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Oded Stark

Why reducing relative deprivation but not reducing income inequality might bring down COVID-19 infections

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Center for Development Research
Genscherallee 3
D – 53113 Bonn
Germany
Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: zef@uni-bonn.de
www.zef.de

The author:
Oded Stark, Universities of Bonn and Warsaw.
Contact: ostark@uni-bonn.de

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Abstract

We examine an assumed link between reducing inequality in income distribution, namely reducing the Gini coefficient on one hand, and improving public health in general and lowering the incidence and severity of COVID-19 in particular on the other hand. The Gini coefficient can be shown to consist of two components, one of which is (a measure of) relative deprivation, which was found to cause social stress that harms public health. Because a component is not the whole, the lowering of inequality in the income distribution by means of reducing the Gini coefficient does not necessarily result in lowering relative deprivation. Specifically, we show that a policy of reducing income inequality aimed at improving public health might not be effective - even when, in the process, no-one's income is reduced, or all incomes increase.

Keywords: Inequality in the distribution of incomes; Attributes of the Gini coefficient; Relative deprivation; Public health; Policy formation

JEL classification: D01; D91; I12; I14; I18

1. Introduction

There is a keen interest in documenting variations in the incidence (the infection and fatality rates) of COVID-19, in identifying causes of the variations, and in forming policy responses. Several recent studies reported an association / correlation between income inequality as measured by the Gini coefficient and measures of infection and mortality of COVID-19. A common theme in these studies is an explicit or implicit policy recommendation: lower income inequality - reduce the Gini coefficient.[1] A sample of these studies includes Elgar et al. (2020), Oronce et al. (2020), Liao and De Maio (2021), Tan et al. (2021), and Wildman (2021). For example, Tan et al. (2021) write: "Targeted interventions should … focus on income inequality measured by the Gini coefficient to … flatten the [COVID-19 pandemic] curve." Wildman (2021), who identifies "a clear association between income inequality [measured by the Gini coefficient] and COVID-19 cases and deaths" (p. 457), concludes that "a goal of government should be to reduce [income] inequalities and [thereby] improve [the COVID-19 outcomes /] underlying health of their populations" (p. 461).

In this paper we argue that income inequality as measured by the Gini coefficient should not be perceived as a cause of COVID-19 cases and mortality; that the Gini coefficient is not an appropriate index for quantifying a cause of COVID-19 cases and mortality; and that reducing the Gini coefficient can actually co-exist with exacerbating a cause of COVID-19 cases and mortality.

A number of studies demonstrate that stress, not inequality, is a cause of poor health outcomes in populations. The standard index of inequality, the Gini coefficient, does not measure the level of stress in a population. As shown in Section 3, the coefficient is equal to a measure of stress divided by aggregate income. This decomposition is neat because we already have in hand a measure of stress in a population - the population's aggregate or total relative deprivation, *TRD*. The *TRD* of a population is the sum of the levels of relative deprivation of the members of the population. In turn, the relative deprivation of a member of

[1] There has been a deluge of studies on the effect of the COVID-19 pandemic on income inequality, where the core question has been: did the pandemic exacerbate inequality within and between countries? One of many examples is a study by Deaton (2021) who sought to sign the impact of pandemic-caused deaths and the consequent change in per capita income on international income inequality, concluding that the sign of the effect is sensitive to the assumptions made. Far fewer studies inquired how income inequality affects COVID-19 infection rates. Indeed, it is somewhat surprising that economists who thus far produced hundreds of studies on the COVID-19 => income inequality link have been somewhat reticent when it comes to studying the income inequality => COVID-19 link.

a population is defined as the sum of the member's income excesses divided by the size of the population.

Example 1

Consider a population of two members whose incomes are $x_2 > x_1 > 0$. In this case, relative deprivation is experienced only by the individual whose income is x_1. The Gini coefficient as a function of income vector *x*, namely $G(x)$, takes the form of

$$G(x) = \frac{\frac{1}{2}(x_2 - x_1)}{x_2 + x_1}.$$

Let the two incomes be $x_1 = 1$ and $x_2 = 3$, and let these incomes be raised, respectively, to 2 and 5. In this setting, while the Gini coefficient decreases from 1/4 to 3/14, *TRD* increases from 1 to 3/2. This example demonstrates that a reduction in the Gini coefficient can co-exist with increasing total relative deprivation. Thus, if stress, as measured by relative deprivation, is to be reduced, then getting there via lowering the Gini coefficient may fail. An appropriate policy response is to operate on relative deprivation directly. Below we elaborate.

