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Policy Stringency, Handwashing and COVID-19 cases: Evidence from Global dataset

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ABSTRACT

Objective: : Since the COVID-19 pandemic, many governments globally have introduced policy measures to contain the spread of the virus. Popular COVID-19 containment measures include lockdowns of various forms (aggregated into government response stringency index [GRSI]) and handwashing (HWF). The effectiveness of these policy measures remains unclear in the academic literature. This study, therefore, examines the effect of government policy stringency and handwashing on total daily reported COVID-19 cases.
Method: : We use a comprehensive dataset of 176 countries to investigate the effect of government policy stringency and handwashing on daily reported COVID-19 cases. In this study, we apply the Lewbel (2012) two-stage least squares technique to control endogeneity.
Results: : Our results indicated that GRSI significantly contributes to the increase in the total and new confirmed cases of COVI-19. Sensitivity analyses revealed that the 1st, 4th, and 5th quintiles of GRIS significantly reduce total confirmed cases of COVID-19. Also, the result indicated that while the 1st quintile of GRIS contributes significantly to reducing the new confirmed cases of COVID-19, the 3rd, 4th, and 5th quintiles of GRSI contribute significantly to increasing the new confirmed cases of COVID-19. The results indicated that HWF reduces total and new confirmed cases of COVID-19; however, such effect is not robust to income and regional effects. Nonlinear analysis revealed that while GRSI has an inverted U-shaped relationship with total and new confirmed cases of COVID-19, HWF has a U-shaped relationship.
Conclusion: : We suggest that policymakers should focus on raising awareness and full engagement of all members of society in implementing public health policies rather than using stringent lockdown measures.

Introduction

On 12 March 2020, the World Health Organisation [WHO] declared the novel coronavirus disease 2019 (COVID-19) as a pandemic [1]. Thus, the outbreak of COVID-19 in Wuhan, China, has now spread its tentacles globally, with over 83 million people affected and over 1.8 million deaths as of 3rd January 2021 [2]. The COVID-19 pandemic has not only claimed lives but has resulted in recession or contraction in economic growth, a surge in the unemployment rate, reduction in stock market activities and international trade [3,4]. It is argued that the development of safe and efficacious vaccines can contribute to controlling the spread of the COVID-19 [5,6]. Therefore, an effort to quicken the development of vaccines to fight against the spread of COVID-19 remains public health priority [7]. For instance, as of mid-December 2020, more than 200 COVID-19 vaccines candidates are in development, and only 11 have entered phase III clinical trials [8].

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However, only two of the COVID-19 vaccines—the adenovirus-vectored vaccine (University of Oxford/AstraZeneca) and one messenger RNA vaccine (BioNTech/Pfizer) — have published interim efficacy results [5, 6,8].

There are some challenges and uncertainties in vaccines' development and global distribution for curbing the spread of COVID-19. Some scholars such as McIntyre, Joo [8] raise uncertainties about the vaccines by raising the following question: How well will some of those at the highest risk of severe diseases be protected by a vaccine, and for how long? Further, to what extent will vaccination protect against infection? Also, Calina, Docea [7] noted that the most difficult challenge for future vaccines is proof of clinical safety and efficacy. The authors further indicated that the biggest challenge of vaccine manufacturing is the construction and validation of production platforms capable of making the vaccine on a large scale. These and many other challenges of the vaccines raise the question of whether it is imperative for countries to continue observing the public and health measures to contain the spread of the Covid-19. Thus, to mitigate the impact of the COVID-19 pandemic, WHO provided some public and health measures such as social distancing, wearing of nose masks, proper handwashing, etc., that countries should implement. These public and health measures are the actions that individuals, governments, institutions, communities, local, national, and international bodies should observe to slow or stop the spread of the COVID-19 [2,9].

After WHO directives, many governments have introduced health, social, and physical policy measures — school closure, workplace closure, restriction on internal movement, cancellation of public events, restrictions on gatherings, public transport closure, stay-at-home requirements, and handwashing to contain the spread of the virus. These policy measures, also known as lockdown measures, seek to slow the spread of the virus by stopping a chain of transmission of COVID-19 and preventing new ones from spreading. However, the media, academics and policymakers have questioned the effectiveness of these policy measures on the spread of COVID-19. For instance, Abrams and Szefler [10] argue that these physical and social policy measures are difficult for individuals with adverse socio-economic determinants and might contribute to both short- and long-term morbidity. To support this argument, Abrams and Szefler [10], as well as Tsai and Wilson [11], indicated that people who are homeless are at higher risk of contracting infectious diseases like COVID-19 during a physical lockdown, especially when public spaces are closed, thereby leading to over-crowding and subsequent worsening the spread of COVID-19.

Some experts argue that socio-economic factors play a key role in the spread of the virus. Because of this, some researchers have been examining the effect of socio-economic factors on the spread of COVID-19 [3, 12-14]. However, the academic literature has paid little attention to the effectiveness of government policy measures and personal hygiene on the spread of COVID. Also, during the outbreak of COVID-19, handwashing has featured strongly in public health policy as a primary preventive measure [15,16]; however, limited studies exist on the effectiveness of handwashing in limiting the spread of the COVID-19.

Therefore, scholars need to provide empirical evidence on whether government policy response measures (hereafter lockdown measures) and handwashing prevent and control the spread of COVID-19. Some studies have attempted to examine the effect of handwashing and lockdown measures on the spread of the COVID-19 [17–20]. However, these studies have only examined the linear effect of these measures on COVID-19 without probing the nonlinear and interactive effects of these measures on the spread of the COVID-19. Also, the existing studies have employed cross-sectional data, and their estimation techniques failed to address the endogeneity inherent in their empirical models. The limitation of the cross-sectional data approach is that the estimates cannot be interpreted as causality, and the failure to control for endogeneity could bias the estimates. Also, the existing studies have not provided evidence on how differences in handwashing and government policy response measures across different income groups and regions affect the spread of the COVID-19 globally. Motivated by these research gaps, this study poses the question of whether government policy response measures and handwashing have effectively reduced COVID-19 cases. Therefore, our paper empirically investigates the effect of government policy response measures and handwashing on COVID-19 cases using a comprehensive dataset of 176 countries.

This study contributes to the literature in the following directions. First, we contribute to the literature on the effectiveness of governments policies in limiting the spread of diseases. Previous studies on the prevalence of influenza have revealed that policy measures such as reducing interpersonal contact, school closure, public transport strikes and controlling travellers from high-incidence locations were effective in reducing the spread of influenza [21–23]. While the effectiveness of these policy measures comes entirely from the outbreak of influenza, it is unclear if these measures would be effective for limiting the spread of COVID-19 [24,25]. Because of this, our study provides empirical evidence on the linear, nonlinear, and interactive effect of government policy response measures and handwashing on the number of COVID-19 cases globally. Second, unlike the existing studies, our study further added to the literature by empirically probing how differences in handwashing and government policy response measures across different income groups and regions affect the spread of the COVID-19 globally. Our study further extends the literature by conducting sensitivity analysis to determine the level of government policy response stringency, which is appropriate for curbing the spread of the COVID-19. Third, our paper contributes to the literature on the socio-economic variables that influence the spread of COVID. In doing so, this study examines if the difference in economic development and regional difference affects the spread of COVID-19. These make our study timely and distinct.

Using the panel data approach and Lewbel [26] two-staged least squares approach to control endogeneity, our results indicated that GRSI significantly contributes to the increase in the total and new confirmed cases of COVI-19. Sensitivity analyses revealed that the 1st, 4th, and 5th quintiles of GRIS significantly reduce total confirmed cases of COVID-19. Also, the result indicated that while the 1st quintile of GRIS contributes significantly to reducing the new confirmed cases of COVID-19, the 3rd, 4th, and 5th quintiles of GRSI contribute significantly to increasing the new confirmed cases of COVID-19. The results indicated that HWF reduces total and new confirmed cases of COVID-19; however, such effect is not robust to income and regional effects. Nonlinear analysis revealed that while GRSI has an inverted U-shaped relationship with total and new confirmed cases of COVID-19, HWF has a U-shaped relationship.

