Effects of income inequality on COVID-19 in Africa: Accounting for literacy and informal sector

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Abstract - The literature has been unexplored regarding the analysis of transmission channels in the study of the relationship between income inequality and COVID-19 spread. The aim of this paper is to fill this gap by on the direct and indirect effects of income inequality on COVID-19 by focusing on a sample of 43 African countries over the period 2020-2022. We use fixed effects regression model. Two indicators of COVID-19 are identified, namely the total number of cases and severity of the disease, as well as two transmission channels, namely the size of the informal sector and literacy. The results of direct analysis show that income inequality positively and significantly affects the spread of COVID-19. Although the indirect analysis supports the positive and significant effect, it appears that estimated coefficients are underestimated in the direct analysis. These results suggest that reducing income gap between individuals is key to coping with health shocks.

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INTRODUCTION

The recent COVID-19 pandemic is arguably the most significant event of the second decade of the 19th century (Brunckhorst et al., 2024; Galanis and Georgiadis, 2024; Hangoma et al., 2024). She affected all social strata around the world, from adults (Lopes and Middleton, 2020) to children (Lopes et al., 2021). It has not only distinguished itself by disrupting the global health system, but also by disrupting both economic and sociological ecosystems (Ginsburgh et al., 2021). It has affected both developed and developing countries (Amate-Fortes and Guarnido-Rueda, 2022). The pandemic has led to containment and social distancing measures that have dealt a severe blow to the global economy (Bargain and Aminjonov, 2021; Henao-Cespedes, 2022).

Analyzing the annual data, the GDP of all developing countries is expected to remain below the pre-pandemic trend. This means a fall in economic activity of 2.8% in 2020 in a context of high uncertainty (World Bank, 2020). Some regions are facing output gaps that are significantly larger than their pre-pandemic performance. In the specific case of sub-Saharan Africa (SSA), for example, the gap in 2023 compared to the pre-pandemic trend is expected to be over 4% (World Bank, 2022). Furthermore, the situation of income inequality in Africa is complex. Seven of the ten most unequal countries in the world are located in Africa, mainly in Southern Africa (World Bank 2020). Oxfam's (2021) study shows that inequality could be on the increase worldwide. In the case of West Africa, the wealth of the region's three richest men rose from $16.8 billion in march 2020 to $23.2 billion in july 2021. In addition, these inequalities undermine countries' economic growth, reduce the impact of policies (Kuznets, 1955; Stiglitz, 2012), and undermine the achievement of the Sustainable Development Goals (World Bank, 2020). Their negative effects on economic performance are associated with increased health shocks, terrorism, political instability and crime leading to a mistrust climate (Wagstaff and Lindelow, 2014; Wilkinson and Pickett, 2011).

In order to explain the causes and effects of COVID-19 spread, the theory of shocks through the Keynesian theory of aggregate supply and demand explains economic fluctuations as the result of shocks due to their negative effects on aggregate supply and demand (Lorenzoni, 2009). COVID-19 created a situation where the supply and demand of goods and services temporarily stopped, bringing countries to the brink of economic recession (Henao-Cespedes, 2022). To better understand the evolution of the pandemic and the effects on aggregate supply and demand, it is important to look at the mechanisms by which the pandemic affects the economy and each other. In addition to the reduction in consumption of goods and services due to the prolonged duration of the pandemic and the social distancing measures that reduce spending and therefore household consumption (Dandonougbo et al., 2021). COVID-19 creates disruptions that can occur in the labour market. This is because COVID-19 keeps production low, which hampers supply chains, labour demand, leading to prolonged periods of layoffs and increased inequality which in turn would lead to the spread of the pandemic (Ahmed et al., 2020; Casarico and Lattanzio, 2022).

In addition, Acemoglu et al. (2020) show in their work that containment harms the economy and reduces the productivity of uninfected members. However, due to income inequalities within social strata, individuals from poor backgrounds do not always respect confinement measures. This in order to be able to satisfy their physiological needs such as food (Stiegler and Bouchard, 2020). Failure to comply with these containment and social distancing measures therefore encourages the COVID-19 spread, particularly in developing economies (Bargain and Aminjonov, 2021). The pandemic did not spread with the same intensity within different countries and/or economies (Diop et al., 2020). Moreover, it could not be brought under control within these economies within the same timeframe, which more or less caused the severity of the pandemic to severely hamper the development of the economies (Pearce et al., 2020). This has led to a continuing debate about the causes of the spread of the disease. In response to this concern, the existing literature has focused on the determinants of the evolution of COVID-19 around the world.

In this vein, investigating the causes of the COVID-19 spread in Africa would enable the implementation of appropriate economic policies to address the major challenges they face, including the achievement of the Sustainable Development Goals and the post COVID-19 recovery that most African economies are facing (Barbier and Burgess, 2020; Roe et al., 2020; Leach et al., 2021). Thus, a review of the existing literature on the determinants of COVID-19 highlights several contributions from different disciplines that have proposed reasonable answers to the question of the spread of the disease worldwide (Diop et al., 2020; Coccia, 2021; Tavares and Betti, 2021; Bontempi and Coccia, 2021).