By construction, relative deprivation is the result of comparisons. We can refer to the people with whom an individual compares his income as comparators. Relative deprivation as the outcome of comparisons that a given individual makes with others whose incomes exceed his own suggests policy interventions that were not considered in the studies listed in the opening paragraph of this section of the paper.

Example 2

Let there be four individuals who suffer from the same illness, but with different degrees of severity: individual 1 is the most seriously ill, individual 4 is the least ill. The individuals require hospitalization. Given the scarcity of rooms, the plan is to place all four individuals in one room. It is well recognized that individuals 1, 2, and 3 will experience social-psychological stress from comparing the gravity of their illness with that of the individuals / individual who are / is not as severely ill as they are. It then becomes known that the hospital can in fact place the individuals in two rooms rather than in one room. There will be no (direct) medical effect from distributing the individuals between two rooms rather than placing them in one room. However, because the comparison group will differ, the extent of social-psychological stress will differ, assuming that the hospital room is the comparison environment. How can the four individuals be distributed between the two rooms so that aggregate social-psychological stress is minimized?

As before, let the relative deprivation in a group of two be half of the difference between the levels of gravity of the illness of the two. In division {{4,2},{3,1}} as well as in division {{4,1},{3,2}} the sum of the levels of relative deprivation is four. In division {{4,3},{2,1}}, the sum of the levels of relative deprivation is two. Thus, a division of {1,2,3,4} into the two subsets of {4,3} and {2,1} minimizes the group's aggregate social-psychological stress.

The usefulness of this example is in demonstrating a protocol of lowering stress that does not involve changes in the levels {1,2,3,4}; the reduction of stress is achieved by means of revised grouping.

The remainder of this paper is organized as follows. In Section 2 we review studies on the adverse health consequences of relative deprivation. In Section 3 we define and decompose the Gini coefficient. In Section 4 we show that lowering the Gini coefficient can co-exist with increasing total relative deprivation. The type of scenario of Example 1 is generalized to the case of more than two individuals, and a sufficient condition is derived for an increase in income of all the individuals to co-exist with an increase in total relative deprivation coinciding with a decrease in the Gini coefficient. The focus on the population's relative deprivation as the target of intervention aimed at lowering social stress invites formulating a condition as to when does a rank-preserving rise in income decrease the relative deprivation of a population, and when does it increase the relative deprivation of a population. This task is the subject of Section 5. Section 6 concludes. Proofs of the three claims presented in Sections 4 and 5 are in the appendix.

2. Stress, relative deprivation, and adverse health outcomes

In medical science, stress is amply documented as a cause of physical and mental harm. For example, with regard to physical harm, Cohen and Williamson (1991) present intriguing evidence about the influence of stress on infectious diseases, and Kivimäki et al. (2006) and Steptoe and Kivimäki (2013) conduct meta-analyses which demonstrate the substantial influence of work-related stress on the risk of coronary disease. With regard to mental harm, Turner et al. (1995) find that exposure to stress is a significant explanatory variable of depressive symptoms and major depressive disorder, and Hammen (2005) reviews studies that yield a robust and causal association between stressful life events and major depressive episodes. Medical science differentiates between two types of stress factors: internal, when stress is caused by illness and medical treatment, and external, which arises from adverse social conditions.[2]

In disciplines ranging from economics and psychology to public health and neuroscience there is widespread recognition that comparisons with others significantly affect wellbeing. In particular, studies have shown that along a variety of dimensions, people are stressed when they lag behind in comparison with their comparators. Examples of such studies span from Lynch et al. (2004), Subramanian and Kawachi (2004), Jones and Wildman (2008) and Zink et al. (2008) to Cundiff et al. (2020) and Pak and Choung (2020). We refer to this type of stress as social-psychological stress or as stress caused by relative deprivation.

The adverse health consequences of relative deprivation are indeed disturbing. Using data for males from the US National Health Interview Survey and from the US Behavioral Risk Factor Surveillance System, Eibner and Evans (2005) report that high relative deprivation is related to an increased probability of smoking. Using data on deaths by suicide in the US so as to identify the importance of interpersonal comparisons and “relative status,” Daly et al. (2013) found compelling evidence that individuals care not only about their own income but also about the income of others in their local area: Daly et al. showed that individual suicide risk rises with others’ income. This finding was obtained using two separate and independent data sets, suggesting that it is not the product of a particular sample design of either data set. The finding is robust to alternative specifications and cannot be explained by geographical variation in suicide classification, cost of living, or access to emergency medical care. The finding is consistent with the idea that relative deprivation, rather than a person’s own absolute income, matters for wellbeing, and that the stress it causes can be severe enough to make people take their own life. Drawing on data from the US National Longitudinal Study of Adolescent Health, Balsa et al. (2014) find that relative deprivation is positively associated with substance abuse (heavy drinking and smoking) in

[2] Damage to a person’s mental health can also affect the health of others, an externality which occurs when physical harm is inflicted on others (domestic violence is an example that comes readily to mind).

adolescent males. The preceding three studies in economics align with several revealing studies in social psychology (for example, Callan et al., 2011; Smith et al., 2012) which document how sensing relative deprivation impacts negatively on personal wellbeing.