Review of related literature

The hands are an essential medium for transmitting microorganisms [27]; therefore, failure to wash the hands properly can result in the transition of microorganisms [28]. The outbreak of the COVID-19 has led to the introduction of many public health measures to contain the transmission of the virus. Among the public health measures, the WHO strongly recommended proper handwashing measures to curb the spread of COVID-19. Handwashing with soap and running water and using alcohol-based hand sanitiser's with a minimum of 60% alcohol when you can't use soap and water is the first public health measure controlling the spread of COVID-19 [28,29]. Although handwashing is important, Kumar, Kumar [29] and Rundle, Presley [17] highlighted that the use of soap and hand sanitisers have an adverse effect on the skin barrier leading to an increased incidence of skin changes. Thus, excessive skin dryness or contact dermatitis are negative dermatological impacts of handwashing, especially in individuals with a history of atopic disease dermatitis [29].

Although handwashing has an adverse dermatological effect, empirical studies have indicated that handwashing contributes significantly to limiting the spread of COVID-19. For instance, Ahmed and Yunus [30] used cross-sectional data to examine the prevalence and factors associated with household handwashing practice in Bangladesh and further explore the correlation between handwashing and the spread of COVID-19 spreads. The study revealed that the overall prevalence of household handwashing was found 56.3%, and the prevalence was significantly varied across the socio-economic status of the households. Using map comparison, the authors indicated the gradually increasing trend of COVID-19 cases in areas where handwashing is low. Specifically, the authors showed that the northern part of Bangladesh had the highest handwashing practice, whereas it had less affected by COVID-19 cases. However, central Bangladesh was hardest hit by COVID-19 cases, and it had around 50% handwashing practice coverage.

Besides handwashing, many governments have introduced policy response measures to curb the transmission of the COVID-19. These measures include school closings, travel restrictions, bans on public gatherings, emergency investments in healthcare facilities, new forms of social welfare provision, contact tracing and other interventions [31]. Conceptually, these policy response measures are mostly to mandate people to stay indoors in the event of an outbreak while flattening the curve of the novel virus [20]. One strand of the literature suggests that the government policy response measures have effectively reduced the number of COVID-19 cases [20]. Contrarily, others argue that strict government response measures could increase the number of COVID-19 cases and death because of the severe economic implications of the measures [18,32]. The empirical findings on the impact of the government policy response on the spread of the COVID have been contradictory.

For instance, Ajide, Ibrahim [20] investigated the effect of lockdown measures on COVID-19 confirmed cases in Nigeria. Using the negative binomial estimator, the study indicated that lockdown measures such as retail and recreation, grocery and pharmacy, parks, transit stations, and workplaces significantly reduce the number of COVID-19 confirmed cases. However, the findings indicated that residential lockdown significantly increases the number of COVID-19 confirmed cases. In another study, Kumar, Priya [18] developed a model to examine how lockdown and social distancing measures have influenced the behavioural conduct of people. In their analysis, the first scenario results indicated that without any policy intervention in place, the maximum number of active cases would peak after 220 days at 180 million cases. The total number of deaths is predicted to be around 12 million, while the recoveries are around 750 million. In the second scenarios results with light and moderate interventions, respectively, the spread of the disease is slightly reduced with a peak number of active cases observed after 300 days and 380 days, respectively, and the maximum number of active cases, deaths, and recoveries are also reduced. In the third scenario with a strict policy intervention, their results indicated that the maximum number of active cases to peak after 600 days to approximately 45 million cases and the total number of deaths is predicted to be around 6 million, while the recoveries are around 400 million.

Also, Chaudhry, Dranitsaris [33] examined the effect of timing and type of policies undertaken towards COVID-19 mortality and related health outcomes in the top 50 countries. Using multivariable negative binomial regression, the study indicated that countries with higher obesity, median population age and longer time to border closures from the first reported case have a higher increasing COVID-19 caseload. Further, the results showed that increased mortality per million was significantly associated with higher obesity prevalence and economic growth, while reduced income dispersion reduced mortality and the number of critical cases. The study further highlighted that rapid border closures, full lockdowns, and widespread testing were not associated with COVID-19 mortality per million people. Chisadza, Clance [32] examined the effect of government response, economic support, and health containment on the number of COVID-19 deaths for 144 countries between March to September 2020. The results indicated that government response, economic support and health containment significantly increased the number of COVID-19 deaths. The study further indicated that government response, economic support and health containment have an inverted U-shaped relationship with the number of COVID-19 deaths.

The literature review suggests that the existing studies have only examined the linear effect of these measures on COVID-19 without probing the nonlinear and interactive effect of these measures on the spread of the COVID-19. Also, the existing studies have employed cross-sectional data, and their estimation techniques failed to address the endogeneity inherent in their empirical models. The limitation of the cross-sectional data approach is that their estimates cannot be interpreted as causality, and their failure to control endogeneity could bias their estimates. Also, the existing studies have not provided evidence on how differences in handwashing and government policy response measures across different income groups and regions affect the spread of the COVID-19 globally. Motivated by these research gaps, our study contributes to the literature by providing empirical evidence on the linear, nonlinear, and interactive effect of government policy response measures and handwashing on the number of COVID-19 cases globally. Therefore, our paper empirically investigates the effect of government policy response measures and handwashing on COVID-19 cases using a comprehensive dataset of 176 countries.

Methodology and Data

Specification of the empirical model

The cross-sectional empirical equation for estimating the effect of policy stringency and handwashing facilities on COVID-19 cases is given in equation (1) as:

$$\mathrm{lnCOVID_i} = \mathrm{a_o} + \beta_1 \mathrm{GRSI_i} + \beta_2 \mathrm{lnHWF_i} + \varepsilon_i \tag{1}$$

Given the number of reported COVID-19 cases differ among regions and income groups, we augment Eq. (1) with income and region dummy variables. The inclusion of these dummy variables in the empirical model enables us to identify which income group and region likely influence the number of COVID-19 cases. In other words, the inclusion of these dummy variables helps to account for geographical factors that are not directly controlled in the empirical model but may influence the spread of COVID-19. Also, the inclusion of the income and regional dummy variables in the model help to account for socio-economic conditions that might affect the spread of COVID-19. The inclusion of the dummy variables yields equation (2):

$$\begin{aligned}\mathrm{lnCOVID_i} = \mathrm{a_o} + \beta_1 \mathrm{GRSI_i} + \beta_2 \mathrm{lnHWF_i} + \beta_j \mathrm{Income\_Dummy_i} \\ + \beta_k \mathrm{Regional\_Dummy_i} + \varepsilon_i\end{aligned} \tag{2}$$

Where: lnCOVID, GRSIandHWFrepresent, respectively, the number of COVID-19 cases, the government response stringency index and handwashing facilities. Also, a_o denotes constant parameter. $\beta_1 ....\beta_k$ are coefficients to be estimated for GRSI, HWF, income and regional dummy variables, respectively, while ε_i is the stochastic error term.

Using the cross-sectional approach helps estimate coefficients on time-invariant variables while averaging time-varying variables across different times[1]. However, cross-sectional data are often associated with problems in modelling the common and individual behaviours of groups, causality inference, and its estimates may be biased. We overcome some of these limitations using the panel data approach. The panel data approach has numerous advantages over the cross-sectional approach. For instance, the panel data approach can model both the common and individual behaviours of groups, contains more information, variability, and efficiency than the cross-sectional data approach [34]. Therefore equations (1)-(2) are re-specify as follows:

[1] The data for this study ranges between 22/01/2020 to 06/01/2021

Table 1
Variables descriptive statistics

Variables	Definitions of variables (Measurements)	Mean	SD	Min	Max	Sources
COVID cases (COVID)	Total confirmed cases of COVID-19 per 1,000,000 people as of 6th January, 2021	4881.3	9880.623	0.001	108044	Our World in Data
Handwashing facilities (HWF)	Share of the population with basic handwashing facilities on-premises.	50.688	32.121	1.188	98.999	Our World in Data
Stringency index (GRSI)	The GRSI is a composite index measuring various lockdowns and stay at home requirements. This GRSI index ranges from 0 to 100, with 100 being the strictest response.	59.711	22.281	0	100	Our World in Data