Specifically, several axes emerge, such as the role of direct transmission occurring from human to human through contact or proximity in the first instance (Chang et al., 2021). Secondly, demographic parameters ranging from population density in relation to socio-economic activities, age, gender, and urbanization(Bertuzzo et al., 2020; Copiello and Grillenzoni, 2020; Ehlert, 2021; Garenne, 2020). Other studies suggest the axis of environmental and climatic factors, such as pollution, humidity, wind speed and temperature associated with the transmission dynamics of COVID-19 (Copat et al., 2020; Ahmadi et al., 2020; Şahin, 2020). Subsequently, health factors, particularly through health inequalities, health expenditure and medical density were discussed (Okoi and Bwawa, 2020; Garenne, 2020). Finally, the last axis explored in the literature on the determinants of the spread and COVID-19 is that of economic factors such as GDP per capita, the level of tourist travel, the employment rate, poverty, inequalities and air transport (Diop et al., 2020; Banik et al., 2020; Farzanegan et al., 2021; Davies, 2021; World Bank, 2022; Garenne, 2020).

In this respect, the diagnosis of a careful reading of these and related studies in the light of developments in the literature on the explanatory factors of the COVID-19 spread recommends further investigation for at least two reasons. The first concerns economic factors, and more specifically income inequalities. Indeed, although the literature has not yet reached a consensus on the possibility of a proven effect of income inequalities on pandemics (Davies, 2021), they have been very weakly associated with COVID-19, particularly in developing economies and specifically in Africa where these inequalities persist (Leach et al., 2021; Wildman, 2021). To the best our knowledge, Wildman's (2021) study is the only one to explicitly address the effect of income inequality on COVID-19 within Organization for Economic Co-operation and Development (OECD) member countries. Concretely, it analyses the relationship between income inequality and COVID-19 deaths in OECD member countries. To this end, it demonstrates a positive and significant association between income inequality and COVID-19 deaths. This is justified by the fact that individuals facing income inequality face many socio-economic disadvantages that can contribute to COVID-19 spread and deaths associated with the disease. However, this work is limited to a direct analysis of this relationship, which could raise questions as the simultaneous consideration of direct and indirect effects would allow us to obtain an overall effect that best reflects the reality of the evolution of the relationship studied (Papyrakis and Gerlagh, 2004).

The second reason refers to the empirical assessment of this relationship, which to the best of our knowledge has not been sufficiently tested empirically, and even less in the context of African economies. Above all, the approach of the channels through which inequalities affect the COVID-19 spread have not yet been explored in the literature. More specifically, the channels of the informal economy and literacy have been left out of empirical assessments of the relationship between income inequality and COVID-19. With regard to the informal sector, studies show that formal sector is associated with the payment of taxes (Besley et al., 2012), something that seems unlikely for people without high incomes. Therefore, income inequality is associated with an increase in the informal sector. Similarly, the conditions in which informal sector activities take place, including crowded markets and congested streets, favour contact between people and therefore the COVID-19 spread (Nguimkeu and Okou, 2021). The rationale for the literacy channel is that income inequality hinders the ability to prevent and treat COVID-19 among the poor who are most vulnerable due to their high illiteracy rates, thus confounding the safety, eradication and control of the spread of the pandemic (Nanda, 2020).

This paper therefore proposes to fill this gap in the existing literature by examining the question of the direct and indirect effects of income inequality on the COVID-19 spread in a sample of 43 African countries. Specifically, this paper extends the existing literature on COVID-19 by examining how income inequality affects the COVID-19 spread. Although the literature analysing the effect of income inequality on the COVID-19 spread is very scarce, the relationship between the two concepts can be established through two channels, namely the informal sector and literacy. In this respect, apart from analysing the direct link between these variables, this paper focuses particular emphasis on the role played by the literacy and the informal

economy in explaining this relationship. Thus, we propose one of the first empirical assessments of transmission channels in the analysis of the relationship between income inequality and COVID-19 spread.

To this end, the existing literature proposes several methodological approaches adopted in direct and transmission channel analyses. In this work, based on the Hausman test, we use the fixed effects model. However, for the specific case of the analysis of transmission channels, we refer to the work of Papyrakis and Gerlagh (2004) and Adams and Fotio (2022). The advantage of this method is that it makes it possible to separate the total effect from the indirect effect. Work based on interactions between variables may underestimate or overestimate the estimated coefficient due to the non-separation of these two effects (Papyrakis and Gerlagh, 2004; Adams and Fotio, 2022). Thus, the results of the direct analysis reveal that income inequality increases the COVID-19 spread in Africa. Although the indirect analysis supports these results, the coefficients estimated from the direct analysis are underestimated. Thus, the informal sector and literacy are the channel through which income inequality affects COVID-19 spread.

The rest of the article is structured as follows: Section 1 presents the methodological approach. The results and discussions are presented in Section 2. Section 3 concludes and proposes some policy implications.

1. METHODOLOGICAL APPROACH

1.1. Analysis model

This paper aims to examine the direct and the mediated effect of income inequality on COVID-19 spread on a sample of 43 Africa countries. The empirical model relates the income inequality of country i at the time t to the natural log of COVID-19 total cases and COVID-19 severity. To choose between fixed or random effects we use Hausman test where the null hypothesis is that the preferred model is random effects versus the alternative hypothesis is the fixed effects (Uprety, 2019)[2]. Regardless of COVD-19 indicator chosen, the results of the Hausman test indicate that fixed effects model is fit well to our data to explain the link between income inequality and COVID-19 spread.

b = conisten under H_O and H_a; obtained from xtreg
B = inconsistent under H_a, efficient under H_o; obtained from xtreg

when COVID-19 is captured by total cases
$Chi^2(5) = (b-B)'[(V_b - V_B)^{-1}](b-B)$ =62.28
$Prob. > Chi^2$=0.000
When COVID-19 is captured by severity:
$Chi^2(5) = (b-B)'[(V_b - V_B)^{-1}](b-B) = 55.35$
$Prob. > Chi^2$=0.000