A common feature of a substantial number of studies that establish a significant positive correlation between social stress, which is measured by relative deprivation, and adverse health outcomes, which range from obesity to suicides, is that the empirical findings of a significant correlation are followed by policy recommendation. In medical terminology: for a diagnosis that relative deprivation is a cause of social stress which harms health, the prescribed remedy is to lower income inequality; doing this will reduce the harm done. For example, in a relative deprivation-based study of self-reported health in Japan, Kondo et al. (2008, p. 984) conclude that relative deprivation is expected to rise as income inequality grows. In a relative deprivation-based study of poor health in the U.S., Subramanyam et al. (2009, p. 327) refer to the "association between income inequality and worse population health status." In a relative deprivation-based study of self-reported physical and mental health in Canada, Mishra and Carleton (2015, p. 148) write: "[Our] results . . . support a large and compelling body of evidence suggesting that income inequality and its downstream consequences have immense and wide-reaching impacts on physical and mental health." In a study of suicide risk in South Korea, Pak and Choung (2020, p. 1) conclude as follows: "[O]ur findings suggest that relative deprivation in income is independently associated with higher odds of suicidal ideation and suicide planning or attempt over and above the effect of absolute income and material living conditions. Narrowing the income gap between individuals would be an effective policy response to a suicide epidemic in South Korea." A recurrent claim of Wilkinson and Pickett, who carved a formidable niche in this sphere, is that reducing inequality in income distribution is a means of lowering relative deprivation: because relative deprivation is a cause of stress, lowering inequality in the distribution of incomes is considered an effective way of reducing an adverse psychological effect that causes a great many ills. Two examples of statements to this effect are: "[T]hat there is a strong association between income distribution and national mortality . . . suggests that the extent of relative deprivation in each society, as measured by its income distribution, is a major determinant of national mortality rates." (Wilkinson, 1992, p. 1084.) "If causes of death . . . are most sensitive to the contextual effects of income inequality, this lends weight to suggestions that .

. . relative deprivation may be [a] determinant of health." (Wilkinson and Pickett, 2008, p. 703.)

To do justice to the existing literature, we refer in some detail to a widely cited review by Deaton (2003), who looks closely at evidence of the effect of income inequality on health and concludes that "The stories about income inequality affecting health are stronger than the evidence" (p. 150). Deaton does not deny the influence of relative deprivation on health outcomes; in his review he refers to relative deprivation some ten times, and he mentions stress some dozen times. While Deaton cites evidence of the role of relative deprivation in causing stress and thereby ill health, he does not use it to recommend policies to lower relative deprivation directly: there is no recommendation to lower relative deprivation, which will lower stress, which thereby will improve health outcomes. Perhaps one reason why Deaton does not do so is that he considers the evidence that he scrutinizes ambiguous. While he comments that "[w]ithin states, the relative deprivation story does well" (p. 149), he also writes that "the relative deprivation model accounts for essentially none of the variation in mortality across states" (p. 149). However, Daly et al. (2013) document meticulously that exactly the opposite holds.[3]

All in all, we discern a distinct policy perspective in the existing literature: lowering income inequality will lower stress, which thereby will improve health outcomes. To this perception we say "no:" this sequence is not an acceptable substitute for the sequence: lowering relative deprivation will lower stress, which thereby will improve health outcomes. While there could be a great many reasons why reducing income inequality is socially desirable, doing so for the sake of lowering relative deprivation may be a miss rather than a hit. Specifically, the argument presented in this paper is that the existence of a seamless link between lowering inequality in income distribution (lowering the Gini coefficient) and a reduction in relative deprivation is an illusion.[4] In particular, a policy aimed at improving public health (and, thus also social welfare) may not be helped by reducing inequality in the distribution of incomes even when, in the process, no income is lowered / all incomes

[3] We already stated that relative deprivation is defined and measured for a reference group. To the extent that people compare themselves to others in their own state but less so or not at all to others in other states, these last two of Deaton's empirical observations can be reasoned analytically.

