants can be used as interaction variables. The effects of time-variant lockdowns may systematically differ by some specific country characteristics.

3. Descriptives and stylized facts

Table A.2 in the Appendix provides descriptive statistics of our data. Figure 3 gives a first glimpse at the potential relations between the main variables of interest: log-

Collaborators (2017).

[10] Instead, one could also set ELD_i to its mean, the results in the main regression would be identical.

[11] For more details check Feenstra et al. (2015).

arithmized COVID-19 cases and deaths per 1 million residents are plotted against the domestic per capita spending on public health care and the Stringency Index, respectively.

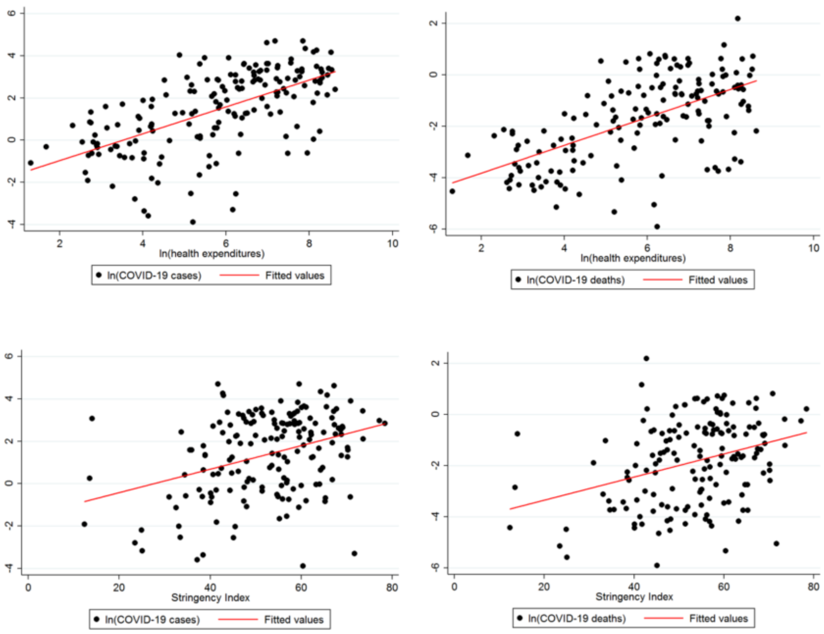


Figure 3: *Correlation COVID-19 cases, deaths, public health care expenditures and lockdown stringency*

All graphs reveal a positive correlation between both COVID-19 related outcomes and the lockdown or health care expenditure variable. This result must be spurious. Intuitively, this pattern should be a reflection of the aforementioned endogeneity bias. The correlations are likely driven by the reverse causality as the information offered by the time-dimension of the data is not visible in these stylized fact plots. Countries with higher infection rates may have been more alerted and their reaction is therefore more stringent compared to countries that are less affected by the crisis. Moreover, countries with a larger share of the elderly may invest more into public health care and simultaneously experience higher COVID-19 death rates on average due to the demographic structure of the society. Considering the information offered by the time dimension of our data is one of our contributions: We exploit the dynamic adjustment path of both the outcome and the main variable of interest.

Enough variation over time is a crucial prerequisite for the application of a fixed-effects model. Figure 4 depicts the strictness for each of the eight stringency-categories

Figure 4: *Heat-map category strictness - development between January and November*

C_l by country and month.[12] Green represents 'no application', yellow defines the lowest level of stringency ($C_l = 1$), bright orange a low-medium level ($C_l = 2$), dark orange a high-medium level ($C_l = 3$) and red is the highest level of stringency ($C_l = 4$). The variation is calculated and displayed for all categories of interest in our study. We are able to identify both, between and within-country variation. Changes in the coloring by row depict the variation between countries. Instead, the variation over time within a country is represented by varying colours between columns. While most countries do

[12]Index l specifies the respective lockdown measures, $l = 1, 2, \ldots, 8$. For more detailed information see Table A.8 in the Appendix.

not change their lockdown policy regarding the cancellation of public events over the observed time period (panel three), the variation in stringency of school and workplace closing (panels one and two), restriction on gatherings as well as stay at home orders (panels four and six) is high. These insights allow us to analyze the effect of lockdown policies conditional in the public health care system on COVID-19 related mortality rates between as well as within countries.

4. Empirical strategy

First of all, we regress weekly changes in logarithmized COVID-19 cases and deaths, $\Delta\ LogCOVID_{iw}$, on its potential determinants. Potential interactions are not considered in this benchmark setup that fits

$$\Delta LogCOVID_{iw} = \alpha + \beta_1 \times lockdown_{iw} + \beta_3 \times LogHealth_i + \beta_4 \times CV_i + \tau_w\ [+\gamma_i] + \varepsilon_{iw}$$

to the data.

The variable *lockdown* is the index that evaluates the stringency of the respective country $i's$ lockdown measures at week w. The individual effects of specific lockdown measures are studied in a robustness check that includes all categories of the lockdown separately. The lockdown information enters the regression lagged by two weeks in the analysis of COVID-19 cases. The preferred measure for the state of the health care system is our demography-adjusted health expenditure variable but we include all other approximations for the quality of public health care in separate regressions. The vector CV_i contains different control variables, such as country i's GDP per capita, openness, share of individuals older than 65, etc. The information on health issues and macroeconomic characteristics is available at the country-year level, hence they are indexed by i. We use the latest information available, which is the year 2015 in case of the HAQI, and 2018 for all other variables.

A similar equation fits the model to changes in COVID-19 related death rates. Differently to the first set-up, this analysis includes the weekly changes of COVID-19 cases lagged by two weeks. The usual course of disease is illustrated in Figure 5[13]. The average time span from infection to death is 11 days, which is why we have chosen a lag of two weeks for the number of infections. Moreover, lockdown measures are included with a four-week-lag, which can be rationalized by the time it takes until the interventions become visible in the data. It takes some time until the intervention affects the number of cases and we know that it takes another two weeks until the reduction in cases passes through to a reduction in the number of COVID-19 related deaths.

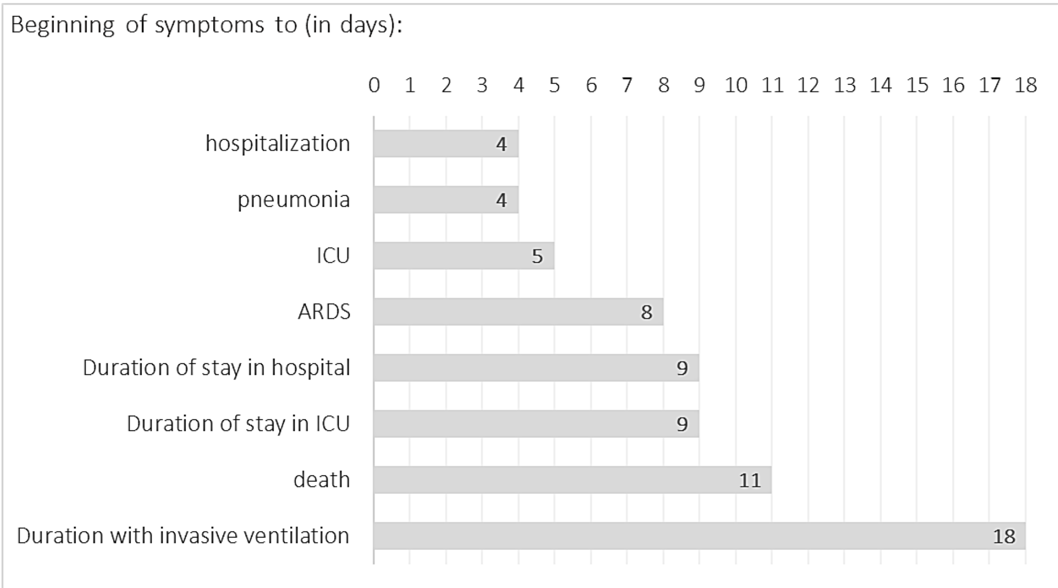


Figure 5: *Average disease process of COVID-19*

We control for time fixed-effects, τ_w, to capture all common effects influencing all countries similarly. Some regressions control for unobserved cross-country heterogeneity by purging the fixed-effects, γ_i. Variables without variation on a weekly basis drop out in the fixed-effects regressions but their indirect effect through the lockdown can be identified by including interaction effects with the health variables of interest. This extended setup allows analyzing potential non-linearities in the data. The model is similar to the one described above but the variables of interest are interacted with each