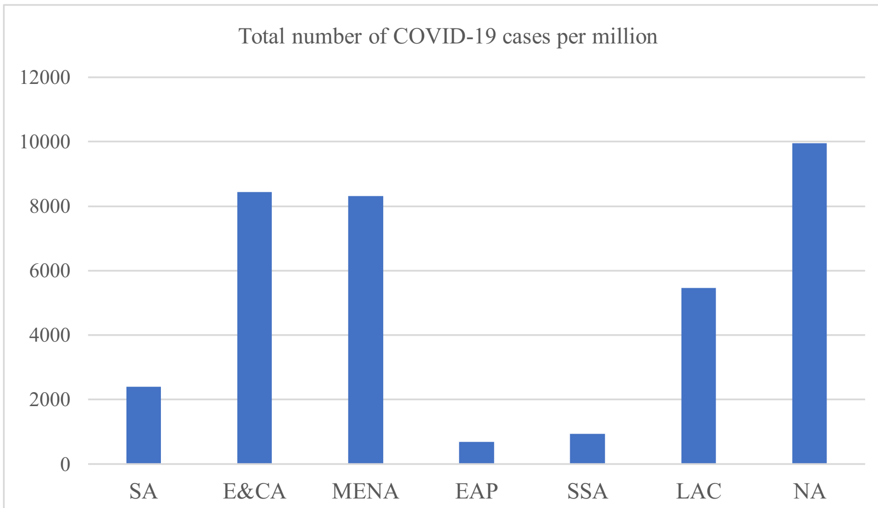

Fig. 1. number of regional COVID-19 cases per million as of 22 January 2020 to 6th January 2021

$$\ln COVID_{it} = b_o + \delta_1 GRSI_{it} + \delta_2 \ln HWF_{it} + \varepsilon_{it} \tag{3}$$

$$\ln COVID_{it} = b_o + \delta_1 GRSI_{it} + \delta_2 \ln HWF_{it} + \delta_j Income\_Dummy_i + \delta_k Regional\_Dummy_i + \varepsilon_{it} \tag{4}$$

From the above equations, $i = 1 - - - N$; $t = 1 - - - T$.Also, a_o denotes constant parameter; $\delta_1 - - - \delta_k$ are coefficients to be estimated and ε_{it} is a stochastic error term.

Estimation technique

We begin the estimation of the above equations with the Ordinary Least-Squares (OLS) technique. However, the OLS estimates could be biased, especially in the presence of endogeneity. Thus, estimating the above equations with OLS could create attenuation bias, thus causing the OLS estimates downwards. To ensure that our results are robust to endogeneity, we utilise the Instrumental Variable (IV) approach as the main estimation technique. Using the IV approach to manage endogeneity requires that appropriate instruments are available to identify the model. According to Baum, Lewbel [35], relying on the conventional instrumental variable (IV) approach requires that the appropriate instrument must satisfy the following conditions: (i) the instrument should be correlated with the endogenous variable (ii) instrument should satisfy orthogonality condition (iii) instrument should satisfy the exclusion restriction such that the effect of the instruments on the dependent variable is indirect. However, Baum, Lewbel [35] and Stock, Wright [36] argue that getting instruments that fulfil these conditions, especially the exclusion restriction, is often challenging for applying the conventional IV approach in applied research.

Therefore, to overcome this problem, this study uses the Lewbel [26] two-stage least squares (TSLS) technique applied when the sources of identification, such as having appropriate external instruments, are not available or weak. The Lewbel TSLS approach includes internally constructed heteroskedasticity-based instruments generated from the residuals of the auxiliary equation, which is multiplied by each of the included exogenous variables in mean-centred form. Besides, when appropriate instruments are not available or weak for identifying structural parameters in the regression models with endogenous or mismeasured regressors, it is vital to apply the Lewbel TSLS. In applied research, the Lewbel instrumental variable approach does not rely on satisfying standard exclusion restrictions. It is demonstrated that applying the Lewbel instrumental variable method without any external instruments produces similar estimates to those obtained when external instruments are used [26].

Data

This study uses cross-sectional data for 176 countries[2] to examine the effect of government policy stringency and personal hygiene on COVID-19 cases. The data for this study is daily data which covers 22 January 2020 to 6th January 2021. The data for this study were retrieved from “Our World in Data”, which is readily available online[3]. The data used herein was chosen for its methodological rigour and for providing evidence related to COVID-19 prevention measures. Following Ajide, Ibrahim [20], we measured the number of COVID-19 cases with daily total confirmed cases of COVID-19 per 1,000,000 people. In addition, we also used the daily new confirmed cases of COVID-19 per 1,000,000 people for robustness check.

This study measured government policy response measures using the Government Response Stringency Index (GRSI), while handwashing facilities were used to measure handwashing (HWF). The GRSI is a composite index measure based on school closure, workplace closure,

[2] See Appendix Table 1 for countries included in the analysis
[3] https://ourworldindata.org/coronavirus-data

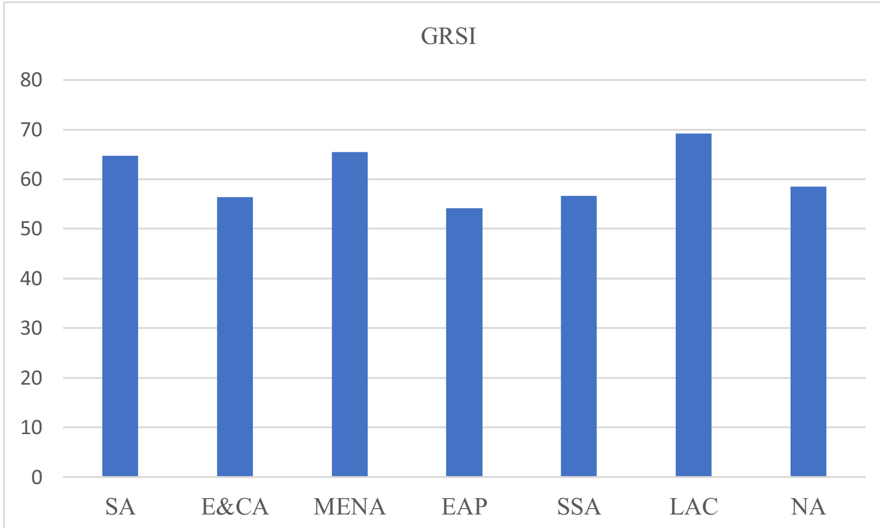

Fig. 2. Regional government response stringency index as of 22 January 2020 to 6^{th} January 2021

Table 2
The linear effect of GRSI and HWF on COVID-19 cases (Lewbel TSLS cross-sectional data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	Total confirmed cases of COVID-19						New confirmed cases of COVID-19					
HWF	-5.692	-0.038	-0.108	0.805***	0.368	0.130	-6.230	-0.154	-0.103	1.012***	0.335	0.095
	(12.139)	(0.316)	(0.235)	(0.306)	(0.228)	(0.218)	(13.242)	(0.350)	(0.256)	(0.338)	(0.240)	(0.241)
GRSI	0.227	0.066***	0.050***				0.250	0.073***	0.057***			
	(0.308)	(0.014)	(0.011)				(0.335)	(0.015)	(0.012)			
LIC		-1.417**			-1.068**			-1.819***			-1.345**	
		(0.609)			(0.537)			(0.619)			(0.525)	
LMIC		-1.071**			-0.868**			-1.322***			-1.058**	
		(0.463)			(0.429)			(0.487)			(0.443)	
E&CA			0.894			0.799			0.988			0.936*
			(0.660)			(0.532)			(0.713)			(0.567)
MENA			0.187			-0.205			0.217			-0.149
			(0.728)			(0.688)			(0.752)			(0.699)
EA&P			-2.305***			-2.325***			-2.391***			-2.370***
			(0.789)			(0.708)			(0.854)			(0.758)
SSA			-0.949			-0.776			-0.996			-0.858
			(0.647)			(0.542)			(0.676)			(0.564)
LAC			0.718			0.863*			0.686			0.826*
			(0.547)			(0.474)			(0.582)			(0.484)
GRSI (1^{st} quintile)				-1.756***	-1.573***	-1.155**				-1.971***	-1.751***	-1.352***
				(0.568)	(0.561)	(0.467)				(0.618)	(0.603)	(0.482)
GRSI (3^{rd} quintile)				-0.409	-0.249	0.099				-0.482	-0.212	0.124
				(0.596)	(0.571)	(0.504)				(0.672)	(0.628)	(0.541)
GRSI (4^{th} quintile)				0.513	0.692	0.640				0.454	0.727	0.663
				(0.421)	(0.433)	(0.456)				(0.442)	(0.477)	(0.477)
GRSI (5^{th} quintile)				0.291	0.397	0.193				0.263	0.500	0.366
				(0.465)	(0.462)	(0.429)				(0.485)	(0.496)	(0.429)
Constant	12.687	3.322***	4.111***	3.850***	5.873***	6.320***	8.525	-1.235	-1.049	-1.523	1.414	1.734
	(24.186)	(1.107)	(1.083)	(0.993)	(1.017)	(0.949)	(26.396)	(1.151)	(1.142)	(1.087)	(1.028)	(1.058)
Observations	83	83	83	83	83	83	83	83	83	83	83	83