[4] In writing on the effect of inequality in income distribution ("income gap") on public health, the level of inequality in the distribution of incomes is habitually measured by means of the Gini coefficient. (This can be seen, for example, in the large number of studies reviewed by Deaton, 2003, and by Lynch et al., 2004.)

increase. If relative deprivation is a measure of social stress, then lowering the Gini coefficient is not synonymous with reducing social stress. The reason for the disconnect is that what people are concerned about and are distressed by is not income inequality as such but, rather, incomes (or measures of incomes) that they are deprived of. This consideration implies a dichotomy between the Gini coefficient on the one hand and social stress and social welfare on the other hand; when incomes are held constant or even increase and the Gini coefficient declines, social stress can nonetheless remain unchanged (social stress can stay as it is) or increase.

In the next section we provide a formal definition of the Gini coefficient for a population. We decompose the coefficient in such a way that it enables us to express it as a product of terms, one of which is a measure of the population's relative deprivation. We do this for the case of a discrete income distribution. With the decomposition displayed, in Section 4 we manipulate an income distribution in the following manner: we let incomes increase, thereby lowering the Gini coefficient. We show that at the very same time, relative deprivation increases. This demonstration enables us to infer that because lowering the Gini coefficient can co-reside with increasing relative deprivation, enacting a policy to lower inequality can not only fail to reduce relative deprivation; it can actually exacerbate relative deprivation: a policy measure aimed at reducing social stress can increase social stress.

3. The Gini coefficient: Definition and decomposition

Let $V^n \subset \mathbb{R}^n$ be a set of ordered vectors, namely

$$V^n = \{(x_1, x_2, \ldots, x_n) \in \mathbb{R}^n : \ x_1 \leq x_2 \leq \ldots \leq x_n\}.$$

Following Sen (1973), the Gini coefficient for $x \in V^n$ can be defined as

$$G(x) \equiv \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} | x_i - x_j |}{2n\sum_{i=1}^{n} x_i}.$$

On noting that $\sum_{j=1}^{n}\sum_{i=1}^{n}\left|x_i - x_j\right| = 2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(x_j - x_i),$ this formula can be rewritten in an equivalent manner, which disposes of the need to operate with absolute values, as

$$G(x)=\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(x_j-x_i)}{n\sum_{i=1}^{n}x_i}.$$

This last representation can be rewritten as

$$G(x)=\frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}(x_j-x_i)}{n\sum_{i=1}^{n}x_i}=\frac{\sum_{i=1}^{n-1}\left[\frac{1}{n}\sum_{j=i+1}^{n}(x_j-x_i)\right]}{\sum_{i=1}^{n}x_i}.$$

For the individual whose income is x_i, the term $\left[\frac{1}{n}\sum_{j=i+1}^{n}(x_j-x_i)\right]$ is the aggregate of the income excesses divided by the size of the population.

By *TI* ("Total Income") we delineate the aggregate or total income of a given population, namely for any $x=(x_1,x_2,\ldots,x_n)\in V^n$:

$$TI(x)=x_1+x_2+\ldots+x_n.$$

Let the *RD* ("Relative Deprivation") of individual *i*, $i=1,2,...,n-1$, whose income is x_i be defined as

$$RD(x_i)\equiv\frac{1}{n}\sum_{j=i+1}^{n}(x_j-x_i),$$

and for individual *n* let $RD(x_n)=0$.

By *TRD* we delineate total relative deprivation (the sum of the levels of relative deprivation of the members of a population), namely for any $x=(x_1,x_2,\ldots,x_n)\in V^n$:

$$TRD(x)\equiv\sum_{i=1}^{n-1}RD(x_i)=\sum_{i=1}^{n-1}\left[\frac{1}{n}\sum_{j=i+1}^{n}(x_j-x_i)\right].$$

For any $x=(x_1,x_2,\dots,x_n)\in V^n$, the Gini coefficient of income distribution of a population, $G(x)$, can finally be represented as [5]

$$G(x)=\frac{\sum_{i=1}^{n-1}\left[\frac{1}{n}\sum_{j=i+1}^{n}(x_j-x_i)\right]}{\sum_{i=1}^{n}x_i}=\frac{TRD(x)}{TI(x)}. \quad (1)$$

4. Lowering the Gini coefficient can co-reside with increasing Total Relative Deprivation

Claim 1. Let $x,y\in V^n$. Consider a population with an ordered vector of incomes x that changes to an ordered vector of incomes y. Let every individual receive a mix of a proportional income growth and a lump sum income transfer. If there exists $a,b\in\mathbb{R}_+, a>1$ such that $y=ax+(b,b,\dots,b)$, then $TI(y)>TI(x);\ G(y)<G(x);\ TRD(y)>TRD(x)$.

Proof. In the Appendix.

Claim 1 is a generalization of the (1, 3) → (2, 5) case of Example 1 (where $a=3/2$ and $b=1/2$).