In either cas, the $Prob. > Chi^2$ is less than 1% level of significance and therefore, the null hypothesis (random effect is appropriate) is rejected. So we use fixed effect estimation. Thus, the specification adopted is as follows:

$$LogY_{it} = \alpha + \beta \times Ineq_{it} + X'_{it} \times \gamma + \tau \times M'_{it} + \sigma_i + \omega_t + \varepsilon_{it} \quad (1)$$

where the subscripts i = country and t = year; $LogY_i$ is the logarithm of the dependent variable which can be either the total number of confirmed COVID-19 cases or the severity of COVID-19; $Ineq_i$ is our main variable of interest which captures income inequality; σ_i and ω_t respectively represent country and time specific fixed effect. The reason for using fixed effect (FE) model is to control each of the 43 countries' own individual characteristics that may influence the predictor variables, income inequality. Heterogeneities across sample countries are controlled by σ_i and ω_t. FE removes the effect of those time-invariant characteristics, so that the result can assess the net effect of the predictors on the outcome variables. The use of the logarithm in the empirical literature is justified by the reduction of skewness in data (Saadi, 2020); X_i is a vector of control variables including: population density, GDP per capita and government effectiveness; M_i represents the vector of other control variables that incorporates the informality rate and the literacy rate into the model; ε_i represents the error term. Finally, β, γ and τ are coefficients to be estimated and α the constant.

All of these identified control variables are in line with the theoretical and empirical literature (Lopes and Mckay 2020; Nguimkeu and Okou 2021; Nguimkeu and Tadadjeu 2021; Koudjom et al. 2022; Wildma, 2021). Indeed, high population density is likely to increase intercommunal contamination even if social distancing measures are respected (Amate-Fortes and Guarnido-Rueda, 2022; Nguimkeu and Tadadjeu, 2021; Koudjom et al., 2022; Garenne, 2021). Thus, just like previous authors, we expect a positive relationship between population density and COVID-19 spread. In the empirical literature, there is a lack of consensus about the effects of income on disease spread. While Nguimkeu and Tadadjeu (2020) and Nguimkeu and Okou (2021) find no significant effect, other authors find a positive and significant effect on disease spread

[2] .Basically, Hausmann test whether the unique errors (ε_i) are correlated with the regressors, the null hypothesis is they are not.

(Wildman, 2022; Koudjoum et al., 2022). Thus, as in previous studies, to capture income level, we use GDP per capita (Ngimkeu and Okou, 2021; Nguimkeu and Tadadjeu, 2020). To capture institutional quality, this research considers government effectiveness. The use of such a variable is justified by all the measures taken by the government to stop the progression of the disease (Desson et al., 2020). These measures include, among other things, partial or complete lockdown, compliance with barrier measures, detection and treatment centers and social transfer policies. Like previous studies (Koudjom et al., 2022; Amate-Fortes and Guarnido-Rueda, 2022), we expect a negative relationship between the two variables.

Also due to the informal economy and the fragility of the education system in most African countries, this study takes into account the rate of informality and the rate of literacy which may favor the increase in the number of COVID-19 cases thanks to non-compliance with barrier measures (Koudjom et al., 2022; Nguimkeu and Tadadjeu, 2021; Lopes and McKay, 2020). Indeed, the activities of the informal sector most often take place without respecting the barrier measures enacted by political decision-makers to stop the progression of the disease (Nguimkeu and Okou, 2021). Although the authors seem unanimous about a positive relationship, very few studies have used the informal sector as a determinant of covid-19. To our knowledge, only Nguimkeu and Okou's work uses the informal sector as a determinant of disease. For these authors, the informal sector increases the spread of the disease (Nguimkeu and Okou, 2021). Thus we expect a positive relationship between the two variables.

Work by Lopes and Mckay (2020) shows that people who are illiterate are less open to health education and are less likely to comply with the advice and guidelines of disease prevention services. Although the role of education is considered decisive in the fight against this disease, to our knowledge, no study has included this variable as a determinant of the spread of the disease. Based on theoretical literature, We expect a positive relationship between the two variables. Thus, the extended version of equation (1) can take the following form:

$$LogY_{it} = \alpha + \beta \times Ineq_{it} + X'_{it} \times \gamma + \tau_1 \times Inf_{it} + \tau_2 \times Lit_{it} + \sigma_i + \omega_t + \varepsilon_{it} \quad (2)$$

Where Inf_i and Lit_i respectively represent the informality rate, i.e., the share of informal employment as a percentage of total employment and the literacy rate measured by the share of the literacy rate of people aged 15 and over. The other variables and symbols remained the same.

1.2. Analysis data

To achieve the objective of this work, this study uses a sample of 43 African countries observed over the period 2020-2022. Five data sources are used to collect the variables necessary for the empirical analysis: (1) the total number of confirmed cases of COVID -19 and disease severity are from the World Health Organization (WHO, 2020); (2) the Gini concentration index that captures income inequality is taken from the World Bank PovcalNet Report (PovcalNet-World Bank, 2019); (3) population density, GDP per capita, official development assistance and literacy rate are taken from World Bank Indicators (World Bank 2020); (4) the informality rate is taken from the International Labor Organization database (ILO, 2020); (5) The institutional variable (government effectiveness) is taken from Worldwide Governance Indicators database (Kaufmann et al., 2017). Detailed definitions and data sources are summarized in Table A2 in the appendix along with the list of countries used (Table A1). The descriptive statistics of the variables used for the analysis of the direct and indirect effect of income inequality on COVID-19 spread in Africa are presented in Table 1 below. Also, Table A4 in the Appendix shows the correlation matrix for the variables used.