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base. The second quintile is used to normalize or provide benchmark for the quintile categories.

international movement restrictions, cancellation of public events, gatherings, public transport closure, and stay-at-home requirements [31]. This GRSI index ranges between 0 to 100, with 100 being the strictest response. The handwashing facilities is a share of the population with basic handwashing facilities on-premises. Except for the GRSI and the dummy variables, the remaining variables were transformed into their natural logarithms before using them for empirical analysis. The transformation of these variables in natural logarithms helps to interpret the estimated coefficients as elasticity. Table 1 presents the descriptive statistics.

Fig. 1 and 2 show the number of regional COVID-19 cases per million and the stringency of the government policy index, respectively. From

Table 3
The linear effect of GRSI and HWF on COVID-19 cases (Lewbel TSLS panel data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	Total confirmed cases of COVID-19						New confirmed cases of COVID-19					
HWF	-5.537***	-0.334***	0.092***	0.708***	0.024	0.129***	-0.761***	-0.025	0.384***	0.690***	0.124***	0.414***
	(0.616)	(0.040)	(0.026)	(0.064)	(0.027)	(0.025)	(0.180)	(0.031)	(0.023)	(0.075)	(0.025)	(0.023)
GRSI	0.078***	0.014***	0.006***				0.032***	0.014***	0.011***			
	(0.006)	(0.001)	(0.001)				(0.002)	(0.001)	(0.001)			
LIC		-2.595***			-2.043***			-2.430***			-2.218***	
		(0.076)			(0.062)			(0.058)			(0.052)	
LMIC		-1.998***			-1.738***			-1.346***			-1.246***	
		(0.052)			(0.047)			(0.041)			(0.039)	
E&CA			2.442***			2.268***			1.470***			1.496***
			(0.099)			(0.091)			(0.064)			(0.060)
MENA			0.793***			0.772***			0.098			0.131*
			(0.111)			(0.104)			(0.071)			(0.070)
EA&P			-1.851***			-2.076***			-1.983***			-2.077***
			(0.100)			(0.092)			(0.081)			(0.077)
SSA			-0.158			-0.366***			-0.465***			-0.457***
			(0.097)			(0.090)			(0.062)			(0.059)
LAC			1.675***			1.690***			1.014***			1.060***
			(0.090)			(0.082)			(0.057)			(0.053)
GRSI (1st quintile)				-1.905***	-1.695***	-1.652***				-0.712***	-0.491***	-0.749***
				(0.067)	(0.066)	(0.061)				(0.059)	(0.056)	(0.050)
GRSI (3rd quintile)				0.085	-0.002	0.061				0.672***	0.583***	0.602***
				(0.054)	(0.054)	(0.048)				(0.050)	(0.049)	(0.043)
GRSI (4th quintile)				-0.496***	-0.450***	-0.592***				0.452***	0.487***	0.338***
				(0.055)	(0.051)	(0.047)				(0.052)	(0.048)	(0.042)
GRSI (5th quintile)				-1.315***	-1.222***	-1.695***				0.225***	0.213***	-0.146***
				(0.061)	(0.052)	(0.048)				(0.058)	(0.049)	(0.043)
Constant	20.208***	7.094***	4.155***	3.450***	7.109***	5.372***	2.198***	1.854***	-0.633***	-1.212***	1.898***	-0.121
	(1.861)	(0.170)	(0.160)	(0.221)	(0.123)	(0.131)	(0.531)	(0.134)	(0.118)	(0.264)	(0.110)	(0.107)
Observations	24746	24746	24746	24746	24746	24746	19161	19161	19161	19161	19161	19161

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base. The second quintile is used to normalize or provide benchmark for the quintile categories.

Fig. 1, North America (NA) on average has the highest number of COVID-19 cases, followed by the Europe & Central Asia (ECA), Middle East and North Africa (MENA) countries, Latin America & Caribbean (LAC), South Asia (SA), Sub-Saharan Africa (SSA) and East Asia & Pacific (EAP) respectively. Fig. 2 also indicates that, on average, LAC has the strictest policy index, followed by MENA, SA, NA, SSA, ECA, and EAP. Fig. 1 and 2 does not indicate the regional correlation between the number of COVID-19 cases the stringency of government policies.

Empirical Results

Analysis of cross-sectional results

We first estimated cross-section results using both the OLS[4] and Lewbel TSLS. We focused on Lewbel TSLS results because of its ability to control endogeneity. The Lewbel TSLS results are displayed in Table 2. In the baseline model (see Model 1) of Table 2, the estimates show that that handwashing facility (HWF) has an insignificant negative effect on total confirmed cases of COVID-19 and continue to be insignificant when the level of economic development and regional dummy variables are included in the models [see Models 2-3]. Also, in the baseline model [Model 1], the government response stringency index (GRSI) has an insignificant positive effect on total confirmed cases of COVID-19. However, the coefficient of the GRSI becomes statistically significant when the level of economic development and regional dummy variables are included in the models [see Models 2-3]. To validate the effect of GRSI on total confirmed cases of COVID-19, the GRSI is divided into five (5) quintiles, with the 1st quintile being the least policy response and the 5th quintile being the strictest policy response. Models 4-6 present the effect of the quintiles of GRIS on total confirmed cases of COVID-19. We observed from these models that using the 2nd quintile of GRSI as the base, the results show that the coefficient on the 1st quintile of GRIS is negative and statistically significant at a 5% level or better. Also, while the 3rd quintile of GRIS has an insignificant negative effect, both the coefficient of 4th and 5th quintiles of GRSI is positive and statistically insignificant.

Similar results are observed when new confirmed cases of COVID-19 are used as a dependent variable. For instance, in the baseline (see Model 7), HWF has an insignificant negative effect on new confirmed cases of COVID-19 and continue to be insignificant when the level of economic development and regional dummy variables are included in the models [see Models 8-9]. Also, in the baseline model [Model 7], GRSI has an insignificant positive effect on total confirmed cases of COVID-19; however, the coefficient of the GRSI becomes statistically significant and positive when the level of economic development and regional dummy variables are included in the models [see Models 8-9]. We also observed from these models that using the 2nd quintile of GRSI as the base, the coefficient on the 1st quintile of GRIS is negative and statistically significant at a 1% level. Also, while the 3rd quintile of GRIS has an insignificant negative effect, both the coefficient of 4th and 5th quintiles of GRSI is positive and statistically insignificant.