[13]In compliance with the epidemiologic profile provided by the Robert Koch Institut (RKI). URL: *https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Steckbrief.html*

other, which allows computing marginal effects as first derivative of

$$\Delta LogCOVID_{iw} = \alpha + \beta_1 \times lockdown_{iw} \ \ [+\beta_2 \times LogHealth_i] \ + \beta_3 \times lockdown_{iw} \times LogHealth_i \\ + [\beta_4 \ CV_i] + \tau_t \ [+\gamma_i] \ + \varepsilon_{iw}$$

with respect to the lockdown variable. We interpret the results in an appropriate graph that depicts the marginal effect and the respective confidence interval conditional on the level of the respective health variable.

5. Results

Table 1 reports the results for the benchmark model that explains changes in COVID-19 cases by lockdown stringency and the age-adjusted health expenditure measure. The coefficients associated with the lockdown and the prevailing health care system proxies can be found in column (1) and (2). Column (3) and (4) present the results for the same model fitted to changes in COVID-19 deaths.

The coefficient associated with the lockdown measure (SI) in column (1) suggests that more stringent lockdown interventions diminish the growth rate of COVID-19 cases. In compliance with the results reported in column (2), the magnitude of the effect is driven by unobserved heterogeneity. The coefficient in column (2) is more than twice as big as the coefficient in column (1). These results are intuitive and supported by the estimation results of Born et al. (2020). The increase of new COVID-19 deaths is negatively affected by lockdown measures with a lag of four weeks, as shown in columns (3) and (4). Again, this effect is stronger when fixed-effects are accounted for (column (4)). Quantifying the results based on the fixed-effects regressions in column (2) and (4) reveals that an increase in lockdown stringency by one standard deviation (27.552) is associated with a slow-down in the growth rate of new COVID-19 cases and deaths by approximately 22 and 13.8 percentage points, respectively.[14]

The effect of a percentage change in COVID-19 cases on death rates is also as expected: A reduction in the growth of new COVID-19 cases by one standard deviation

[14] The marginal effect is calculated as $-0.008 \times 27.552 = 0.22$ and $-0.005 \times 27.552 = 0.138$.

Table 1: *Benchmark regression results*

Dependent variable	$\Delta Log - COVID - Cases$		$\Delta Log - COVID - Deaths$	
	(1)	(2)	(3)	(4)
	b/se	b/se	b/se	b/se
SI_{w-2}	-0.003***	-0.008***		
	(0.00)	(0.00)		
SI_{w-4}			-0.002**	-0.005***
			(0.00)	(0.00)
$\Delta Log - Covid - Cases_{w-2}$			0.282***	0.256***
			(0.03)	(0.03)
Log(adj.public HE)	0.004		0.010	
	(0.01)		(0.02)	
Log(GDP p.c.)	-0.021		-0.004	
	(0.02)		(0.03)	
(Import+Export)/GDP	-0.049**		-0.019	
	(0.02)		(0.03)	
Share of individuals age > 65	0.001		0.000	
	(0.00)		(0.00)	
Constant	0.563***	0.454***	0.599*	0.797***
	(0.20)	(0.16)	(0.32)	(0.23)
Time FE	x	x	x	x
Country FE		x		x
Number of obs.	5593	5593	4229	4229
R within	0.319	0.335	0.189	0.193
Adj. R	0.313	0.330	0.179	0.184

Standard errors in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) and (2) is the change in logarithmized COVID-19 cases per one million. The dependent variable in column (3) and (4) is the change in logarithmized new COVID-19 deaths per one million. The lockdown variable is the Stringency Index, SI. health care proxy is logarithmized adjusted public health care expenditures, $log(adj.\ HE$. Further regressors are logarithmized GDP per capita, $log(GDPp.c.)$, the share of imports + exports over GDP, $(Import + Export)/GDP$, and the share of individuals with age > 65. We control for the time trend by including time fixed-effects. In column (2) and (4) country-fixed effects are included.

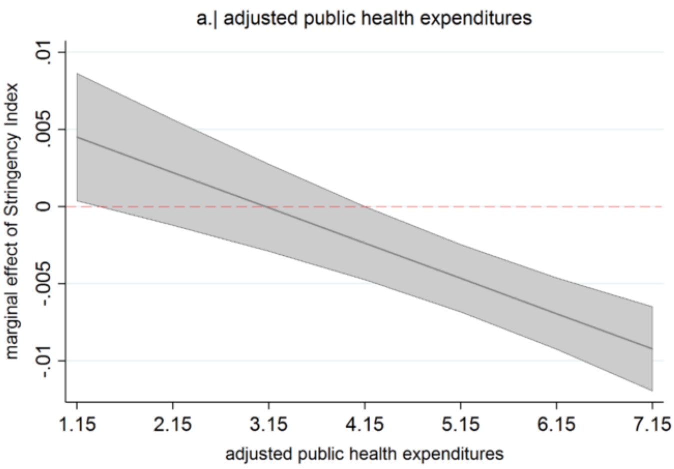
(0.705) is related to a decrease in the growth rate of COVID-19 related deaths by approximately 18 percentage points. Public health expenditures and per capita GDP are not significantly related to the changes in COVID-19 cases and deaths but these effects may still work through the lockdown intervention. Interestingly, the share of the elderly is also insignificant. Infection and death rates are not systematically related to the share of the elderly.[15]

Interaction effects. For the estimation of the interaction effects we only focus on the more accurately measured changes in COVID-19 related deaths. Figure 6 presents interaction results with adjusted public health care expenditures. The diagram in the

[15]The regression results are robust against changes in the approximation of public health care quality. Tables A.4 to A.7 present the regression results applying four different measures of health care system quality.

left panel is a graphical representation of the estimation results reported in column (2) of the regression table in the right panel.