Summary statistics for all these variables are presented in Table 1. Table 1 shows that, on average, confirmed cases and the severity of COVID-19 over the period 2020-2022 amount to 143531.5 cases and 39.339 % respectively. A careful analysis of our main variables of interest over the period 2020 to 2022 shows that in most African countries, income inequality, the informality rate and the literacy rate are respectively 54.93%, 80.52% and 72.98%. In terms of socio-economic variables, average per capita income and population density are respectively US$4.80 e+10 and 122.2705 inhabitants/km2. Institutional quality, captured by government efficiency, averages -0.682.

Table 1. Descriptive statistics

Variables	Observations	Mean	Std. Dev.	Min	Max
Dependent variables					
Total COVID-19 cases	129	143531.5	476722.3	226	4028160
COVID-19 severity	127	39.399	15.00179	7.638	70.92282
Interest variables					

Income inequality (%)	127	54.92898	7.495525	31.92	67.46
Informality (%)	120	80.52203	19.08803	15.06	98.62
Literacy rate (%)	128	72.9844	13.91951	27.28	96.2
Control variables					
GDP per capita	128	4.80 e+10	9.49 e+10	5.47 e+10	4.77 e+10
Government effectiveness	128	-0.6820138	0.6618482	-2.131399	0.8995878
Population density	120	122.2705	146.1064	3.0233	634.1182

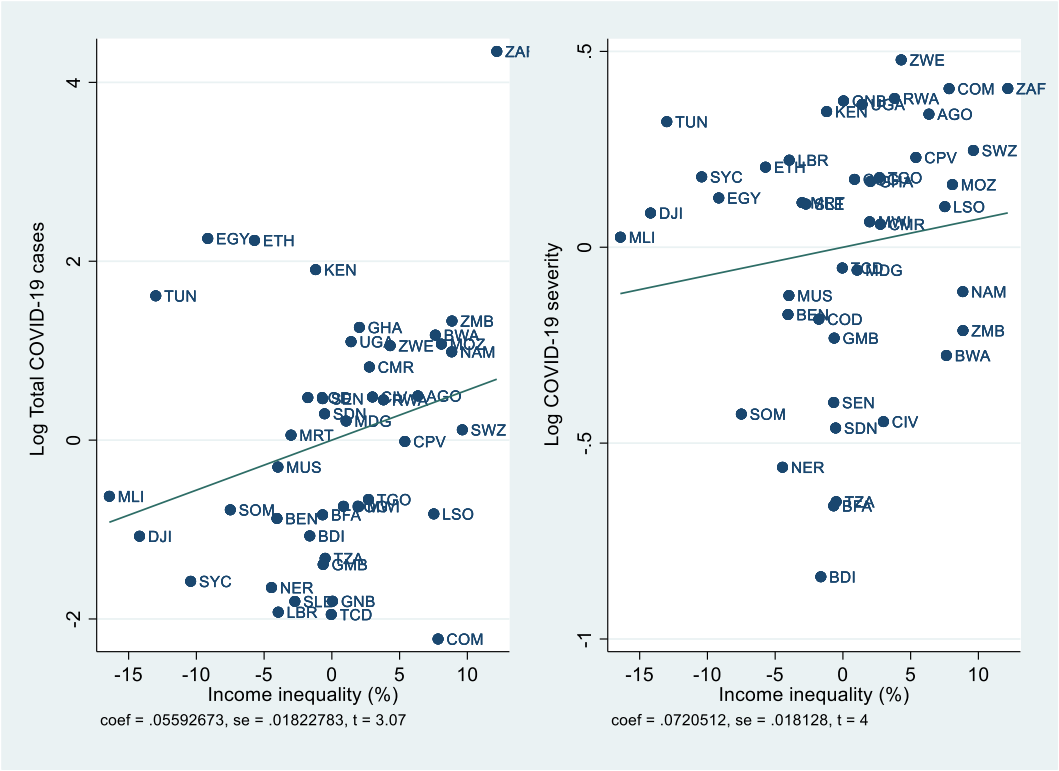
Source: Authors

1.3. Descriptive analyzes

The first cases of COVID-19 were reported in most African countries in early March 2020 while the number of confirmed cases increased rapidly after 15 March 2020. As of April 10 2020, some African countries Africa already had more than 6,000 confirmed cases. South Africa had the largest outbreak in Africa with 1,039,161 cases from March to December 2020 associated with 28,033 death cases, while Seychelles had the lowest number of confirmed cases (226) associated with 0 deaths over the same period. Considering the years 2021 (January-December) and 2022 (January-October), we find that South Africa is still recording more cases and deaths, i.e., 3,446,532 cases associated with 91,061 deaths in 2021. Also, we note in this country that the number of confirmed cases and deaths are respectively estimated at 4,028,160 and 102,311 in 2022. In addition, the statistics indicate that in 2021 it is rather Chad which experienced fewer cases (5,701) associated with 181 deaths. However, in 2022 we also see that it is rather Sao Tome and Principe which records fewer cases (6,266) associated with 77 deaths. Table A3 in the Appendix presents the multicollinearity test (variance inflation factor, VIF). The results show that VIF=1.56 and 1.3 respectively in the case of COVID-19 cases and COVID-19 severity, this value indicates a moderate correlation between the explanatory variables of the model, but it is often not severe enough to require special attention. Furthermore, Figure 1 presents the scatter plot of the relationship between income inequality, the number of COVID-19 infections and the severity of the pandemic in Africa. It appears from this figure that the total number of cases was higher in South Africa, lower in countries such as: Comores, Chad, Liberia, Guinea-Bissau, Sierra Leone, Niger, Seychelles, Gambia and Tanzania. On the other hand, the severity of the disease was lower in Burundi. One of the reasons why South Africa has seen the most cases is its high rate of urbanization.