A sufficient condition for an increase in income for all the individuals to co-exist with an increase in total relative deprivation and a decrease in the Gini coefficient is provided in the next claim.

Claim 2. Let $x,y\in V^n$. Consider a population with a vector of incomes x that changes to a vector of incomes y. If $y-x\in V^n$ and $G(y-x)<G(x)$, then $TI(y)>TI(x)$; $G(y)<G(x)$; $TRD(y)>TRD(x)$.

Proof. In the Appendix.

Claim 2 informs us that if $y-x$ is an ordered vector such that $y_1-x_1\le y_2-x_2\le\dots\le y_n-x_n$, and if the Gini coefficient calculated for that vector is smaller than the Gini coefficient calculated for the vector x (namely when the increase in incomes

[5] A link between a measure of a population's stress and the Gini coefficient was heuristically identified by Sen (1973, p. 33): "In any pair-wise comparison the man with the lower income can be thought to be suffering from some depression on finding his income to be lower. Let this depression be proportional to the difference in income. The sum total of all such depressions in all possible pair-wise comparisons takes us to the Gini coefficient."

from *x* to *y* is bigger for richer individuals in absolute terms, but bigger for poorer individuals in relative terms), then an increase in the incomes of a population from *x* to *y* results in an increase in *TRD* of the population, and in a reduction of the Gini coefficient in the population. In other words, when the additional income is distributed among the individuals in such a way that the richer individuals obtain a larger part of the extra income in absolute terms (as per the assumption $y - x \in V^n$), but a smaller part in relative terms, that is to say, the additional income is divided more equally than the initial income (as per the assumption $G(y-x) < G(x)$), then while the Gini coefficient decreases, *TRD* increases.

When we look into the construction of the Gini coefficient, *G*, and *TRD*, we notice that *TRD* is the aggregate of the levels of relative deprivation, *RD*, of members $i = 1, 2, ..., n-1$ of the population. The *RD* of individual *i* is reduced when the income of an individual positioned to the right of individual *i* in the income distribution is reduced, but is not affected when the income of an individual who is positioned to the left of individual *i* in the income distribution is reduced. However, *G* is sensitive to both these changes (it will be reduced in the first case but increased in the second case). It is this asymmetry between the two indices that gives rise to a divergence between their predictions.

5. When does a rank-preserving rise in income decrease the relative deprivation of a population, and when does it increase the relative deprivation of a population?

When the top income in any income distribution increases, *TRD* goes up, which itself increases the magnitude of the Gini coefficient; aggregate income goes up, which itself decreases the magnitude of the Gini coefficient; and yet the net outcome is that the Gini coefficient increases; the *TRD* effect dominates.[6] From here onwards, we streamline notation, presenting $TRD(x)$ as *TRD* and $G(x)$ as *G*.

Looking at cases that involve more than two individuals, we get from the definition of *TRD* that for individual $k = 1, 2, ..., n$ whose income is y_k,

$$\frac{dTRD}{dy_k} = \frac{(k-1)-(n-k)}{n} = \frac{2k-1-n}{n} . \tag{2}$$

[6] The two-person case is also revealing when both incomes increase. When percentage-wise the higher income increases by more than the lower income, then the *TRD* effect is stronger than the aggregate income effect, and the Gini coefficient increases.

Namely a marginal increase of the income of individual *k* changes *TRD* by $\frac{2k-1-n}{n}$.[7] The reason for having the term $2k-1-n$ in the numerator of (2) is that individual *k* inflicts relative deprivation on $k-1$ individuals who are on his left in the income distribution, and is subject to relative deprivation inflicted on him by $n-k$ individuals who are on his right in the income distribution. Thus, in the *TRD* calculation, the income of individual *k* appears $(k-1)+[-(n-k)]=2k-1-n$ times. (We note that in the construction of *TRD*, income y_k does not enter the formulas of the relative deprivation of individuals $k+1, k+2, \ldots, n$.)

We ask when an increase in *TRD* will dominate a concurrent increase in total income such that the magnitude of the Gini coefficient will "succumb to the power" of its *TRD* numerator rather than to the "force" of its *TI* denominator. In order to respond to this question, we first formulate a condition under which upon a marginal increase of the income y_k of individual *k*, *TRD* will increase. Clearly, for $2k-1-n \geq 0$, which is the same as $k \geq \frac{n+1}{2}$, it follows from (2) that $\frac{dTRD}{dy_k} \geq 0$. This is an interesting result in its own right: a rank-preserving rise in an income in the upper half of the income distribution increases the aggregate relative deprivation of a population. And by the same token, a rank-preserving rise in an income in the lower half of the income distribution decreases the aggregate relative deprivation of a population.