Figure 6: *Marginal Interaction Effects: Stringency & Adjusted health care Expenditures*

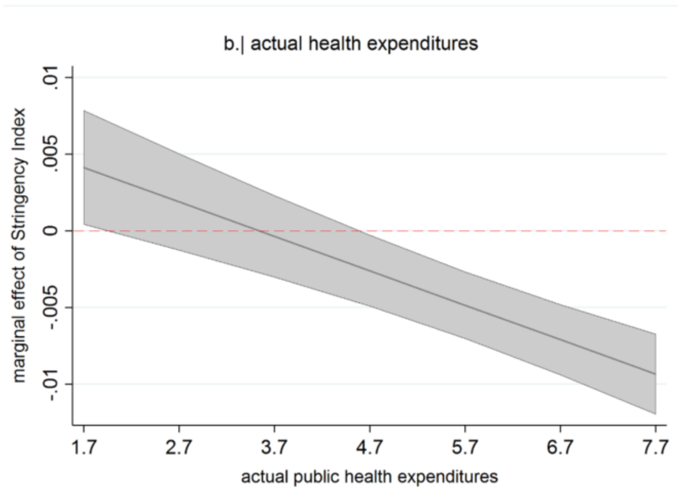


Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.268***	0.240***
	(0.03)	(0.03)
log(adj. pub. HE)	0.146***	
	(0.04)	
SI_{w-4}	0.008***	0.007***
	(0.00)	(0.00)
$log(adj.\ pub.\ HE) \times SI_{w-4}$	-0.002***	-0.002***
	(0.00)	(0.00)
log(GDP p.c.)	-0.019	
	(0.03)	
(Import+Export)/GDP	-0.029	
	(0.03)	
Share of individuals age>65	-0.002	
	(0.00)	
Constant	-0.070	0.691***
	(0.32)	(0.20)
Marginal Effect at mean (5.344) = -0.004		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.194	0.199
adj. R	0.185	0.190

Marginal effects are calculated based on specification in column (2). Standard errors in parentheses. Significance levels are indicated by * p<0.10, ** p<0.05, and *** p<0.010. The lockdown variable is the Stringency Index, SI. Adjusted public health care expenditures, ($ln(adj.\ pub.\ HE)$), approximate the health care quality. Control variables are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$ and the share of individuals with age > 65.

Changes in COVID-19 cases have a positive and highly significant impact on changes in COVID-19 related deaths in both specifications: A reduction in the growth rate of new daily COVID-19 cases by one standard deviation is associated with a reduction in the ratio between Covid-19 related deaths of today over Covid-19 related deaths reported in the previous period by approximately 17 percentage points. This result is in line with the results discussed in Table 1. The effects of both lockdown measure and public health expenditures are positive and highly significant but the marginal effect in this analysis must be interpreted conditional on the level of the interaction variable. The marginal effect of lockdown stringency can be calculated by applying $\frac{\delta \Delta logCOVID_{iw}}{\delta SI_{w-4}} = \beta_1 + \beta_3 logHE$. Evaluated at the sample mean $ln(adj.HE) = 5.344$, we find a negative effect of approximately $ME_{adj.\ HE}(5.344) \approx -0.004$. Hence, a positive change of the Stringency Index by one standard deviation (27.552) is associated with a reduction in the growth of new COVID-19 related deaths by approximately 10.2 percentage points. The confidence interval in the interaction plot includes the value zero for levels of adjusted health expenditures from the minimum up to values of around 4.5. Lockdowns had no significant impact in countries with per capita expenditures for health at the bottom of the distribution. This result is independent from the adjustments of health expenditure by the effects associated with the share of the elderly. Figure 7 shows comparable results based upon the absolute level of domestic health expenditures per capita.

Figure 7: *Marginal Interaction Effects: Stringency & Unadjusted Health Expenditures*



Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.264***	0.235***
	(0.03)	(0.03)
log(pub. HE)	0.146***	
	(0.04)	
SI_{w-4}	0.009***	0.008***
	(0.00)	(0.00)
$log(pub.\ HE) \times SI_{w-4}$	-0.002***	-0.002***
	(0.00)	(0.00)
log(GDP p.c.)	-0.022	
	(0.03)	
(Import+Export)/GDP	-0.030	
	(0.03)	
Share of individuals age>65	-0.004*	
	(0.00)	
Constant	-0.143	0.647***
	(0.31)	(0.18)
Marginal Effect at mean (5.771) = -0.004		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.196	0.200
adj. R	0.186	0.192

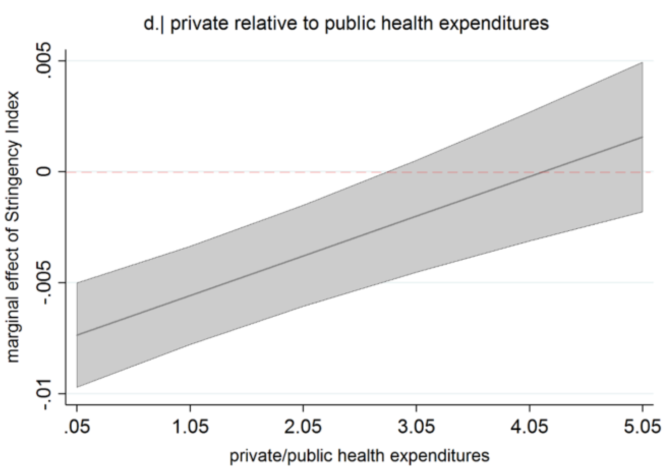
Marginal effects are calculated based on the specification reported in column (2). Standard errors in parentheses. Significance levels are * p<0.10, ** p<0.05, and *** p<0.010. The lockdown strength is quantified with the stringency index, SI. Unadjusted public health care expenditures per capita ($ln(pub.\ HE)$) find application approximating health care system quality. Control variables are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, and the share of individuals with age > 65.

Lower growth rates in COVID-19 cases caused a reduction in changes of new daily deaths. The magnitude is very close to the results shown in Table 1 as well as the estimations using the adjusted measures of health care expenditures. Likewise the direct effects of health care expenditure and the Stringency Index are highly significant and positive. In contrast, the interaction term between lockdown strength and health care expenditures is highly significant and negative. Calculating the marginal effect of lockdown stringency at the sample mean of public health expenditures, $ln(pub.HE) = 5.771$, shows that a rise in lockdown restrictiveness by one standard deviation is related to a 9.8 percentage points reduction in average daily COVID-19 death growth rate. The marginal effect of lockdown stringency becomes stronger when per capita expenditure into the public health system was already big before the crisis.

We also include public health care expenditures weighted by the share of population younger than 65 years as another proxy of public health expenditures cleaned up by a potential effect of the elderly. The effects are similar to the results discussed in the last two paragraphs and suggest a slow-down in the growth of average COVID-19 deaths by around 9.5 percentage points if the stringency of lockdown measures increases by one standard deviation. The graphical presentation of the marginal effect of lockdown stringency conditional on public health care weighted by the share of population younger than 65 years as well as the estimated coefficients can be found in Figure A.1 in the Appendix.

Figure 8 presents the marginal effect of lockdown stringency conditional on the ratio between private and public health expenditures as well as the corresponding estimates.

Figure 8: *Marginal Effects with Interaction: Stringency & private/public healthcare expenditures*



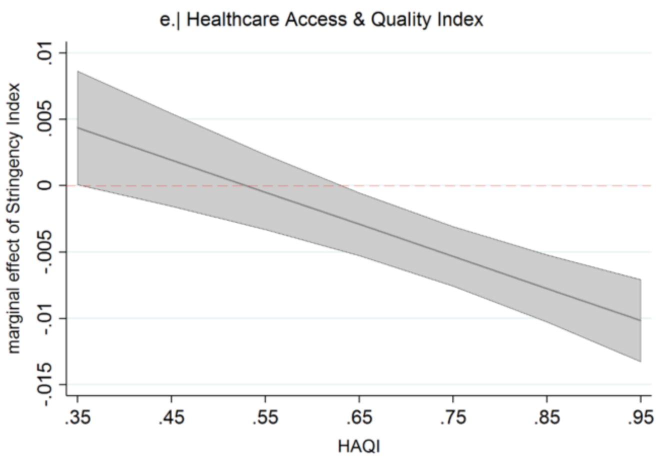
Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.276***	0.248***
	(0.03)	(0.03)
private/public HE	-0.099***	
	(0.03)	
SI_{w-4}	-0.003***	-0.007***
	(0.00)	(0.00)
private/public HE $\times SI_{w-4}$	0.001***	0.002***
	(0.00)	(0.00)
log(GDP p.c.)	0.003	
	(0.01)	
(Import+Export)/GDP	-0.019	
	(0.03)	
Share of individuals age>65	-0.001	
	(0.00)	
Constant	0.663**	0.743***
	(0.29)	(0.22)
Marginal Effect at mean (1.209) = -0.005		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.191	0.196
adj. R	0.182	0.187

Marginal effects are calculated based on specification in column (2). Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The lockdown strength is quantified with the stringency index,SI. Private relative to public health care expenditures ($ln(pub.\ HE)$) find application approximating health care system quality. Control variables are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, and the share of individuals with age > 65.