Indeed, COVID-19 pandemic is an urban crisis – about 95% of total cases are in urban areas (United Nations Settlements Programme, 2020b; Smit, 2020). South Africa is one of the most urbanized countries in Africa with around 67 % of its population living in urban ares (United Nations Settlements Programme, 2020a). This can make it easier for the virus to spread quickly in areas where people live and work in close proximity to each other. Cape Town, the second largest city in South Africa, has been one of the cities most affected in Africa – it has had more than 70,000 cases (South African Government, 2020 ; Smit, 2020). Cities are considered the epicenter in infectious disease transmission, not only because of international travel and migration, but also because urbanization is associated with negative health outcomes and utilization (Stillwaggon, 2002; Nguimkeu and Tadadjeu, 2020). World Bank data on urbanization as a percentage of total population for the least-affected countries in our sample show that over the period 2020-2022, Burundi has the lowest urbanization rates of 13.708%, 14.058% and 14.417%, for the years 2020, 2021 and 2022 respectively. Given that there is a positive relationship between urbanization and disease spread (Nguimkeu and Tadadjeu, 2020; Smit, 2020), such a situation may justify Burundi as the country with the lowest severity forms of the disease. Similarly, Figure 1 also shows that the slope of the relationship between income inequality and the total number of cases, and between income inequality and disease severity, is positive, proof that there is a positive relationship on the one hand between income inequality and the total number of cases and on the other hand between income inequality and the severity of the disease.

Figure 1. Relationship between income inequality, total number of COVID-19 cases and COVID-19 severity index in Africa in 2020



Source: Authors

This direct positive relationship between income inequality and the total number of confirmed COVID-19 cases will be confirmed by econometric estimates. However, the number of cases of COVID-19 infection has probably been underestimated in Africa due to the lack of screening capacity in many countries (WHO, 2020). Although the number of confirmed cases remains low, when Africa is compared to other continents of the world, the negative effects are still noticeable, including the contraction of economic activity leading to a drastic decline in people's livelihoods, accentuating income inequalities in Africa, especially in sub-Saharan Africa (IMF, 2020; Nguimkeu and Okou, 2021).

Furthermore, it should be recalled that most economies in African countries are informal. Consequently, people in these countries tend to face higher levels of informality, illiteracy and income inequality coupled with a lack of social protection (Nguimkeu and Okou, 2021; Amin and Okou, 2020), and have no replacement income or savings in case of unexpected external shocks, such as COVID-19. Therefore, social distancing measures to control the virus may be ineffective for African populations, as staying at home and not working implies the loss of income crucial to their livelihoods, potentially driving up income inequalities.

2. RESULTS AND DISCUSSION

2.1. Analysis of the direct effect of income inequality on COVID-19 spread

2.1.1 Basic results

Table 2 presents the basic results. The first two columns of this table present the results where our dependent variable is the total number of cases while in the other two columns the dependent variable is the severity of the disease. In the second column of each block, we introduce the variable that captures literacy and the informal sector. In Table 2, all coefficients have the expected signs in terms of the direction of the relation between the independent and dependent variables. The coefficient of determination R^2, in all equations is 61% or more, and the high value of F tests, 26.69, decisively rejects the hypothesis of joint non-significance of the independent variables. With respect to our variable of interest, namely income inequality, the results show that it positively and significantly affects COVID-19 at the 1% (columns 1, 2 and 4) and 5% (column 3) thresholds. Therefore, all other things being equal, a one-percentage-point increase in income inequality is associated with 31.6% (column 1) and 89.8% (column 2), increase in the total number of COVID-19 cases. Similarly, a one-percentage-point increase in income inequality is associated with a 64.7% (column 3) and 58.2% (column 4) increase in disease severity. These results are consistent with those obtained in previous work. The work of Koudjom et al. (2022) show that income inequality has a positive and significant effect on the total number of cases and the severity of COVID-19. Similarly, the work of Wildman

(2021) shows that income inequality jointly increases the total number of cases and the number of deaths due to COVID-19 in OECD countries. The positive effect of income inequalities can be explained by the fact that the most disadvantaged social classes can not respect the barrier measures to limit the spread of the disease. Despite state social transfers, the disadvantaged classes are forced to continue going about their business, since they live on daily income (Cartlitz and Makhura, 2021; Durizzo et al., 2021; Bargain, 2021). In the specific case of Africa, the social transfers put in place to support populations were not sufficient to reduce the income gap between social classes (Koudjom et al., 2022). Consequently, populations with low incomes are forced to continue going about their business, thus promoting the spread of COVID-19.

As far as our control variables are concerned, the results are generally satisfactory. Table 2 shows that population density and the informal sector have a positive and significant effect on the spread of the disease, government effectiveness and literacy have a negative and significant effect. Regarding the variables with a positive effect, the positive effect of population density is also consistent with numerous studies in the empirical literature (Nguimkeu and Tadadjeu, 2021; Nguimkeu and Okou, 2021; Koudjom et al., 2022). Studies show that respiratory diseases such as COVID-19 are transmitted through contact (Alirol et al., 2011). High population density increases inter-community contact and therefore the spread of COVID-19. Finally, the positive effect of the informal sector on COVID-19 spread is also consistent with studies by Nguimkeu and Okou (2021). The informal sector in Africa being characterized by crowded markets, congested streets and communal sanitation facilities may be the cause for the spread of the disease.