We next analyze the effect of a marginal increase in income y_k of individual *k* on the Gini coefficient exhibited in (1). To begin with, we note that from (1) and (2),

$$\frac{dG}{dy_k} = \frac{\frac{2k-1-n}{n} TI - TRD}{\left(TI\right)^2} \tag{3}$$

which implies that $\frac{dG}{dy_k} > 0$ if $\frac{2k-1-n}{n} TI - TRD > 0$. We formulate and prove a claim which reveals that there is an individual, k, such that a marginal increase of the income of individual *k* or of the income of any individual who is positioned to the right of individual *k* in the income distribution will result in the *TRD* effect dominating the *TI* effect. Consequently,

[7] When $k = n$, the right-most term of (2) reduces to $\frac{n-1}{n}$.

the Gini coefficient will increase. From the preceding discussion, the intuition behind this result suggests to search for such a *k* in the upper part of the income distribution.

Claim 3. There exists a $k \in \left\{ \left\lfloor \frac{n+1}{2} \right\rfloor + 1, \ldots, n \right\}$ (we refer to this *k* as the "pivotal *k*") such that for any $i \geq k$, a marginal increase of TRD will dominate the concurrent marginal increase of *TI*, causing the Gini coefficient to increase. Namely for $i \geq k$: $\frac{dTRD}{dy_i} > 0$; $\frac{dTI}{dy_i} > 0$; and

$$\frac{dG}{dy_i} = \frac{d\frac{TRD}{TI}}{dy_i} > 0.$$

Proof. In the Appendix.

The significance of Claim 3 is that by defining a line of demarcation, the claim settles a tension. The tension arises when a gain from higher income is accompanied by pain from higher relative deprivation. The claim responds to the associated "dilemma of the Gini coefficient" by dividing a given income distribution into two mutually exclusive and jointly exhaustive domains such that the effects of an increase in income in each of the two domains are the opposite of each other. In the hypothetical case in which inequality is all that matters to a policy maker, the claim provides a precisely defined guide.

6. Conclusion

An obvious conclusion from the review of studies undertaken in Section 2 and of the analysis conducted in Sections 3, 4, and 5 is the appeal of discovering the relationship between a population's total relative deprivation and measures of the population's intensity of COVID-19. The search for links between background variables and "pre-existing conditions" as underlying risk factors on the one hand, and dimensions of COVID-19 (being infected, the severity of infection) on the other hand, need not only refrain from interpreting an association as causality, but also recognize that an observed (visible) variable may merely be the "façade" of an underlying substantive variable. We already showed that total relative deprivation as a population's measure of social-psychological stress is the variable to reckon with, not the Gini coefficient. A guide to policy formation is *not* to assume that less inequality means less relative deprivation but to address relative deprivation *directly*. Stating things positively, a policy principle, already hinted at by Example 2, is that relative deprivation can be lowered by manipulating the reference group: comparisons with others can be made more favorable by changing the identity or the composition of the group of "others." Governments have a variety of policy instruments - including the tools of information, organization, and integration - with which they can influence relative deprivation, even without modifying the core magnitudes or values. Going a little beyond Example 2, consider the case of the integration (merger) of two groups of two individuals each, groups *A* and *B*, refer to income as the characterizing variable, and assume that pair-wise incomes are distinct, namely not two incomes are the same. When the groups are separated, let the *TRD* of group *A* be denoted by TRD_A, and let the *TRD* of group *B* be denoted by TRD_B. Upon a merger of the two groups into one, let the *TRD* of the merged group be denoted by TRD_C. In Stark (2015), the following claim is presented and proven: $TRD_C > TRD_A + TRD_B$. This property alone suggests that in and by themselves, government policies which result in revision of the social space of people (the composition of people's comparison group) - such as redrawing of district boundaries, merging of municipalities, financial and other integration with other countries, and the encouragement of migrants to assimilate - can exacerbate social stress.

The idea that variation in the level of stress can help explain variation in the intensity of the manifestations of COVID-19 is not all that surprising when we bear in mind that, by and large, stress is a cause of all sorts of ailments; as conventional medical wisdom has it, stress weakens or depresses the immune system.

Needless to add, stress can be measured in a variety of ways, of which relative deprivation is one. For example, the level of stress can be gauged by means of the level of cortisol, a steroid hormone (sometimes referred to as the "stress hormone") released by the adrenal glands. When an individual is under stress, the adrenal gland releases measurable cortisol into the bloodstream. This method of measuring stress does not, however, negate the role of relative deprivation as a cause of stress; the chain to bear in mind is: higher relative deprivation => higher stress => elevated level of cortisol => more severe manifestations of COVID-19. To the best of our knowledge, no study to date sought to assess the link between the level of relative deprivation experienced by individuals (as defined in Section 3) and the individuals' level of cortisol. This inquiry could yield intriguing findings.

