Title: Lockdowns lose one third of their impact on mobility in a month

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Abstract: In 2020 as the COVID-19 pandemic spread widely, countries imposed lockdowns to control its spread. We investigate effectiveness of lockdowns via the observed impact on mobility. We find that lockdowns are effective in reducing mobility: median mobility is reduced by a third of its baseline value at the start of a lockdown and by half in the subsequent two weeks. For countries with long lockdowns, most observed a significant rebound in mobility during the lockdown period. For the median country, a third of the mobility reduction achieved was lost within a month, and lockdowns lose all their effectiveness in about four months. Thus, we find that while lockdowns are effective at significantly reducing mobility, they are also subject to substantial fatigue as the lockdown periods extend longer.

One Sentence Summary: While lockdowns are effective at significantly reducing mobility, they are also subject to substantial fatigue.

Main text: The United States recorded its first confirmed case of the novel coronavirus disease (COVID-19) in late January, 2020 in the state of Washington (*1*). By the end of January, thousands of cases were observed in China and cases appeared to be spreading globally, leading the World Health Organization (WHO) to declare COVID-19 to be a Public Health Emergency of International Concern (*2*). By March 2020, COVID-19 had spread to over a hundred countries with over a hundred thousand cases and more than four thousand dead, further leading the WHO to declare it a global "pandemic" (*3*).

As COVID-19 spread globally, governments in many countries started instituting formal policies with the aim of mitigating the potential outbreak and loss of life within their individual jurisdictions. Starting with travel advisories and travel restrictions, the policies quickly escalated to more severe actions such as stay at home requirements (SHR) which we refer to as lockdowns. The intent of imposing lockdowns was to restrict and reduce the movement of citizens, which in turn would lead to lower contact among people, and hence to lower cases and lesser loss of life (*4, 5*). Indeed, scholars have analyzed the impact of mobility on the spread of the disease and shown that a reduction in mobility can slow the spread (*6-9*).

At the same time, many have questioned the appropriateness of governments imposing lockdowns and the general efficacy of lockdowns and quarantines (*10*). The editorial board of the Wall Street Journal publicly opined "*These shutdowns are extraordinary and have costs, not least the harm to small business owners. Americans may simply decide to ignore the orders after a time. Absent a more thorough explanation of costs and benefits, we doubt these extreme measures will be sustainable for long as the public begins to chafe at the limits and sees the economic consequences*" (*11*). More generally, research shows that government policy, the alignment of public interests, and compliance interact closely (*12, 13*). In this research, we specifically focus our attention on the broader issue of whether and to what extent have lockdowns been effective in terms of achieving their objectives of reducing mobility.

A casual observation of the policies adopted by governments around the world suggests that the severity of the rules as well as the extent of their enforcement has varied significantly across countries. At the same time, the effects that these lockdown policies had on subsequent mobility has also been varied. Motivated by these observations, in this work we investigate the following research questions: [i] How effective are lockdowns in reducing mobility? [ii] Is their effectiveness long-lasting, at least during the time when they are in effect? [iii] If there is variation in their long-term effectiveness across countries, what mobility patterns and country characteristics explain these differences?

Our work contributes to a growing body of research analyzing the impact of government policies on factors such as mobility (*14, 15*). Prior research has found that government policies as well as pandemic severity impacts social distancing that is practiced within communities, and that less social distancing is practiced after observing local mitigation (*16*). Researchers have also shown that social distancing and lower population density may be associated with decreased spread of the coronavirus (*17*). Other work has shown that risk attitudes can be a critical factor in predicting mobility reduction, and that regions with more risk averse attitudes may be more likely to change behavior in a pandemic (*18*). Compliance with mobility restrictions have also

been shown to be associated with social connections and partisan beliefs (*19, 20*). We focus on the impact of lockdowns on mobility and characterize the extent and dynamics of the reduction in mobility achieved by imposing lockdowns in countries across the world.