Finally, the variables with a negative effect include: government efficiency and literacy. The negative effect of government effectiveness is consistent with the work of Koudjom et al. (2022). This negative effect is explained by the fact that the appearance of the first cases in the various African countries was followed by measures to stop the spread of the disease. Finally, the negative effect of literacy also corroborates the results of the work of Lopes and Mckay (2020) which show the importance of education on improving health. Lack of education is sometimes associated with misinformation, non-compliance with barrier measures. Educated populations better understand the merits of respecting the barrier measures necessary to stop the progression of the disease (Lopes and Mckay,2020).

Table 2. Effect of income inequality on COVID-19 spread in Africa

	Log Total COVID-19 cases		**Log COVID-19 severity**	
	(1)	(2)	(3)	(4)
GINI concentration index	0.316***	0.898***	0.647**	0.582***
	(0.071)	(0.290)	(0.273)	(0.191)
Log Population density	0.648***	0.225*	0.317***	1.024***
	(0.137)	(0.133)	(0.104)	(0.220)
Log GDP per capita	-0.177	-0.523*	-0.456	-0.585
	(0.189)	(0.271)	(0.304)	(0.364)
Government effectiveness	0.485	-0.225*	-0.619	-0.501***
	(0.362)	(0.133)	(0.490)	(0.117)
Informality		0.461**		0.690***
		(0.215)		(0.251)
Literacy		-0.202*		-0.317***
		(0.118)		(0.103)
R^2	**0.663**	**0.693**	**0.610**	**0.739**
Fisher	**18.260**	**26.080**	**22.140**	**26.690**
Number of countries	**43**	**43**	**43**	**43**

Note: Significance *** **Note:** Significance *** p<0.01; ** p<0.05; * p<0.1; (.) Standard deviations.
Source: Authors

2.1.2 Robustness analysis

Two robustness analyses are carried out. First, the fixed-effects approach minimizes the impact of experimental errors, while improving the information available in the measurement process. However, it is not always efficient and can generate high variances. So, with a view to using an unbiased estimator of the model parameters generating a lower variance, we also use the Generalized least squares estimator proposed by Aitken (1935) as a robustness measure. The results obtained in Table 3 are consistent with those obtained in Table 2, namely a positive and significant effect of income inequality on the total number of cases and disease severity. Similarly, the results obtained by the control variables are also consistent with those obtained in Table 2. Indeed, we obtain a positive and significant effect of population density and informal sector on the one hand, a negative and significant effect of government effectiveness and literacy on the total

number of cases and disease severity on the other. Second, Figure 1 shows that South Africa has high values for the total number of cases, while Burundi has low values for disease severity. To obtain more robust estimators, we remove these two countries from our sample and repeat the estimations (using fixed effect estimator). Overall, even after removing the outliers, the results obtained in Table 4 confirm those obtained in Table 2.

Table 3. Effect of income inequality on COVID-19 spread, a robustness analysis on GLS approach

	Log Total COVID-19 cases		**Log COVID-19 severity**	
	(1)	(2)	(3)	(4)
GINI concentration index	0.202***	0.274***	0.594*	0.113***
	(0.057)	(0.055)	(0.314)	(0.0155)
Log Population density	0.658	0.579**	0.446*	0.408***
	(0.425)	(0.294)	(0.240)	(0.115)
Log GDP per capita	-0.661***	-0.736**	-0.192	0.697
	(0.253)	(0.358)	(0.182)	(0.116)
Government effectiveness	-1.032***	-0.824***	-0.224***	-0.448**
	(0.0553)	(0.0739)	(0.0591)	(0.212)
Informality		0.268**		0.677***
		(0.121)		(0.083)
Literacy		-0.250***		-0.804***
		(0.033)		(0.094)
Chi2	**2490.08**	**21115.40**	**1044.13**	**1738.07**
Prob (Chi2)	**0.000**	**0.000**	**0.000**	**0.000**
Number of countries	**43**	**43**	**43**	**43**

Note: Significance *** p<0.01; ** p<0.05; * p<0.1; (.) Standard deviations.
Source: Authors

Table 4. Effect of income inequality on COVID-19 spread, a robustness on the removing of outliers

	Log Total COVID-19 cases		**Log COVID-19 severity**	
	(1)	(2)	(3)	(4)
GINI concentration index	0.0201**	0.0181**	0.0098**	0.011*
	(0.01005)	(0.0078)	(0.0049)	(0.0057)
Log Population density	0.447**	0.35*	0.613**	-0.49
	(0.1943)	(0.194)	(0.2554)	(0.35)
Log GDP per capita	0.897***	0.121**	0.639***	0.503
	(0.095)	(0.0605)	(0.1278)	(1.110)
Government effectiveness	-0.972	-0.838	-0.518	-0.668
	(1.839)	(2.136)	(0.763)	(0.899)
Informality		0.148***		0.257***
		(0.0296)		(0.042)
Literacy		-0.032**		-0.206**
		(0.016)		(0.089)
R^2	**0.561**	**0.661**	**0.447**	**0.607**
Fisher	10.38	18.59	12.43	17.49
Number of countries	**41**	**41**	**41**	**41**

Note: Significance *** p<0.01; ** p<0.05; * p<0.1; (.) Standard deviations. *Source: Authors*