As before, the marginal effect of lockdown stringency must be computed conditional on the private to public health expenditure ratio. The marginal effect is significant and negative for countries with relatively high public expenditures in health. Calculating the marginal effect at the sample mean, $private/public\ HE = 1.209$, under consideration of the interaction effect, a one standard deviation increase in lockdown restrictiveness is associated with a reduction in growth of COVID-19 related deaths by around 12.6 percentage points. This result supports the link discussed in the introduction. A relatively large private health care sector may restrict access to medical treatment, and thereby distort individual incentives in a way that lockdown measures become less effective. Consistently, we can draw the conclusion that a well funded public health care system supports the effectiveness of lockdown measures, and thereby, constitute one important component in the pandemic control.

Figure 9 presents results with a broad proxy for the quality of public health care, the *healthcare Access* & *Quality Index* (HAQI). The marginal effect plot confirms the benchmark results.

Figure 9: *Marginal Effects with Interaction: Stringency & HAQI*



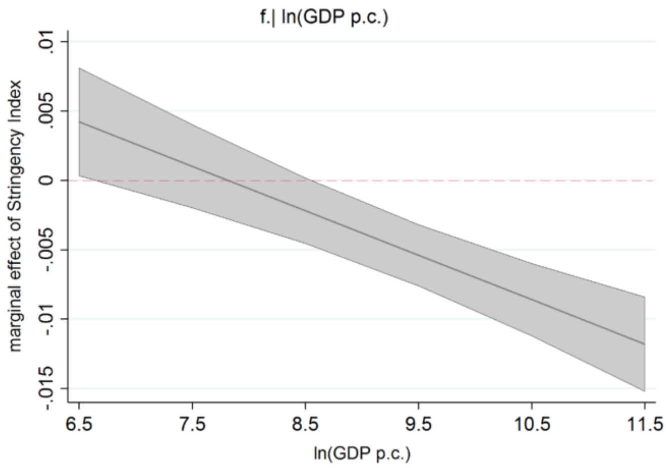
Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.267***	0.239***
	(0.03)	(0.03)
HAQI	1.530***	
	(0.37)	
SI_{w-4}	0.013***	0.013***
	(0.00)	(0.00)
$HAQI \times SI_{w-4}$	-0.020***	-0.024***
	(0.00)	(0.00)
log(GDP p.c.)	-0.018	
	(0.03)	
(Import+Export)/GDP	-0.025	
	(0.03)	
Share of individuals age>65	-0.003	
	(0.00)	
Constant	-0.395	0.707***
	(0.37)	(0.20)
Marginal Effect at mean (0.730) = -0.005%		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.194	0.198
adj. R	0.185	0.189

Marginal effects are calculated based on specification in column (2). Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The lockdown strength is quantified with the stringency index, SI. The health care Access & Quality Index ($HAQI$) finds application approximating health care system quality. Control variables are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, and the share of individuals with age > 65.

The direct effects of lockdown stringency and quality of the health care system are highly significant and positive. In contrast, the interaction term between both variables of interest is highly significant and negative. An increase in lockdown stringency by one standard deviation is associated with a reduction of new daily COVID-19 death growth by 12.5 percentage points for economies characterized by sample mean health care access and quality, $HAQI = 0.730$. A high quality health care system that provides equal access amplifies the expected lockdown effects.

Lastly, we test in how far these results are driven by the economic development status of a country prior the pandemic. Doing so, we conduct the same regression analysis including GDP per capita as a proxy for economic development. The results are presented in Figure 10. As before, the diagram in the left panel visualizes the marginal effect of lockdown stringency conditional on GDP per capita, while the table in the right panel shows the corresponding estimation results.

Figure 10: *Marginal Effects with Interaction: Stringency & $GDPp.c.$*



Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.266***	0.239***
	(0.03)	(0.03)
log(GDP p.c.)	0.164***	
	(0.04)	
SI_{w-4}	0.024***	0.025***
	(0.01)	(0.01)
$log(GDPp.c.) \times SI_{w-4}$	-0.003***	-0.003***
	(0.00)	(0.00)
log(pub. HE)	0.019	
	(0.02)	
(Import+Export)/GDP	-0.036	
	(0.03)	
Share of individuals age>65	-0.004*	
	(0.00)	
Constant	-1.111**	0.684***
	(0.46)	(0.20)
Marginal Effect at mean (9.360) = -0.003		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.195	0.199
adj. R	0.186	0.191

Marginal effects are calculated based on specification in column (2). Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The lockdown strength is quantified with the stringency index, SI. GDP p.c. serves as proxy for economic development status. Control variables are the logarithmized public health care expenditures per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, and the share of individuals with age > 65.

The effect of changes in COVID-19 infections is again highly significant and positive. The estimation results concerning the Stringency Index, GDP per capita and their interaction are in line with the results presented in Figures 6 to 9: The direct effects of GDP per capita and the Stringency Index are significantly positive, while the interaction effect between those two variables is significantly negative. Interpreting the marginal effect of the Stringency Index conditional on the average development status of countries in our sample, a one standard deviation increase in lockdown restrictiveness is associated with a reduction in the growth rate of new COVID-19 related deaths by 8.5 percentage points. Consistently, the effectiveness of a lockdown is partly driven by the economic development status of a country. Nevertheless, our results suggest that the public health care system is one main pillar in the pandemic control, represented by the higher marginal effects. The estimates support the hypothesis in the beginning of this paper (Figure 3): In developing countries, the development level is a good proxy for the public health care system. This relationship changes when GDP per capita increases and the dispersion in public health care spending becomes stronger. Consequently, at a certain level of income, the expenditures per capita in the public health system make a difference in the effectiveness of lockdown measures.

Based on the marginal effects calculated in Figures 6 to 10 we can summarize that investments in the public health care system support the effectiveness of lockdown measures and strengthen the reduction in COVID-19 death rates. Additionally, we can show that a private health care system does not necessarily compensate for a public health care system. Having a sizeable private health sector relative to public health care can diminish the effect and the reduction in death rates.

Disentangle the effectiveness of specific lockdown measures

We substitute the composite lockdown variable (Stringency Index) from the benchmark regressions by individual lockdown indicators. Table A.8 in the Appendix presents the results in a country fixed-effects regression including all lockdown categories[16] separately. In compliance with the results depicted in Table A.8, lockdown measures associated with a high effectiveness on changes in cases and deaths are the closure of schools and work places, and the cancellation of public events.

Interaction results between the significant categories and health are presented in Table 2. The table is structured as follows: each regression includes all lockdown measures that were significant in Table A.8 and the coefficients for the interaction with public health care quality or economic development.

[16] These include eight categories: school closing, workplace closing, cancel public events, restriction on gatherings, close public transport, stay at home requirements, restrictions on internal movements, and international travel controls. The categories are included as dummy variables in the regression.