When the first draft of this paper was written, postulating a link between social stress, which we have measured by relative deprivation, and the intensity of COVID-19 was a logical conjecture, a follow-up interpretation of prevailing evidence on the causal chain mentioned in the preceding paragraph. In the course of the past two years, direct evidence has emerged supporting this conjecture. (In part, this evidence suggests amplification of the chain, by adding that a consequence of higher stress is not only a weakened or depressed immune system, but also reduced effectiveness of vaccines. Madison et al. (2021) argue that the robust evidence that stress impairs the immune system's response to vaccines applies in the case of COVID-19 vaccines.) Peters et al. (2021) summarize studies suggesting that stress-related factors such as socio-economic status contribute to an increase in COVID-19 infections. Peters et al. also report that there are abundant indications that high levels of cortisol have a negative impact on defense mechanisms against respiratory viruses in general and COVID-19 in particular. Tan et al. (2020) report reduced survival from COVID-19 of patients with baseline high cortisol concentrations. And, in general, elevated cortisol levels appear to exacerbate the severity of COVID-19.

A final note of conclusion takes us to the domain of identifying and defining the appropriate research agenda: for a long period of time, a good many researchers have looked repeatedly at the link between income inequality, as measured by the Gini coefficient, and morbidity and mortality, recently and not for the first time at an "association between income inequality and COVID-19 cases and mortality" (recall our reference to the Oronce et al. (2020) study; names of researchers who produced many studies on a link between the Gini coefficient and health outcomes appear in the References Section below). This paper can serve also as a research policy appeal: disconnect from Gini, engage in relative deprivation.

Appendix: Proofs of the claims

To facilitate the proofs of Claims 1 and 2, we first state and prove a supportive lemma.

Lemma 1.

TI and *TRD* are "linear" on V^n, namely for any $a \in \mathbb{R}_+$ and any $x, y \in V^n$

(i) $TI(x+y) = TI(x) + TI(y)$; $TRD(x+y) = TRD(x) + TRD(y)$;

(ii) $TI(ax) = aTI(x)$; $TRD(ax) = aTRD(x)$.

Moreover, if $x = (b, b, \ldots, b)$, $b \in \mathbb{R}_+$ then

(iii) $TI(x) > 0$; $TRD(x) = 0$.

Proof.

Properties (i), (ii), and (iii) are immediate consequences of the formulae of *TI* and *TRD* (it suffices to substitute the formulas for *TI* and *TRD* (presented in Section 2) into (i), (ii), and (iii)).

Q.E.D.

Proof of Claim 1.

By Lemma 1

$$TRD(y) = TRD(ax + (b, b, \ldots, b)) = TRD(ax) + TRD(b, b, \ldots, b) = TRD(ax) = aTRD(x) > TRD(x)$$

$$TI(y) = TI(ax + (b, b, \ldots, b)) = TI(ax) + TI(b, b, \ldots, b) = aTI(x) + TI(b, b, \ldots, b) > TI(x);$$

$$G(y) = \frac{TRD(y)}{TI(y)} = \frac{TRD(ax + (b, b, \ldots, b))}{TI(ax + (b, b, \ldots, b))} = \frac{aTRD(x)}{aTI(x) + TI(b, b, \ldots, b)}$$
$$< \frac{aTRD(x)}{aTI(x)} = \frac{TRD(x)}{TI(x)} = G(x).$$

Q.E.D.

Proof of Claim 2.

By Lemma 1, part (i)

$$TI(y) = TI(x + (y - x)) = TI(x) + TI(y - x) > TI(x)$$

$$TRD(y) = TRD(x + (y - x)) = TRD(x) + TRD(y - x) > TRD(x).$$

From the assumption that $\frac{TRD(y-x)}{TI(y-x)} = G(y-x) < G(x) = \frac{TRD(x)}{TI(x)}$, it follows that

$$TRD(y-x) < \frac{TRD(x)TI(y-x)}{TI(x)}.$$

Thus,

$$\begin{aligned}
G(y) = \frac{TRD(y)}{TI(y)} &= \frac{TRD(x)+TRD(y-x)}{TI(x)+TI(y-x)} \\
&< \frac{TRD(x)+\frac{TRD(x)TI(y-x)}{TI(x)}}{TI(x)+TI(y-x)} \\
&= \frac{TRD(x)[TI(x)+TI(y-x)]}{TI(x)[TI(x)+TI(y-x)]} = \frac{TRD(x)}{TI(x)} = G(x).
\end{aligned}$$

Q.E.D.