2.2 Analysis of the indirect effect of income inequality on COVID-19 spread

For the analysis of the indirect and total effect of income inequality on COVID-19 spread in Africa, we draw on the work of Papyrakis and Gerlagh (2004) and Adams and Fotio (2022). We adapt the described methodology to the context of our study. The main hypothesis of this study is that inequalities can have not only a direct, but also an indirect effect on the COVID-19 spread in such a way that they generate externalities that can either amplify or slow down the spread of COVID-19. Thus, Equation (1) may be underestimated (or overestimated) if inequalities indirectly affect COVID-19 spread. Two channels are identified in the literature (Gradstein, 2007; Gutiérrez-Romero, 2022), namely the informality and the literacy. To determine the existence of a mediated relationship, we specify a system of structural equations represented by Equations (1) and (3) in which the mediating variables are dependent. Equation (3) can be written as follows:

$$M_{its} = \delta_0 + \delta_1 \times Ineq_{it} + \chi_{its} \quad (3)$$

Where M_{is} is the vector of the s transmission channels (informality and literacy) in country i. δ_1 is the elasticity of the s channel with respect to income inequality. δ_0 is the constant, and χ_{is} is the error term. The mediation effect is only possible if δ_1 is significant. After replacing Equation (3) in Equation (1), we obtain the following Equation (4):

$$LogY_{it} = (\alpha + \tau\delta_0) + X'_{it} \times \gamma + (\beta + \delta_1\tau)Ineq_{it} + \tau\chi_{its} + \sigma_i + \omega_t + \varepsilon_{it} \quad (4)$$

In Equation (4), β indicates the direct effect, while $\tau\delta_1$ tells us about the indirect effect. Similarly, $(\beta + \tau\delta_1)$ reflects the total effect of income inequality on the spread of COVID-19. We estimate the direct and indirect effects of income inequality on the COVID-19 spread using structural equation modeling. In addition, following the work of Adams and Fotio (2022), the indirect effect is obtained using the product of the Sobel coefficients. This effect is obtained from the following Equation (5):

$$Indirect\ effect = \frac{\partial LogY_i}{\partial M'_{is}} \times \frac{\partial M'_{is}}{\partial Ineq_i} = \tau\delta_1 \quad (5)$$

Table 5. Effect of income inequality on the mediators

	Informality	**Literacy**
	(1)	(2)
GINI concentration index	0,914***	-0,591**
	(0,168)	(0,224)
Constant	7,305**	18,06***
	(3,616)	(6,225)
Number of countries	**43**	**43**

Note: Significance *** p<0.01; ** p<0.05; * p<0.1; (.) Standard deviations. *Source: Authors*

Table 6. Total effect of income inequality on COVID-19 spread

	Log Total COVID-19 cases	**Log COVID-19 severity**
	(1)	(2)
GINI concentration index	1.438***	1.399***
	(0.352)	(0.256)
Log Population density	0.225*	1.024***
	(0.133)	(0.220)
Log GDP per capita	-0.523*	-0.585
	(0.271)	(0.364)
Government effectiveness	-0.225*	-0.501***
	(0.133)	(0.117)
χ_{i1} **Informality**	0.461**	0.690***
	(0.215)	(0.251)
χ_{i2} **Literacy**	-0.202*	-0.317***
	(0.118)	(0.103)
R^2	**0.693**	**0.739**
Fisher	**26.080**	**26.690**
Number of countries	**43**	**43**

Note: Significance *** p<0.01; ** p<0.05; * p<0.1; (.) Standard deviations. *Source: Authors*

Table 2 shows that income inequality increases COVID-19 spread in Africa. Although these results are interesting, they may not reflect reality. We hypothesis that in addition to this direct effect, income inequality may indirectly affect the spread of COVID-19. In this case, the net effect of income inequality may be different from its direct effect. To test this hypothesis, we estimate the effect of income inequality on transmission channels. The results are contained in Table 5. As expected, income inequality indirectly affects COVID-19 spread through its effects on the informal sector and literacy. All things being equal, a one-percentage-point increase in income inequality is associated with a 91.4 % increase in the informal sector and a 59.1% reduction in literacy in Africa. These results are consistent with those obtained by Chong and Gradstein (2007) and Gutiérrez-Romero (2022). These results can be explained by the fact that due to low and/or unevenly distributed incomes, individuals prefer to enter the informal sector, as the formal sector requires the payment of taxes and fixed fees for registration with the authorities (Besley et al. 2012). Therefore, migrating to the formal sector requires sufficient wealth or many assets (Gutiérrez-Romero, 2022). Furthermore, the negative effect of income inequality on literacy rate can't be directly compared to previous work. Nevertheless, studies show that income inequalities lead to inequalities in consumption expenditure

(Krueger and Perri 2002). This disparity in consumption expenditure may be driven fundamentally by lower spending on education.

However, Table 6 assesses the total effect of income inequality on COVID-19 spread in Africa. The results reveal that the positive indirect effect of income inequality on the COVID-19 spread is greater than the direct positive effect contained in Table 2. All things being equal, an increase of one point compared to the average of income inequality results in an increase in the total number of cases of 1,438 (column 1, compared to 0.898 in the case of the direct effect obtained in Table 2) and the severity of the disease of 1.399 (column 2, against 0.582 in the case of the direct effect obtained in Table 2). These results indicate that the direct effect alone underestimates the effect of income inequality on COVID-19 spread in Africa.