Table 2: *Compare interactions effects between lockdown and diverse health care expenditure measures*

	$\Delta log(COVID-19\ deaths)$					
	(1)	(2)	(3)	(4)	(5)	(6)
$C1_{w-4}$ - school closing						
$C1_{w-4}$	0.121 (0.12)	0.103 (0.12)	0.003 (0.06)	-0.130** (0.05)	0.139 (0.16)	0.365 (0.25)
$\times adj.\ HE$	-0.044** (0.02)					
$\times pub.\ HE$		-0.038** (0.02)				
$\times weight.\ HE$			-0.039***(0.01)			
$\times \frac{private}{public} HE$				0.008 (0.03)		
$\times HAQI$					-0.370* (0.21)	
$\times GDP$						-0.051* (0.03)
C2 - workplace closing						
$C2_{w-4}$	0.170 (0.14)	0.176 (0.13)	0.018 (0.06)	-0.119***(0.04)	0.519** (0.23)	0.959***(0.32)
$\times adj.\ HE$	-0.047** (0.02)					
$\times pub.\ HE$		-0.043**				
$\times weight.\ HE$			-0.031** (0.01)			
$\times \frac{private}{public} HE$				0.006 (0.02)		
$\times HAQI$					-0.818***(0.29)	
$\times GDP$						-0.109***(0.03)
C3 - cancel public events						
$C3_{w-4}$	0.155 (0.14)	0.170 (0.13)	0.011 (0.07)	-0.181***(0.05)	0.249 (0.19)	0.608** (0.31)
$\times adj.\ HE$	-0.052** (0.02)					
$\times pub.\ HE$		-0.049** (0.02)				
$\times weight.\ HE$			-0.040** (0.02)			
$\times \frac{private}{public} HE$				0.053** (0.03)		
$\times HAQI$					-0.508** (0.25)	
$\times GDP$						-0.077** (0.03)
C4 - restrictions on gatherings						
$C4_{w-4}$	0.106 (0.13)	0.130 (0.12)	0.099 (0.06)	-0.038 (0.05)	0.245 (0.19)	0.087 0.31
$\times adj.\ HE$	-0.017 (0.02)					
$\times pub.\ HE$		-0.018 (0.02)				
$\times weight.\ HE$			-0.022 (0.01)			
$\times \frac{private}{public} HE$				0.041 (0.03)		
$\times HAQI$					-0.278 (0.24)	
$\times GDP$						-0.007 (0.03)
C6 - stay at home requirements						
$C6_{w-4}$	0.089 (0.17)	0.097 (0.15)	-0.001 (0.08)	-0.083* (0.05)	0.060 (0.22)	0.199 (0.34)
$\times adj.\ HE$	-0.023 (0.03)					
$\times pub.\ HE$		-0.023 (0.02)				
$\times weight.\ HE$			-0.010 (0.02)			
$\times \frac{private}{public} HE$				0.035 (0.03)		
$\times HAQI$					-0.105 (0.28)	
$\times GDP$						-0.025 (0.03)
constant	0.843***(0.12)	0.823***(0.12)	0.796***(0.12)	0.855***(0.13)	1.235***(0.36)	0.843***(0.12)
Number of obs.	4273	4358	4273	4358	4692	4358
R within	0.186	0.182	0.190	0.177	0.174	0.182
adj. R	0.176	0.173	0.180	0.167	0.165	0.172

Standard errors are in parentheses. Significance levels are * p<0.10, ** p<0.05, *** p<0.010. The dependent variable is changes in logarithmized new COVID-19 deaths per one million residents. Regressors are different lockdown categories: $C1$ = school closing, $C2$ = workplace closing, $C3$ = cancel public events, $C4$ = restrictions on gatherings, and $C6$ = strict stay at home orders. In each regression we include country and time fixed-effects. Specifications differ in the application of public health care expenditures. Health care expenditures in columns (1) to (3) are logarithmized per capita expenditures. In column (1) public health care expenditures adjusted by demographic factors, *adj. HE*. Results in column (2) are estimated using unadjusted public health care expenditures, *pub. HE*. We weight public health expenditures by the share of elderly in the specification presented in column (3), *weight. HE*. The estimation results depicted in column (4) and (5) include private relative to public health care expenditures, $\frac{private}{public} HE$, and the Health care Access & quality Index, $HAQI$, respectively. Results in column (6) are estimated including the logarithmized GDP per capita, GDP, as a proxy for economic development.

In column (1) our demographically adjusted health care expenditures find application. Column (2) presents the results using unadjusted public health care expenditures per capita. Results estimating the effects under the consideration of health care expenditures weighted by the share of population younger than 65 years are depicted in column (3). Columns (4) and (5) show the results for the ratio between private and public health care expenditures (column (4)) and the Health care Access & Quality Index (column (5)), respectively. Column (6) presents the coefficients estimated in the model with GDP per capita. Each regression is conducted using country fixed-effects to control for country-specific unobserved heterogeneity and time fixed-effects to control for a time trend.

The results in Table 2 are in line with the results obtained in estimations applying the stringency index. School and workplace closures as well as cancellation of public events are lockdown measures associated with a reduction in the growth rate of new COVID-19 deaths conditional on the prevailing health care system. The direct effects are insignificant but the interaction terms are significantly negative in almost specifications. To evaluate the effect we plot the marginal effect of school and workplace closures as well as the cancellation of public events conditional in the demographically adjusted public health care status in Figure A.2.

The marginal effects plotted in Figure A.2 suggest that lockdown measures only work effectively if the government provides a minimum level of public health care. Consistently, we are able to draw the conclusion, that the effectiveness of lockdown policies are magnified by a well funded health care system. Economies with levels of per capita public health expenditures below the mean do not benefit from lockdown policies. These results support the insights presented in figures 7 to 10.[17]

6. Conclusion

This paper investigated the effectiveness of different lockdown policies and their relationship with national spending on health care. A well funded public health

[17]The graphical presentation of the marginal effects of the categories "restriction on gatherings" and "stay at home orders" can be found in Figure A.3 in the Appendix.

care system supports the effectiveness of lockdown measures. This finding can be rationalized as highlighted in the introduction and the literature review. An improved access to health care decreases the risk for a severe course of disease following a COVID-19 infection and improves the survival rates for severe cases, which magnifies the pass-through from reduced infections due to the lockdown to mortality rates. More generally, a good health system helps enforcing lockdown rules. Our results support these hypothesizes.

One methodological contribution of our study is proposing a fixed-effects estimation strategy that addresses cross-country differences. This strategy allows inference of the results for a large set of countries that differ with respect to many unobserved factors.

Notably, we found that there is a "minimum-level" of health expenditure at which the marginal effect of lockdown measures turns significant. This suggests that a lockdown becomes effective when a certain level of health care infrastructure is guaranteed. Especially developing countries may have difficulties reaching this critical level due to budget constraints. Developed countries have more scope for devoting larger shares of their GDP to the health sector but we observe that per capita GDP and per capital health expenditures are far from being perfect substitutes in high-income countries.

We also examine the role of more specialized lockdown measures such as school and work place closings in an extension. These findings show that the effects of individual policies are rarely significant. This should not be taken as evidence against the effectiveness of individual lockdown measures. Lockdown measures are usually implemented simultaneously, which makes it difficult to isolate the statistical effects of specific measures. Instead, these findings suggest that the joint implementation of various lockdown measures in combination with the public health care system decisively influence the course of the pandemic.

Our finding that the effectiveness of a lockdown is increasing in the level of health expenditure is robust to different specifications of health care spending. Overall, our results allow concluding that strict lockdown measures are an effective instrument of limiting negative consequences for health. In the long run, economic development combined with the provision of a well funded, effective and high quality public health care system are the more important determinants in the pandemic. Development strategies and investments in prevention of future pandemics in both developing and developed countries should be focusing more on strengthening the public health care sector.