Analysis of panel data results

In this section, we present the panel data results that are estimated

[4] The OLS cross-sectional results are presented in Appendix Table 2

Table 4
The nonlinear effect of GRSI and HWF on COVID-19 cases (Lewbel TSLS panel data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	GRSI						HWF					
	Total confirmed cases of COVID-19			New confirmed cases of COVID-19			Total confirmed cases of COVID-19			New confirmed cases of COVID-19		
HWF	-0.279***	-0.111***	0.074***	0.510***	0.043*	0.357***	-0.510***	-0.266***	-0.356***	-0.450***	-0.233***	-0.385***
	(0.077)	(0.028)	(0.023)	(0.063)	(0.025)	(0.023)	(0.081)	(0.084)	(0.085)	(0.066)	(0.065)	(0.073)
GRSI	0.217***	0.204***	0.222***	0.108***	0.092***	0.119***	0.014***	0.012***	0.006***	0.014***	0.012***	0.010***
	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$GRSI^2$	-0.002***	-0.002***	-0.002***	-0.001***	-0.001***	-0.001***						
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)						
HWF^2							0.171***	0.059***	0.107***	0.195***	0.078***	0.155***
							(0.014)	(0.015)	(0.017)	(0.011)	(0.012)	(0.014)
LIC		-2.226***			-2.299***			-1.913***			-1.991***	
		(0.060)			(0.051)			(0.059)			(0.049)	
LMIC		-1.760***			-1.266***			-1.696***			-1.135***	
		(0.045)			(0.039)			(0.049)			(0.041)	
E&CA			1.891***			1.294***			2.192***			1.161***
			(0.087)			(0.060)			(0.106)			(0.071)
MENA			0.566***			0.021			0.566***			-0.187**
			(0.098)			(0.069)			(0.115)			(0.076)
EA&P			-2.367***			-2.207***			-1.970***			-2.197***
			(0.089)			(0.078)			(0.102)			(0.084)
SSA			-0.778***			-0.710***			0.079			-0.284***
			(0.085)			(0.059)			(0.097)			(0.063)
LAC			1.423***			0.939***			1.544***			0.846***
			(0.079)			(0.053)			(0.092)			(0.059)
Constant	0.249	1.691***	-0.280	-3.805***	-0.455***	-3.089***	3.819***	5.865***	4.297***	-0.528***	1.417***	0.065
	(0.269)	(0.176)	(0.175)	(0.220)	(0.157)	(0.135)	(0.137)	(0.144)	(0.180)	(0.111)	(0.111)	(0.132)
Observations	24746	24746	24746	19161	19161	19161	24746	24746	24746	19161	19161	19161

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base.

using the Lewbel TSLS[5]. The Lewbel TSLS panel data results are presented in Table 3. From Table 3, the estimates show that HWF has a statistically significant negative effect on total confirmed cases of COVID-19 in Models 1-2. However, the coefficient on the HWF becomes positive and significant when regional dummy variables are included in the model [see Model 3]. Also, in the baseline model [see Model 7], HWF has a significant negative effect on new confirmed cases of COVID-19; however, HWF becomes positive and significant after including income and regional dummy variables. These results suggest that HWF reduces total and new confirmed cases of COVID-19; however, such effect is not robust to income and regional dummy variables.

The estimate also shows that GRSI has a significant positive effect on total and new confirmed cases of COVID-19 at a 1% level in all specifications. This result suggests that the government using stringent policy responses would be associated with an increasing number of total and new confirmed cases of COVID-19. The significant positive effect of GRSI on the number of COVID-19 cases could also be attributed to individuals failing to comply with these policy directives because of their adverse economic and psychological impact. For instance, Abrams and Szefler [10] argue that these stringent measures are more difficult for people with adverse socio-economic circumstances and would make these measures ineffective for curbing the spread of the COVID-19. Additionally, these policy measures' health and socio-economic implications make people not comply with these policy directives. Bukuluki, Mwenyango [13] and Tani, Cheng [37] also argue that some of these policy measures have increased income and financial insecurity, anxiety, sexual and gender-based violence, thereby making individuals not adhere to these policy directives. It is also indicated that these GRSI measures are implemented to encourage stay at home; however, stay at home measures (residential lockdown) significantly increases the number of COVID-19 confirmed cases since an infected person usually has one or more family members or close relatives infected [20]. Similarly, WHO indicated that outdoor gatherings are safer than indoor ones, particularly if indoor spaces are small and without outdoor air coming in[6]. Our result is similar to Chisadza, Clance [32] findings, which indicated that the strictest government response measures are associated with more COVID-19 deaths.

For the sensitivity analysis, the results suggest that using the 2nd quintile of GRSI as the base; the 1st, 4th, and 5th quintile of GRIS significantly reduces total confirmed cases of COVID-19 at a 1% level while the 3rd quintile of GRIS has an insignificant effect on the total confirmed cases of COVID-19. On the other hand, the estimate suggests that the 1st quintile of GRIS has a significant negative effect on new confirmed cases of COVID-19 at a 1% level while the 3rd, 4th, and 5th quintiles of GRSI have a significant positive effect on the new confirmed cases of COVID-19 at a 1% level. These observations suggest that if we consider the effect of the different quintiles of GRSI on total confirmed cases of COVID-19, we can argue that GRIS contributes to the reduction of total confirmed cases of COVID-19, confirming Ajide, Ibrahim [20], findings in Nigeria that lockdown measures such as retail and recreation, grocery and pharmacy, parks, transit stations, and workplaces contribute significantly to a decline in the total confirmed cases of COVID-19. However, suppose we consider the effect of the different quintiles of GRSI on total confirmed cases of COVID-19. In that case, we can argue that the lower (1st) quintile of GRIS contributes to the reduction of new confirmed cases of COVID-19 while higher (3rd, 4th, and 5th) quintiles contribute to the rise of new confirmed cases of COVID-19. This result is consistent with Kumar, Priya [18] simulation analysis. In their simulation analysis, Kumar, Priya [18] demonstrated that in a case where light and moderate interventions are respectively applied, the spread of the disease is slightly reduced with a peak number of active cases observed after 300 days and 380 days, respectively, and the maximum number of active cases, deaths, and recoveries are also

[5] The OLS panel data results are presented in Appendix Table 3

[6] https://www.who.int/emergencies/diseases/novel-coronavirus-2019/advice-for-public

Table 5
Interactive effect between GRSI and HWF on COVID-19 cases (Lewbel TSLS panel data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	Total confirmed cases of COVID-19						New confirmed cases of COVID-19					
HWF	-1.750***	-1.583***	-0.633***	0.416***	0.085**	0.091***	-0.098	-0.273***	0.352***	0.633***	0.269***	0.383***
	(0.115)	(0.109)	(0.101)	(0.036)	(0.034)	(0.035)	(0.080)	(0.078)	(0.068)	(0.040)	(0.041)	(0.039)
GRSI	-0.107***	-0.079***	-0.041***				-0.028***	-0.013***	0.006*			
	(0.006)	(0.005)	(0.005)				(0.004)	(0.004)	(0.003)			
GRSI × HWF	0.035***	0.026***	0.014***				0.012***	0.007***	0.001			
	(0.002)	(0.002)	(0.001)				(0.001)	(0.001)	(0.001)			
LIC		-2.068***			-1.772***			-2.095***			-1.962***	
		(0.058)			(0.056)			(0.047)			(0.047)	
LMIC		-1.737***			-1.566***			-1.219***			-1.149***	
		(0.046)			(0.045)			(0.038)			(0.038)	
E&CA			2.373***			2.233***			1.439***			1.494***
			(0.098)			(0.089)			(0.064)			(0.060)
MENA			0.715***			0.743***			0.065			0.120*
			(0.108)			(0.100)			(0.070)			(0.069)
EA&P			-1.822***			-2.031***			-2.004***			-2.088***
			(0.098)			(0.088)			(0.080)			(0.076)
SSA			-0.052			-0.278***			-0.406***			-0.407***
			(0.100)			(0.086)			(0.063)			(0.058)
LAC			1.575***			1.578***			0.991***			1.032***
			(0.089)			(0.079)			(0.057)			(0.053)
GRSI (1st quintile)				1.101***	1.294***	0.930***				-0.274	0.239	-0.086
				(0.206)	(0.207)	(0.194)				(0.193)	(0.189)	(0.177)
GRSI (3rd quintile)				-1.433***	-1.589***	-1.514***				-0.211	-0.141	-0.187
				(0.159)	(0.155)	(0.145)				(0.160)	(0.162)	(0.148)
GRSI (4th quintile)				-2.165***	-1.744***	-1.917***				-0.132	0.538***	0.018
				(0.166)	(0.159)	(0.150)				(0.169)	(0.164)	(0.153)
GRSI (5th quintile)				-3.476***	-2.803***	-3.085***				-0.819***	0.003	-0.630***
				(0.177)	(0.169)	(0.157)				(0.177)	(0.173)	(0.161)
GRSI (1st quintile) × HWF				-0.928***	-0.916***	-0.790***				-0.138**	-0.224***	-0.207***
				(0.066)	(0.066)	(0.060)				(0.062)	(0.060)	(0.054)
GRSI (3rd quintile) × HWF				0.437***	0.462***	0.458***				0.248***	0.206***	0.223***
				(0.047)	(0.045)	(0.041)				(0.048)	(0.047)	(0.042)
GRSI (4th quintile) × HWF				0.471***	0.353***	0.371***				0.160***	-0.018	0.091**
				(0.048)	(0.046)	(0.042)				(0.050)	(0.048)	(0.043)
GRSI (5th quintile) × HWF				0.587***	0.407***	0.375***				0.273***	0.048	0.132***
				(0.049)	(0.047)	(0.043)				(0.050)	(0.049)	(0.043)
Constant	10.198***	11.199***	6.620***	4.467***	6.753***	5.472***	0.708***	2.607***	-0.534**	-1.010***	1.271***	-0.027
	(0.394)	(0.374)	(0.369)	(0.115)	(0.123)	(0.147)	(0.266)	(0.261)	(0.248)	(0.128)	(0.151)	(0.151)
Observations	24746	24746	24746	24746	24746	24746	19161	19161	19161	19161	19161	19161