Proof of Claim 3.

The proof proceeds in two steps. First, we formulate conditions under which $\frac{dTRD}{dy_i} > 0$ and $\frac{dTI}{dy_i} > 0$ hold. Taking this step enables us to narrow the domain over which to search for the pivotal *k*. Second, we investigate (3) as a function of *k*, with the aim of ascertaining that there exists a unique point at which there is a sign change of (3) from negative to positive.

From (2) we know that for $k > \frac{n+1}{2}$, $\frac{dTRD}{dy_k} > 0$. Also, for any $k = 1, 2, ..., n$, $\frac{dTI}{dy_k} = 1 > 0$. Noting that k is an integer, we therefore confine our search for the pivotal *k* to the domain $k \in \left\{ \left\lfloor \frac{n+1}{2} \right\rfloor + 1, \ldots, n \right\}$.

Because, as already noted, from (3) it follows that $\frac{dG}{dy_i}$ is positive if the term $\frac{2k-1-n}{n} TI - TRD$ is positive, we inspect this term, expressing it as a function $D(k) = \frac{2k-1-n}{n} TI - TRD$ for $k = 1, 2, ..., n$. Three properties of $D(k)$ are of interest:

(i) $D\left(\left\lfloor \frac{n+1}{2} \right\rfloor\right) < 0$;

(ii) $D(n) > 0$;

(iii) $D(k)$ monotonically increases with respect to *k*.

Taken together, (i), (ii), and (iii) imply that there exists a unique $k \in \left\{\left\lfloor \frac{n+1}{2} \right\rfloor + 1, \ldots, n\right\}$ such that $D(i) > 0$ for all $i \geq k$ and $D(i) \leq 0$ for $i < k$.[8] For $i \in \{k, k+1, \ldots, n\}$, $\frac{dTRD}{dy_i} > 0$ and $\frac{dTI}{dy_i} > 0$, inequalities that we know hold because $\{k, k+1, \ldots, n\}$ is a subset of the domain $\left\{\left\lfloor \frac{n+1}{2} \right\rfloor + 1, \ldots, n\right\}$, and for this domain we have already established that these two inequalities hold.

What remains to complete the proof is to show that properties (i), (ii), and (iii) indeed hold.

Property (i) holds because $D\left(\left\lfloor \frac{n+1}{2} \right\rfloor\right) = \frac{2\left\lfloor \frac{n+1}{2} \right\rfloor - 1 - n}{n} TI - TRD \leq -TRD < 0$.

To understand why property (ii) holds, we first note that $D(n) = \frac{2n-1-n}{n} TI - TRD = \frac{n-1}{n} TI - TRD$. To show that $\frac{n-1}{n} TI - TRD$ is positive, we recall that in the remark that follows (2) we noted that in calculating *TRD*, individual *k* whose income is y_k appears $2k-1-n$ times. Summing over all the individuals, $k = 1, 2, ..., n$, we can exploit this feature and express TRD in a different form than in (2):

$$TRD = \sum_{k=1}^{n} \frac{2k-1-n}{n} y_k \ .$$

[8] We note that because k is a discrete variable, it could be the case that $D(k) > 0$ will hold only for $k = n$.

Because for $k = n$ we get that $\frac{2k-1-n}{n} = \frac{n-1}{n}$, and because for $k = n-1$ we get that $\frac{2k-1-n}{n} = \frac{n-3}{n}$, we can establish that

$$
\begin{aligned}
TRD &= \sum_{k=1}^{n} \frac{2k-1-n}{n} y_k = \frac{n-1}{n} y_n + \sum_{k=1}^{n-1} \frac{2k-1-n}{n} y_k \\
&< \frac{n-1}{n} y_n + \sum_{k=1}^{n-1} \frac{n-3}{n} y_k = \frac{n-1}{n} y_n + \frac{n-3}{n} \sum_{k=1}^{n-1} y_k < \frac{n-1}{n} y_n + \frac{n-1}{n} \sum_{k=1}^{n-1} y_k = \frac{n-1}{n} TI.
\end{aligned}
$$

Namely $TRD < TI$. From the result $TRD < \frac{n-1}{n} TI$ it follows that $D(n) = \frac{n-1}{n} TI - TRD > 0$ holds.

Finally, that property (iii) holds follows directly from the definition of $D(k) = \frac{2k-1-n}{n} TI - TRD$ upon noting that TI and TRD in this expression do not depend on k, so that a higher *k* translates into a higher $D(k)$.

Q.E.D.

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