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A. Descriptives & Definitions

Table A.1: *List of Countries*

Nr.	Country Name	Nr.	Country Name	Nr.	Country Name
1	Algeria	54	Guinea	107	Romania
2	Angola	55	Haiti	108	Russia
3	Argentina	56	Honduras	109	Rwanda
4	Australia	57	Hungary	110	Senegal
5	Austria	58	Iceland	111	Serbia
6	Azerbaijan	59	India	112	Seychelles
7	Bahrain	60	Indonesia	113	Sierra Leone
8	Bangladesh	61	Iran	114	Singapore
9	Barbados	62	Ireland	115	Slovak Republic
10	Belarus	63	Israel	116	Slovenia
11	Belgium	64	Italy	117	South Africa
12	Belize	65	Jamaica	118	South Korea
13	Benin	66	Japan	119	Spain
14	Buthan	67	Jordan	120	Sri Lanka
15	Bolivia	68	Kazakhstan	121	Sudan
16	Bosnia and Herzegovina	69	Kenya	122	Suriname
17	Botswana	70	Kuwait	123	Sweden
18	Brazil	71	Kyrgyz Republic	124	Switzerland
19	Bulgaria	72	Latvia	125	Tajikistan
20	Burkina Faso	73	Lebanon	126	Tanzania
21	Cambodia	74	Lesotho	127	Thailand
22	Cameroon	75	Liberia	128	Togo
23	Canada	76	Lithuania	129	Trinidad and Tobago
24	Cape Verde	77	Luxembourg	130	Tunisia
25	Central African Republic	78	Madagascar	131	Turkey
26	Chad	79	Malawi	132	Uganda
27	Chile	80	Malaysia	133	Ukraine
28	China	81	Mali	134	United Arab Emirates
29	Colombia	82	Mauritania	135	United Kingdom
30	Congo	83	Mauritius	136	United States
31	Costa Rica	84	Mexico	137	Uruguay
32	Côte d'Ivoire	85	Moldova	138	Uzbekistan
33	Croatia	86	Mongolia	139	Venezuela
34	Cyprus	87	Morocco	140	Vietnam
35	Czech Republic	88	Mozambique	141	Zambia
36	Denmark	89	Myanmar	142	Zimbabwe
37	Djibouti	90	Namibia		
38	Dominican Republic	91	Nepal		
39	Ecuador	92	Netherlands		
40	Egypt	93	New Zealand		
41	El Salvador	94	Nicaragua		
42	Estonia	95	Niger		
43	Ethiopia	96	Nigeria		
44	Fiji	97	Norway		
45	Finland	98	Oman		
46	France	99	Pakistan		
47	Gabon	100	Panama		
48	Gambia	101	Paraguay		
49	Georgia	102	Peru		
50	Germany	103	Philippines		
51	Ghana	104	Poland		
52	Greece	105	Portugal		
53	Guatemala	106	Qatar		

Table A.2: *Descriptive Statistics*

	Obs.	Mean	Std. Dev.	Min	Max
COVID-19 indicators					
Δlog *Deaths*	4738	0.119	0.754	-7.646	8.117
Δlog *Cases*	6300	0.176	0.705	-3.515	6.362
health care expenditure and quality measures					
ln(adj. public health expenditures)	6916	5.344	1.540	1.153	7.982
ln(public health expenditures)	7326	5.771	1.781	1.683	8.625
ln(weighted public health expenditures)	6903	3.132	2.389	-1.881	6.947
private/public health expenditures	7326	1.209	1.299	0.054	5.973
health care Access and Quality Index	7900	0.730	0.144	0.382	0.916
Lockdown measures					
stringency index	7659	52.872	27.552	0	100
C1 - school closing	7443	0.420	0.494	0	1
C2 - workplace closing	7393	0.114	0.317	0	1
C3 - cancel public events	7394	0.587	0.492	0	1
C4 - restrictions on gatherings	7393	0.322	0.467	0	1
C5 - close public transport	7395	0.150	0.357	0	1
C6 - stay at home requirements	7392	0.318	0.466	0	1
C7 - restrictions on internal movements	7436	0.373	0.484	0	1
C8 - international travel controls	7438	0.596	0.491	0	1
Macroeconomic determinants					
ln(GDP p.c.)	7326	9.360	1.208	6.581	11.765
(import+export)/GDP	7280	0.598	0.438	0.032	2.627
share in population age>65	7185	8.823	6.356	1.035	27.109
N	7913				

Table A.3: *Category definition - policy measures*

Category	Category name	Category description and coding
C_1	*school closing*	$C_1 = 0$: no measures $C_1 = 1$: recommend closing, or all school open with alterations resulting in significant differences compared to usual. $C_1 = 2$: require closing (some levels or categories) $C_1 = 3$: require closing all levels
C_2	*workplace closing*	$C_2 = 0$: no measures $C_2 = 1$: require closing (or work from home) $C_2 = 2$: require closing (or work from home) for some sectors or worker categories $C_2 = 3$: require closing (or work from home) all-but-essential workplaces
C_3	*cancel public events*	$C_3 = 0$: no measures $C_3 = 1$: recommend cancelling $C_3 = 2$: require cancelling
C_4	*restrictions on gatherings*	$C_4 = 0$: no measures $C_4 = 1$: restrictions on gatherings above 1000 people $C_4 = 2$: restrictions on gatherings between 101 - 1000 people $C_4 = 3$: restrictions on gatherings between 11 - 100 people $C_4 = 4$: restrictions on gatherings of 10 people or less.
C_5	*close public transport*	$C_5 = 0$: no measures $C_5 = 1$: recommend closing (or significantly reduce volume) $C_5 = 2$: require closing (or prohibit most citizens from using it)
C_6	*stay at home requirements*	$C_6 = 0$: no measures $C_6 = 1$: recommend not leaving home $C_6 = 2$: require not leaving home with exceptions for daily exercise, grocery shopping, and 'essential' trips $C_6 = 3$: require not leaving home with minimal exceptions
C_7	*restrictions on internal movement*	$C_7 = 0$: no measures $C_7 = 1$: recommend not to travel between regions/cities $C_7 = 2$: internal movement restrictions in place
C_8	*International travel controls*	$C_8 = 0$: no measures $C_8 = 1$: Screening $C_8 = 2$: Quarantine arrivals from high-risk regions $C_8 = 3$: Ban on arrivals from some regions $C_8 = 4$: Ban on all regions or total border closure
H_1	*Public information campaigns*	$H_1 = 0$: No COVID-19 public information campaign $H_1 = 1$: public officials urging caution about COVID-19 $H_1 = 2$: coordinated public information campaign (e.g. across traditional and social media)

B. Robustness Checks

Table A.4: *Alternative measure of public health care system quality - log(unadjusted health expenditures)*

	$\Delta log(cases)$		$\Delta log(deaths)$	
	(1)	(2)	(3)	(4)
$\Delta log(cases_{w-2})$			0.282***	0.256***
			(0.03)	(0.03)
SI_{w-2}	-0.003***	-0.008***		
	(0.00)	(0.00)		
SI_{w-4}			-0.002**	-0.005***
			(0.00)	(0.00)
log(adj. HE)	0.004		0.010	
	(0.01)		(0.02)	
log(GDP p.c.)	-0.021		-0.004	
	(0.02)		(0.03)	
(import+export)/GDP	-0.049**		-0.019	
	(0.02)		(0.03)	
Share of individuals age >65	0.001		-0.000	
	(0.00)		(0.00)	
Constant	0.563***	0.454***	0.599*	0.797***
	(0.20)	(0.16)	(0.32)	(0.23)
Number of obs.	5593	5593	4229	4229
R within	0.319	0.335	0.189	0.193
adj. R	0.313	0.330	0.179	0.184

Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) and (2) is the change in logarithmized COVID-19 cases per one million residents. In column (3) and (4) the dependent variable is the changes in logarithmized new COVID-19 deaths per one million residents. Regressors are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, the share of individuals with age > 65 and unadjusted logarithmized public health care expenditures, $ln(unadj. HE$. The lockdown variable is defined by the Stringency Index, SI.