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base. The second quintile is used to normalize or provide benchmark for the quintile categories.

reduced. On the other hand, the authors indicated that with strict policy intervention, the maximum number of active cases to peak after 600 days to approximately 45 million cases and the total number of deaths is predicted to be around 6 million, while the recoveries are around 400 million.

The level of economic development dummy suggests that the number of COVID-19 cases in low-income countries (LIC) and lower-middle-income countries (LMIC) are significantly lower than in higher and middle-income countries. On average, the magnitude of the reduction coefficient is much higher in low-income countries. We argue that the relatively lower number of reported COVID-19 cases in low-income countries is due to their inability to conduct mass testing to identify people having the COVID-19 virus. On the other hand, the ability of higher-income countries to conduct mass testing enables these countries to identify more individuals having COVID-19, thereby increasing their reported cases. The mass testing in itself increases the spread of the COVID-19 as Acemoglu, Makhdoumi [38] argue that testing helps to contain affected individuals but reduces voluntary social distancing or increases social activities. Also, the resource capacity of high-income countries to produce COVID-19 vaccines and the earlier spread of COVID-19 vaccines information in these economies may have contributed to the rise of COVID-19 cases. For instance, in their experimental analysis, Andersson, Campos-Mercade [39] indicated that information about the safety, effectiveness, and availability of COVID-19 vaccines reduces peoples' voluntary social distancing, adherence to hygiene guidelines, and their willingness to stay at home and further increase the number of COVID-19 cases.

Further, the regional dummy variable results suggest that the number of COVID-19 cases in the Middle East and North Africa (MENA), Europe & Central Asia (E&CA) and Latin America & the Caribbean (LAC) are relatively higher than the cases in North America and South Asia. However, for East Asia & Pacific (EA&P) and Sub-Saharan Africa (SSA), the number of COVID cases are relatively lower than the cases in North America and South Asia. These results suggest that geographical differences play a vital role in the spread of the COVID. In summary, the income and regional effect analysis indicate that the number of COVID-19 cases is not homogenous among regions and income groups.

In Table 4, we examine the nonlinear effect of GRSI and HSW on total and new confirmed cases of COVID-19. From Table 4, the estimate suggests that GRSI has a significant positive effect on total and new

Table 6
Interactive effect between income and regional dummies, GRSI and HWF on COVID-19 cases (Lewbel TSLS panel data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
	Total confirmed cases of COVID-19				New confirmed cases of COVID-19			
HWF	0.869***	-0.421***	-1.097***	0.074***	1.031***	0.028	0.099	0.401***
	(0.059)	(0.030)	(0.233)	(0.025)	(0.051)	(0.025)	(0.162)	(0.023)
GRSI	0.012***	0.016***	0.005***	0.039***	0.013***	0.015***	0.009***	0.019***
	(0.001)	(0.003)	(0.001)	(0.005)	(0.001)	(0.002)	(0.001)	(0.003)
LIC	1.076***	-0.735***			1.147***	-1.718***		
	(0.263)	(0.206)			(0.223)	(0.147)		
LMIC	2.750***	-3.243***			3.427***	-1.673***		
	(0.276)	(0.216)			(0.233)	(0.166)		
LIC × HWF	-0.661***				-0.715***			
	(0.065)				(0.056)			
LMIC × HWF	-1.095***				-1.125***			
	(0.066)				(0.057)			
LIC × GRSI		-0.035***				-0.011***		
		(0.003)				(0.002)		
LMIC × GRSI		0.020***				0.005**		
		(0.003)				(0.002)		
E&CA			-15.805***	6.086***			-16.398***	3.220***
			(2.002)	(0.454)			(1.466)	(0.266)
MENA			-48.960***	1.523***			-32.707***	-0.048
			(2.683)	(0.493)			(1.962)	(0.296)
EA&P			-8.374***	-2.202***			18.455***	-3.762***
			(0.992)	(0.394)			(2.023)	(0.278)
SSA			-5.163***	3.022***			-1.824***	0.490**
			(0.927)	(0.387)			(0.634)	(0.225)
LAC			-2.782***	4.397***			-0.566	1.745***
			(1.004)	(0.448)			(0.699)	(0.267)
E&CA × HWF			4.207***				4.013***	
			(0.460)				(0.338)	
MENA × HWF			11.316***				7.400***	
			(0.614)				(0.448)	
EA&P × HWF			1.625***				-4.699***	
			(0.249)				(0.472)	
SSA × HWF			1.304***				0.370**	
			(0.234)				(0.164)	
LAC × HWF			1.138***				0.398**	
			(0.250)				(0.177)	
E&CA × GRSI				-0.055***				-0.026***
				(0.006)				(0.004)
MENA × GRSI				-0.010				0.002
				(0.007)				(0.004)
EA&P × GRSI				0.013**				0.028***
				(0.005)				(0.004)
SSA × GRSI				-0.051***				-0.014***
				(0.005)				(0.003)
LAC × GRSI				-0.040***				-0.010***
				(0.006)				(0.004)
Constant	2.042***	7.304***	8.920***	2.049***	-2.631***	1.549***	0.576	-1.292***
	(0.257)	(0.206)	(0.923)	(0.388)	(0.214)	(0.157)	(0.629)	(0.231)
Observations	24746	24746	24746	24746	19161	19161	19161	19161

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base.

confirmed cases of COVID-19, while GRSI squared has a significant negative effect on total and new confirmed cases of COVID-19 at a 1% level [see Models 1-6]. These estimates suggest that GRSI have an inverted U-shaped relationship with total and new confirmed cases of COVID-19. Thus, at the initial stage of implementing GRSI, COVID-19 cases increase, but after a certain threshold of GRSI, the number of COVID-19 cases declines. Also, the estimate suggests that HWF has a significant negative effect on total and new confirmed cases of COVID-19 while HWF squared has a significant positive effect on total and new confirmed cases of COVID-19 at a 1% level [see Models 7-12]. These estimates suggest that HWF have a U-shaped relationship with total and new confirmed cases of COVID-19. Thus, at the initial stage of implementing HWF, COVID-19 cases decline, but after a certain threshold of HWF, the number of COVID-19 cases increases.

Analysis of interactive results

This section examines the interactive effect between GRIS and HWF on the number of COVID-19 cases. Table 5 displays the interactive effect between GRSI and HWF results. From Table 5, GRSI interacts with HSW to have a significant positive effect on total and new confirmed cases of COVID-19 at a 1% level. Also, using the quintiles of GRSI, the 1st quintile of GRIS interacts with HWF to have a significant negative effect on the total confirmed cases of COVID-19 at a 1% level. However, the interaction between the 3rd, 4th, and 5th quintiles of GRSI and HWF is positive and statistically significant at a 1% level. These results suggest that the strictest government response measures conditions handwashing to increase the number of COVID-19 increases. The most stringent government response measures increase financial insecurity [13,37], making most households unable to afford hand cleaning sanitisers. It was observed that when the government introduced lockdown measures, there was a shortage of hand sanitisers and the price of hand sanitisers further increased, which adversely affected handwashing practice. Also, the strictest government response measures do not encourage handwashing because these measures are implemented to encourage stay at home; people who stay at home do not mostly wash hands frequently.