Finally, based on Table 2 (columns 2 and 4) and Table 5, we calculate the contribution of each transmission channel to the total indirect effect of income inequality on COVID-19 spread. Similar to previous work by Adams and Fotio (2022) or more recently by Yeyouomo and Asongu (2023), we rely on the Sobel product coefficient approach. The results contained in Table 7 reveal that the informal sector is the channel that contributes most to the total effect. Considering the total number of cases, the informal sector explains 77.93% against 22.07% for literacy of the indirect positive effect of income inequality on the spread of COVID-19. In the case of disease severity, the informal sector explains 77.1% and literacy 22.9% of the direct positive effect of income inequality on the spread of the disease.

Table 7: Indirect transmission channels and their relative contribution

	Log Total COVID-19 cases		Log COVID-19 severity	
	Coef	Relative contribution	Coef	Relative contribution
Informality	0.4213	77.93 %	0.6306	77.1 %
Literacy	0.1193	22.07 %	0.1873	22.9 %
Total	0.5406	100 %	0.8179	100 %

Source: Authors' construction

The results of the mediation analysis are robust to the use of interaction variables between income inequality and literacy on the one hand and between income inequality and the informal sector on the other. The results are contained in Table A1 in the appendix.

3. CONCLUSION

This study empirically assesses direct and indirect effects of income inequality on COVID-19 spread on a sample of 43 African countries over the period 2020-2022, by using fixed effects regression model.The results of the direct analysis suggest that income inequality increases COVID-19 spread in Africa. Beyond these direct effects, the results of indirect analysis confirm positive and significant effect of income inequality on COVID-19 spread. This effect is made possible thanks to the informal sector and literacy. Overall, the informal sector is the main channel that explains 77.93% in the case of the total number of cases, and 77.1% in the case of the severity of the disease. These results show that direct analysis underestimates the effect of

income inequality on COVID-19 spread. The coefficients obtained from the indirect analysis are larger than those obtained from the direct analysis. The results of the direct analysis are robust to estimation using the general least squares (GLS) method and to the elimination of outliers. These results show that governments need to take steps to reduce income inequalities, as these are an obstacle to tackling health shocks through the negative externalities they generate on literacy and the informal sector. On the one hand, COVID-19 highlights the need for a certain level of knowledge to ensure that citizens have sufficient information to change their behaviour to limit spread of the disease (Legido-Quigley et al., 2020). On the other hand, this pandemic also highlights the need to find mechanisms to ensure the transition from the informal to the formal sector, as informal sector has been the source of a large spread of the disease.

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Appendix

TableA1. List of countries

Angola	Congo	Guinea-Bissau	Mozambique	Sudan
Benin	Cote d'Ivoire	Kenya	Namibia	Tanzania
Botswana	Democratic Republic of Congo	Lesotho	Niger	Togo
Burkina Faso	Djibouti	Liberia	Rwanda	Tunisia
Burundi	Egypt	Madagascar	Senegal	Uganda
Cameroon	Eswatini	Malawi	Seychelles	Zambia
Cape Verde	Ethiopia	Mali	Sierra Leone	Zimbabwe
Chad	Gambia	Mauritania	Somalia	
Comoros	Ghana	Mauritius	South Africa	

Source: Authors

Table A2. Variables definition

Variables	Definitions	Sources
Log Total COVID-19 cases	The number of confirmed cases of COVID-19 in Africa	WHO (2022)

Log COVID-19 severity (%)	Also known as severity of infection, this is the extent of illness in people infected with the corona virus	WHO (2022)
GINI concentration index (%)	This index highlights income inequality at the aggregate population level	PovcalNet-World Bank (2022)
Size of population aged 65 and over	The size of population aged 65 and over in each African Countries	WDI (2022)
Population density	The average number of inhabitants in the given area per square kilometer	WDI (2022)
Log GDP per capita	Measures level of income per capital in each African Country	WDI (2022)
Health expenditure per capita	The quality of the health care system, as represented by the level of health expenditure per capital in each African country	WDI (2022)
Informality (%)	Measures the size of informal employment in each African country. It is measure by the share of informal employment as a percentage of total employment	ILO (2022)
Literacy rate (%)	It refers to the percentage of people ages 15 and above who can both read and write with understanding a short simple statement about their everyday life	WDI (2022)
Government effectiveness	Measures institutional quality	Worldwide Governance Indicators (Kaufmann et al., 2022)

Source: Authors

Table A3. Multicollinearity test

Variables	Log Total COVID-19 case		Log COVID-19seve-rity	
	VIF	1/VIF	VIF	1/VIF
Log Total COVID-19 cases	1.88	0.530598		
Log COVID-19 Severity			1.05	0.954535
Log GDP per capita	1.88	0.530549	1.21	0.828568
Population density	1.17	0.856297	1.17	0.857406
Informality (%)	1.71	0.585228	1.65	0.606829
Government effective-ness	1.54	0.647624	1.55	0.647211
Literacy rate (%)	1.19	0.839398	1.2	0.836549
Mean VIF	1.56		1.3	

Source: Authors

Table A4 : Correlation matrix

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Log Total COVID-19 cases	1.0000							
(2) Log COVID-19 severity	0.1304	1.0000						
(3) Income inequality (%)	0.0424	0.1305	1.0000					
(4) Informality (%)	-0.3906	-0.1407	0.2213	1.0000				
(5) Literacy rate (%)	0.1796	-0.0456	0.0739	-0.2947	1.0000			
(6) Log GDP per capita	0.5860	-0.0420	-0.0213	0.0483	0.2796	1.0000		
(7) Government effectiveness	0.3956	0.0689	-0.1084	-0.5535	0.1029	0.0319	1.0000	
(8) Population density	-0.1170	0.0550	-0.1191	-0.1186	0.0615	-0.2124	0.2392	1.0000

Source: *Authors*