Table A.5: *Alternative measure of public health care system quality - log(weighted health expenditures)*

	$\Delta log(cases)$		$\Delta log(deaths)$	
	(1)	(2)	(3)	(4)
$\Delta log(cases_{w-2})$			0.282***	0.256***
			(0.03)	(0.03)
SI_{w-2}	-0.003***	-0.008***		
	(0.00)	(0.00)		
SI_{w-4}			-0.002**	-0.005***
			(0.00)	(0.00)
$log(weight.\ HE)$	0.005		0.010	
	(0.01)		(0.02)	
log(GDP p.c.)	-0.021		-0.004	
	(0.02)		(0.03)	
(import+export)/GDP	-0.049**		-0.019	
	(0.02)		(0.03)	
Share of individuals age >65	0.001		-0.000	
	(0.00)		(0.00)	
Constant	0.564***	0.454***	0.600*	0.797***
	(0.20)	(0.16)	(0.32)	(0.23)
Number of obs.	5593	5593	4229	4229
R within	0.319	0.335	0.189	0.193
adj. R	0.313	0.330	0.179	0.184

Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) to (3) is the change in logarithmized COVID-19 cases per one million. In column (4) to (6) the dependent variable is the changes in logarithmized new COVID-19 deaths per one million. Regressors are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, the share of individuals with age > 65 and the logarithmized public health care expenditures weighted by the share of population younger than 65 years, $ln(weight.\ HE)$. The lockdown variable is defined by the Stringency Index, SI.

Table A.6: *Alternative measure of public health care system quality - private/public health care expenditures)*

	$\Delta log(cases)$		$\Delta log(deaths)$	
	(1)	(2)	(3)	(4)
$\Delta log(cases_{w-2})$			0.282***	0.256***
			(0.03)	(0.03)
SI_{w-2}	-0.003***	-0.008***		
	(0.00)	(0.00)		
SI_{w-4}			-0.002**	-0.005***
			(0.00)	(0.00)
private/public HE	0.002		-0.007	
	(0.01)		(0.01)	
log(GDP p.c.)	-0.014		0.005	
	(0.01)		(0.01)	
(import+export)/GDP	-0.048**		-0.020	
	(0.02)		(0.03)	
Share of individuals age >65	0.001		-0.000	
	(0.00)		(0.00)	
Constant	0.524***	0.454***	0.579*	0.797***
	(0.19)	(0.16)	(0.30)	(0.23)
Number of obs.	5593	5593	4229	4229
R within	0.319	0.335	0.189	0.193
adj. R	0.313	0.330	0.179	0.184

Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) to (3) is the change in logarithmized COVID-19 cases per one million. In column (4) to (6) the dependent variable is the changes in logarithmized new COVID-19 deaths per one million. Regressors are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, the share of individuals with age > 65 and private relative to public health care expenditures, $private/public\ health\ expenditures$. The lockdown variable is defined by the Stringency Index, SI.

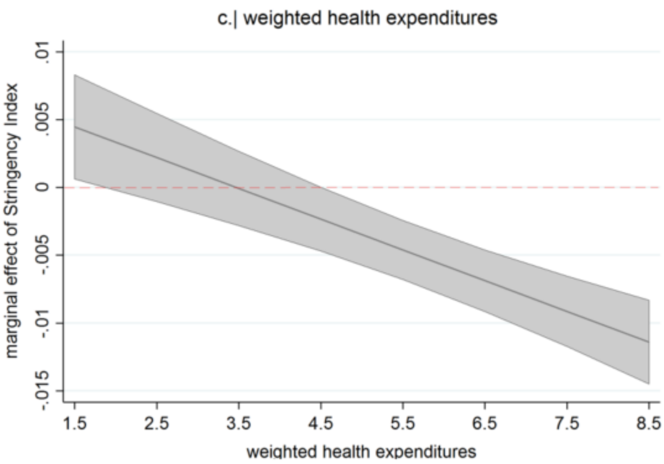
Table A.7: *Alternative measure of public health care system quality - health care Access & Quality Index*

	$\Delta log(cases)$		$\Delta log(deaths)$	
	(1)	(2)	(3)	(4)
$\Delta log(cases_{w-2})$			0.281***	0.256***
			(0.03)	(0.03)
SI_{w-2}	-0.003***	-0.008***		
	(0.00)	(0.00)		
SI_{w-4}			-0.002***	-0.005***
			(0.00)	(0.00)
HAQI	0.379**		0.348	
	(0.17)		(0.24)	
log(GDP p.c.)	-0.051***		-0.025	
	(0.02)		(0.03)	
(import+export)/GDP	-0.046**		-0.014	
	(0.02)		(0.03)	
Share of individuals age >65	-0.001		-0.002	
	(0.00)		(0.00)	
Constant	0.614***	0.454***	0.621**	0.797***
	(0.18)	(0.16)	(0.30)	(0.23)
Number of obs.	5593	5593	4229	4229
R within	0.320	0.335	0.189	0.193
adj. R	0.314	0.330	0.180	0.184

Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) to (3) is the change in logarithmized COVID-19 cases per one million. In column (4) to (6) the dependent variable is the changes in logarithmized new COVID-19 deaths per one million. Regressors are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, the share of individuals with age > 65 and the health care Access & Quality Index, $HAQI$. The lockdown variable is defined by the Stringency Index, SI.

C. Disentangle Lockdown Effects

Figure A.1: *Marginal Effects with Interaction: Stringency & actual health care expenditures*



Dependent variable: $\Delta log(COVID-19\ deaths)$	(1)	(2)
$\Delta log(COVID-19\ cases)_{w-2}$	0.265***	0.236***
	(0.03)	(0.03)
log(weight. HE)	0.147***	
	(0.04)	
SI_{w-4}	0.009***	0.008***
	(0.00)	(0.00)
$log(pub.\ HE) \times SI_{w-4}$	0.002***	-0.002***
	(0.00)	(0.00)
log(GDP p.c.)	-0.021	
	(0.03)	
(Import+Export)/GDP	-0.030	
	(0.03)	
Share of individuals age>65	-0.004*	
	(0.00)	
Constant	-0.132	0.656***
	(0.31)	(0.18)
Marginal Effect at mean (5.720) = -0.003		
time FE	x	x
country FE		x
Number of obs.	4229	4229
R within	0.195	0.200
adj. R	0.186	0.191