We further explore the interactive effect of income and regional dummy variables and GRSI and HWF on COVID-19 cases. These interactions capture how the difference in GRSI and handwashing across income groups and regions affect the number of COVID-19 cases globally. Table 6 displays these interactive effect results. From Table 6, the results also suggest that LIC interacts with HWF to have a significant negative effect on total confirmed cases of COVID-19 at a 1% level. Similarly, LMIC interacts with HWF to have a significant negative effect on total confirmed cases of COVID-19 at a 1% level. On the other hand, LIC interacts with GRSI to have a significant negative effect on total confirmed cases of COVID-19 at a 1% level. Contrarily, LMIC interacts with GRSI to have a significant positive effect on total confirmed cases of COVID-19 at a 1% level. Also, all the regional dummy variables interact with HWF to significantly increase total confirmed cases of COVID-19. Similarly, except for E&CA, the remaining regional dummy variables interact with HWF to significantly increase new confirmed cases of COVID-19. Thus, for the case of E&CA, HWF contributes significantly to reducing new confirmed cases of COVID-19, while the opposite effect is observed in other regions. It is also observed that LAC, E&CA and SSA dummy variables interact with GRSI to have a significant negative effect on total confirmed cases of COVID-19 at a 1% level. In comparison, the EA&P dummy interacts with GRSI to have a significant positive effect on total confirmed cases of COVID-19 at a 5% level.

Conclusions and Policy implications

Since the COVID-19 pandemic, many governments globally have introduced policy measures to contain the spread of the virus. Popular COVID-19 containment measures include lockdowns of various forms (aggregated into government response stringency index) and handwashing. The effectiveness of these policy measures remains unclear in the academic literature. This study, therefore, investigates the effect of government policy stringency (GRSI) and handwashing (HWF) on the number of COVID-19 using panel data for 176 countries. In this study, we applied the Lewbel (2012) two-stage least squares technique to estimate the effect of GRSI and HWF on the number of COVID-19. Using the Lewbel (2012) two-stage least squares technique to control for endogeneity, the results that emanated from this study are summarised as follows:

1 The results indicated that HWF reduces total and new confirmed cases of COVID-19; however, such effect is not robust to income and regional effects. Also, the results showed that GRSI significantly contributes to the increase in the total and new confirmed cases of COVI-19. Sensitivity analyses revealed that relative to the 2nd quintile of GRSI, the 1st, 4th, and 5th quintiles of GRIS significantly reduce total confirmed cases of COVID-19, while the 3rd quintile of GRIS has an insignificant effect on the total confirmed cases of COVID-19. On the other hand, relative to the 2nd quintile of GRSI, the results indicated that the 1st quintile of GRIS contributes significantly to reducing the new confirmed cases of COVID-19 while the 3rd, 4th, and 5th quintiles of GRSI contribute significantly to increasing the new confirmed cases of COVID-19.

2 Our results indicated that GRSI and HWF have nonlinear effects with total and new confirmed cases of COVID-19. For instance, the nonlinear analysis revealed that GRSI has an inverted U-shaped relationship with total and new confirmed cases of COVID-19. The implication is that at the initial stage of implementing GRSI, COVID-19 cases increase, but after a certain threshold of GRSI, the number of COVID-19 cases declines. Contrarily, it is indicated that HWF has a U-shaped relationship with total and new confirmed cases of COVID-19. This suggests that at the initial stage of implementing HWF, COVID-19 cases decline, but after a certain threshold of HWF, the number of COVID-19 cases increases.

3 The conditional effect analysis revealed that GRSI interacts with HSW to have a significant positive effect on total confirmed cases of COVID-19. Also, using the quintiles of GRSI, the 1st quintile of GRIS interacts with HWF to significantly reduces the total confirmed cases of COVID-19. However, the interaction between the 3rd, 4th, and 5th quintiles of GRIS and HWF substantially increases the total confirmed cases of COVID-19.

4 The analysis indicated that the number of COVID-19 cases is not homogenous among regions and income groups. For instance, we observed that the total and new confirmed cases of COVID-19 in low-income countries (LIC) and lower-middle-income countries (LMIC) are significantly lower than those in higher and middle-income countries. On average, the magnitude of the reduction effect is much higher in low-income countries. From a regional perspective, the results indicated the total and new confirmed cases of COVID-19 in the Middle East and North Africa (MENA), Europe & Central Asia (E&CA) and Latin America & the Caribbean (LAC) are relatively higher than the cases in North America and South Asia. However, for East Asia & Pacific (EA&P) and Sub-Saharan Africa (SSA), the total and new confirmed cases of COVID-19 are relatively lower than the cases in North America and South Asia.

5 The results indicated that lower and lower-middle income countries dummy variables interact with HWF to have a significant negative effect on total confirmed cases of COVID-19 at a 1% level. Also, while the LIC dummy interacts with GRSI to significantly reduce total confirmed cases of COVID-19, the LMIC dummy interacts with GRSI to substantially increase total confirmed cases COVID-19. Also, all the regional dummy variables interact with HWF to significantly increase total confirmed cases of COVID-19. Similarly, except for E&CA, the remaining regional dummy variables interact with HWF to significantly increase new confirmed cases of COVID-19. Thus, for the case of E&CA, HWF contributes significantly to reducing new confirmed cases of COVID-19, while the opposite effect is observed in other regions. The estimate also highlighted that while LAC, E&CA and SSA dummy variables interact with GRSI to reduce total confirmed cases of COVID-19 significantly, the EA&P dummy interacts with GRSI to increase total confirmed cases of COVID-19 significantly.

Our results proffer some important policy implications. It was observed globally that the lockdown measures implemented to curb the spread of COVID-19 were not welcome by most people because of the associated adverse health, social and economic implications, hence failure for people to comply with these policies directives. Therefore, we argue that for these policy measures to contribute significantly to curbing the spread of the COVID-19, all members of society should fully engage, including; communities and professional groups, in implementing these public health policies already proposed by WHO. Also, as recommended by WHO and suggested to be effective in the case of Sweden [see 16], there should be a mutual relationship between the government and society based on mutual trust giving responsibility to individuals. In line with Kumar, Priya [18] suggestions, our findings highlight the need for policymakers to raise awareness among people rather than stringent lockdown measures to control the spread of the COVID-19.

Our study provides preliminary evidence on the effect of government policy stringency (lockdown measures) and handwashing on COVID-19 cases using a global dataset. However, our results should be interpreted with caution because of the following limitations. One of the limitations of this study is that the government response stringency measure is a composite index; this study could not examine the respective effect of the individual lockdown measures such as retail and recreation, grocery and pharmacy, parks, transit stations, workplaces, and residential lockdowns on the number of COVID-19 cases. Also, while this study was interested in the stringency of government response measures on COVID-19 cases, this study did not examine the effect of economic support and health containment on the number of COVID-19 cases. Also, since the existing socio-economic variables, such as hospital beds, GDP per capita, testing capabilities, and poverty, are annual data, we could not incorporate them in the analysis since COVID-19 is measured daily. We included income and regional dummy variables in the analysis to prevent the omission bias caused by the failure to include these socio-economic variables. In the future, researchers can examine the effect of these variables on the number of COVID-19 cases using either global or country-specific datasets.

Ethical approval

Not required.

Patient Consent

Not required.

CRediT authorship contribution statement

Janet Dzator: Conceptualization, Methodology, Formal analysis, Writing – review & editing, Funding acquisition, Supervision. **Alex O. Acheampong:** Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Michael Dzator:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Francesco Paolucci:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Bruno Lule Yawe:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Emmanuel Ekow Asmah:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Francis Kwaw Andoh:** Conceptualization, Methodology, Writing – review & editing, Funding acquisition. **Allen Kabagenyi:** Conceptualization, Writing – review & editing, Funding acquisition. **James Gillespie:** Conceptualization, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest.

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APPENDIX

appendix 1, appendix 2, appendix. 3

Appendix Table 1
Countries included in the analysis

Low-income countries
Afghanistan, Burkina Faso, Burundi, Central African Republic, Chad, Democratic Republic of Congo, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Haiti, Liberia, Madagascar, Mali
Mozambique Myanmar, Niger, Rwanda, Sierra Leone, Somalia, South Sudan, Sudan, Syria
Tajikistan, Togo, Uganda.
Lower-middle income countries
Algeria, Angola, Bangladesh, Benin, Bhutan, Bolivia, Cambodia, Cameroon, Cape Verde, Comoros, Congo, Cote d'Ivoire, Djibouti, Egypt, El Salvador, Eswatini, Ghana, Honduras, India, Kenya, Kyrgyzstan, Laos, Lesotho, Mauritania, Mongolia, Morocco, Nepal, Nicaragua
Nigeria, Pakistan, Papua New Guinea, Philippines, Sao Tome and Principe, Senegal, Sri Lanka
Tanzania, Timor, Tunisia, Ukraine, Uzbekistan, Vietnam, Zambia, Zimbabwe
Upper-middle income countries
Albania, Argentina, Armenia, Azerbaijan, Belarus, Belize, Bosnia and Herzegovina, Botswana
Brazil, Bulgaria, China, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, Equatorial Guinea, Fiji, Gabon, Georgia, Grenada, Guatemala, Guyana, Indonesia
Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kosovo, Lebanon, Libya, Malawi, Malaysia, Maldives
Mexico, Moldova, Namibia, Paraguay, Peru, Russia, Serbia, South Africa, Suriname, Thailand
Turkey, Venezuela
High income countries
Andorra, Antigua and Barbuda, Australia, Austria, Bahamas, Bahrain, Barbados, Belgium, Brunei, Canada, Chile, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany
Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Kuwait, Latvia, Liechtenstein, Lithuania
Luxembourg, Malta, Mauritius, Monaco, Montenegro, Netherlands, New Zealand, Norway, Oman, Panama, Poland, Portugal, Qatar, Romania, San Marino, Saudi Arabia, Seychelles, Singapore, Slovakia, Slovenia, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, Uruguay

Total number of countries: 176 countries

Appendix Table 2
The linear effect of GRSI and HWF on COVID-19 cases (OLS cross-sectional data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	Total confirmed cases of COVID-19						New confirmed cases of COVID-19					
HWF	0.407**	0.196	0.165	0.526***	0.294	0.301	0.447**	0.187	0.195	0.567***	0.289	0.338
	(0.168)	(0.188)	(0.203)	(0.154)	(0.190)	(0.203)	(0.184)	(0.203)	(0.227)	(0.168)	(0.205)	(0.229)
GRSI	0.068***	0.062***	0.048***				0.075***	0.068***	0.055***			
	(0.014)	(0.013)	(0.012)				(0.015)	(0.014)	(0.013)			
LIC		-1.082**			-1.178**			-1.330***			-1.413***	
		(0.455)			(0.518)			(0.442)			(0.512)	
LMIC		-0.941**			-0.912**			-1.131**			-1.085**	
		(0.427)			(0.440)			(0.444)			(0.455)	
E&CA			0.800			0.752			0.886			0.869
			(0.700)			(0.572)			(0.748)			(0.599)
MENA			0.070			-0.292			0.089			-0.273
			(0.773)			(0.747)			(0.791)			(0.741)
EA&P			-2.268***			-2.286***			-2.351**			-2.313***
			(0.850)			(0.763)			(0.919)			(0.815)
SSA			-0.611			-0.552			-0.628			-0.539
			(0.650)			(0.543)			(0.688)			(0.566)
LAC			0.663			0.836			0.626			0.788
			(0.591)			(0.520)			(0.618)			(0.521)
GRSI (1^{st} quintile)				-1.761***	-1.564**	-1.226**				-1.980***	-1.746***	-1.453***
				(0.571)	(0.593)	(0.486)				(0.614)	(0.635)	(0.503)
GRSI (3^{rd} quintile)				-0.252	-0.219	0.017				-0.233	-0.194	0.006
				(0.583)	(0.601)	(0.539)				(0.645)	(0.654)	(0.586)
GRSI (4^{th} quintile)				0.618	0.719	0.590				0.623	0.744	0.592
				(0.441)	(0.460)	(0.468)				(0.473)	(0.498)	(0.481)
GRSI (5^{th} quintile)				0.519	0.432	0.091				0.626	0.521	0.220
				(0.440)	(0.488)	(0.450)				(0.458)	(0.512)	(0.446)
Constant	0.838	2.557***	3.170***	4.732***	6.160***	5.709***	-4.448***	-2.349**	-2.074*	-0.119	1.590	0.862
	(0.702)	(0.932)	(1.062)	(0.546)	(0.911)	(0.909)	(0.774)	(0.980)	(1.121)	(0.578)	(0.965)	(1.009)
Observations	83	83	83	83	83	83	83	83	83	83	83	83
R2	0.374	0.423	0.563	0.371	0.419	0.562	0.400	0.463	0.580	0.403	0.464	0.580

Heteroscedasticity robust standard errors in parentheses. * $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base. The second quintile is used to normalize or provide benchmark for the quintile categories.

Appendix Table 3
The linear effect of GRSI and HWF on COVID-19 cases (OLS panel data estimates)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	Total confirmed cases of COVID-19						New confirmed cases of COVID-19					
HWF	0.491***	0.073***	0.210***	0.566***	0.181***	0.230***	0.742***	0.249***	0.456***	0.769***	0.286***	0.470***
	(0.018)	(0.021)	(0.024)	(0.016)	(0.020)	(0.023)	(0.016)	(0.018)	(0.022)	(0.015)	(0.018)	(0.022)
GRSI	0.015***	0.012***	0.006***				0.015***	0.012***	0.011***			
	(0.001)	(0.001)	(0.001)				(0.001)	(0.001)	(0.001)			
LIC		-1.972***			-1.800***			-2.027***			-1.975***	
		(0.056)			(0.056)			(0.046)			(0.046)	
LMIC		-1.742***			-1.638***			-1.186***			-1.150***	
		(0.047)			(0.045)			(0.038)			(0.038)	
E&CA			2.375***			2.212***			1.427***			1.463***
			(0.099)			(0.091)			(0.064)			(0.060)
MENA			0.731***			0.721***			0.057			0.100
			(0.110)			(0.103)			(0.071)			(0.069)
EA&P			-1.883***			-2.103***			-2.015***			-2.100***
			(0.100)			(0.092)			(0.081)			(0.077)
SSA			-0.014			-0.241***			-0.383***			-0.393***
			(0.096)			(0.089)			(0.061)			(0.058)
LAC			1.641***			1.661***			0.991***			1.042***
			(0.090)			(0.082)			(0.057)			(0.053)
GRSI (1st quintile)				-1.930***	-1.702***	-1.643***				-0.690***	-0.488***	-0.745***
				(0.068)	(0.067)	(0.061)				(0.057)	(0.056)	(0.050)
GRSI (3rd quintile)				0.082	0.010	0.070				0.671***	0.593***	0.605***
				(0.054)	(0.053)	(0.048)				(0.050)	(0.049)	(0.043)
GRSI (4th quintile)				-0.469***	-0.472***	-0.590***				0.440***	0.469***	0.339***
				(0.053)	(0.051)	(0.047)				(0.050)	(0.048)	(0.042)
GRSI (5th quintile)				-1.256***	-1.263***	-1.696***				0.198***	0.183***	-0.145***
				(0.054)	(0.052)	(0.048)				(0.051)	(0.049)	(0.043)
Constant	2.512***	5.476***	3.704***	3.945***	6.455***	4.970***	-2.183***	0.775***	-0.904***	-1.492***	1.217***	-0.340***
	(0.072)	(0.111)	(0.151)	(0.065)	(0.096)	(0.125)	(0.060)	(0.096)	(0.112)	(0.059)	(0.089)	(0.103)
Observations	24746	24746	24746	24746	24746	24746	19161	19161	19161	19161	19161	19161
R2	0.051	0.114	0.191	0.105	0.159	0.257	0.145	0.230	0.296	0.162	0.242	0.324

Heteroscedasticity robust standard errors in parentheses.* $p < 0.10$
** $p < 0.05$
*** $p < 0.01$. Note: In the income group models, upper-middle and high-income countries are used for the base. In the regional groups model, North America and South Asia regions are used as the base. The second quintile is used to normalize or provide benchmark for the quintile categories.

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