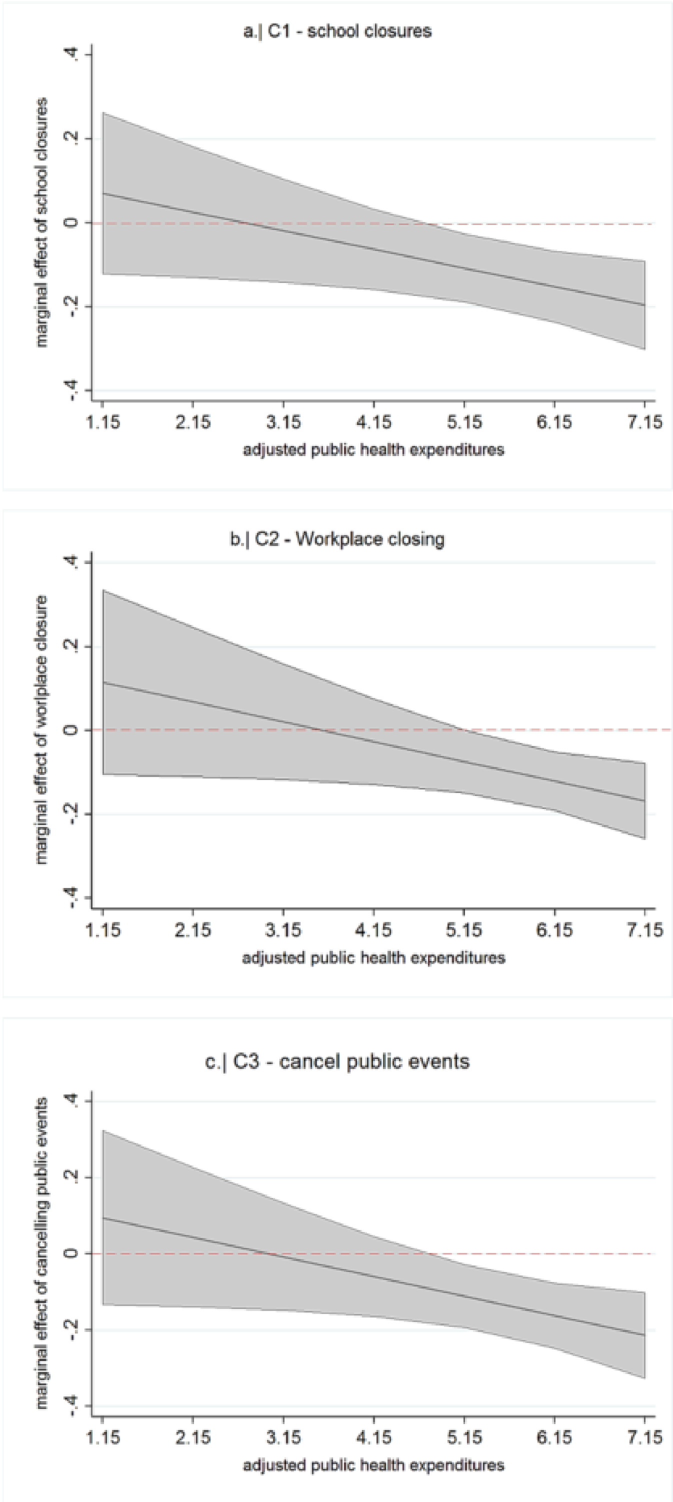
Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The lockdown strength is quantified with the stringency index. SI. Public health care expenditures are weighted by the share population younger than 65 years, ($ln(weigh.\ pub.\ HE)$) and approximate health care system quality. Control variables are the logarithmized GDP per capita, $ln(GDPp.c.)$, the share of imports + exports over the GDP, $(import + export)/GDP$, and the share of individuals with age > 65.

Table A.8: *Regression results including 8 lockdown variables separately*

	(1) $ln(\Delta cases)$ b/se	(2) $ln(\Delta deaths)$ b/se
$\Delta cases_{w-2}$		0.247***
		(0.03)
school closing$_{w-2}$	-0.127***	
	(0.03)	
school closing$_{w-4}$		-0.092***
		(0.03)
workplace closing$_{w-2}$	-0.089***	
	(0.03)	
workplace closing$_{w-4}$		-0.083***
		(0.03)
cancel public events$_{w-2}$	-0.147***	
	(0.03)	
cancel public events$_{w-4}$		-0.096***
		(0.03)
restrictions on gatherings$_{w-2}$	-0.062**	
	(0.03)	
restrictions on gatherings$_{w-4}$		0.008
		(0.03)
close public transport$_{w-2}$	0.044	
	(0.04)	
close public transport$_{w-4}$		0.020
		(0.03)
stay at home requirements$_{w-2}$	-0.074***	
	(0.03)	
stay at home requirements$_{w-4}$		-0.024
		(0.03)
restrictions on internal movements$_{w-2}$	0.060**	
	(0.03)	
restrictions on internal movements$_{w-4}$		0.015
		(0.03)
international travel controls$_{w-2}$	0.019	
	(0.03)	
international travel controls$_{w-4}$		0.051*
		(0.03)
constant	0.396**	1.136***
	(0.15)	(0.40)
Number of obs.	6171	4622
R within	0.304	0.178
adj. R	0.298	0.169

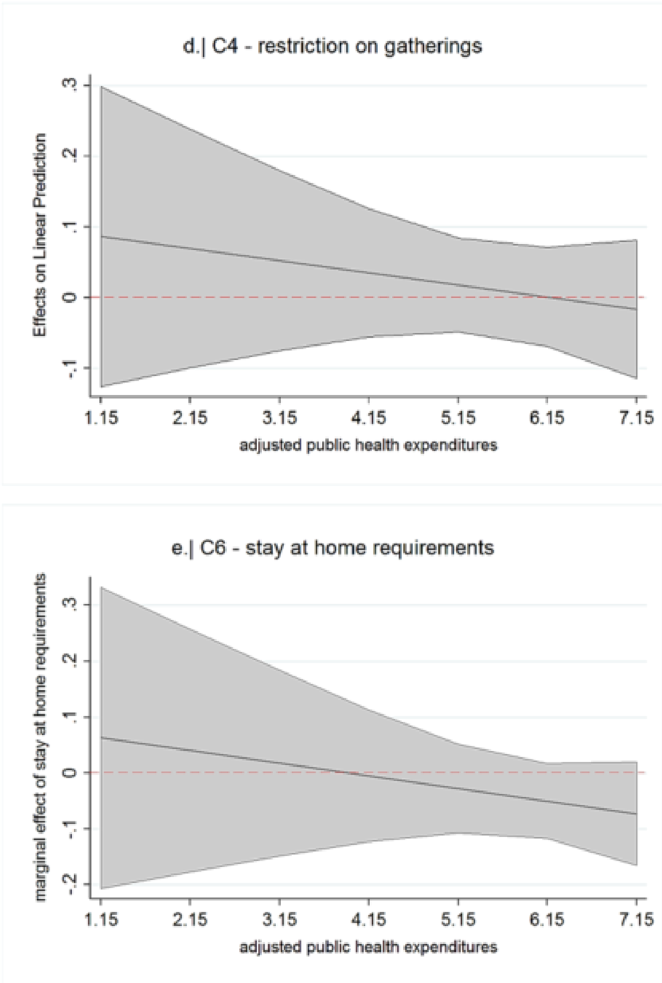
Standard errors are declared in parentheses. Significance levels are defined: * p<0.10, ** p<0.05, *** p<0.010. The dependent variable in column (1) is logarithmized changes in new COVID-19 cases per one million. In column (2) the dependent variable is logarithmized changes in new COVID-19 deaths per one million. Regressors are different lockdown categories: school closing, workplace closing, cancel public events, restrictions on gatherings, close public transport, stay at home orders, restrictions on internal movements and international travel controls. Additionally, logarithmized changes in cases with a two week delay find application in column (2). In every regression we control for country-specific unobserved heterogeneity and the time trend, including country- and time fixed-effects.

Figure A.2: *Marginal Effects of school & workplace closures and public event cancellation conditional on health expenditures*



Marginal effects are calculated based on the specification depicted in column (1) of Table 2.

Figure A.3: *Marginal Effects of restriction on gatherings & stay at home orders conditional on health expenditures*



Marginal effects are calculated based on the specification depicted in column (1) of Table 2.