Empirical Approach: To study the impact of lockdowns on mobility we analyze policy and mobility data for 116 countries. For each country, we identify the first time that a general requirement to stay at home (i.e., a lockdown) is imposed on its citizens and its duration. Using the metric of mobility at workplaces, we compute a baseline level of mobility prior to the start of the lockdown for that country to understand mobility levels before restrictions went into effect. Using regression models that controls for day-of-the-week effects we characterize the evolution of mobility levels throughout the duration of a lockdown. Via further regression analyses, we assess whether differences across countries in mobility responses to lockdowns can be explained by country characteristics such as demographics and socioeconomic indicators.

Analysis and Results: To understand mobility patterns over the past year, regardless of policy or other interventions, we first compute the median mobility by month in each country for all 116 countries under study and generate a boxplot of these medians by month (Figure 1). During the initial phase, we observe a global median decline in mobility of 10.5 and 47.0 percentage points in March and April 2020 respectively, compared to the baseline reference levels of January-February 2020. This is followed by a pattern of gradual and partial recovery that extends through June 2020, with mobility levels remaining relatively stable thereafter.

Next, we visualize the implementation of lockdown policies across the world as measured by the proportion of countries in our sample that are under lockdown on any given day (Figure 2). Interestingly, the mobility decline and recovery observed in Figure 1 coincides with the implementation and subsequent relaxation of lockdowns observed in Figure 2. The highest proportion of countries requiring their citizens to stay at home is observed during April 2020 (69.9%). This proportion stayed at high levels during March to May 2020, and then decreased to lower levels in June 2020, and stayed low for a long time thereafter.

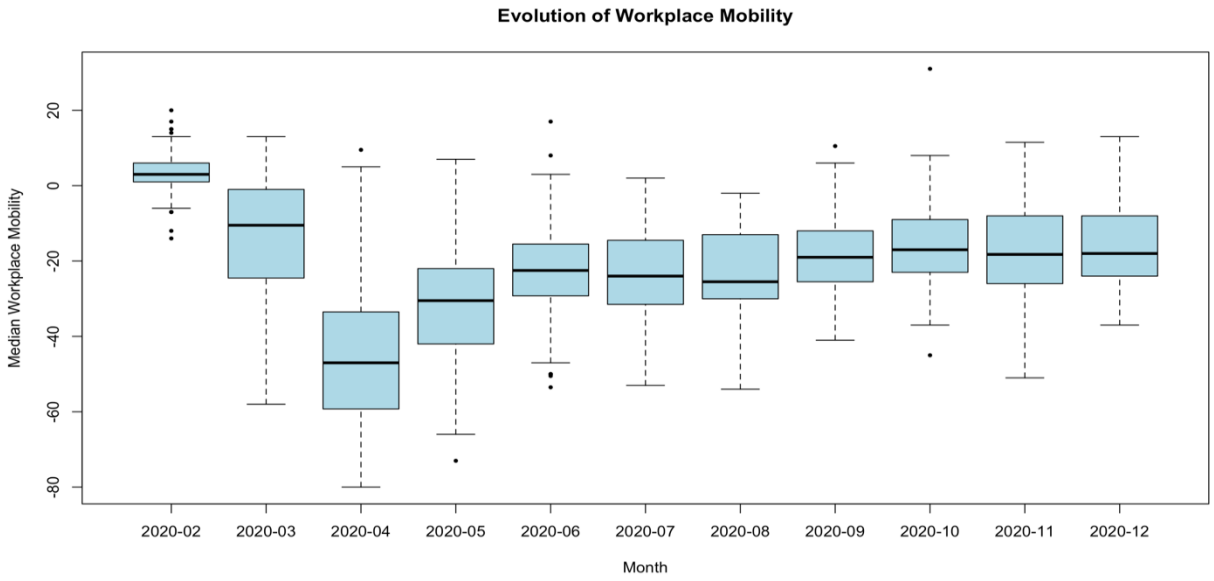

Fig. 1: Evolution of workplace mobility. Boxplot of the average workplace mobility observed for each country in that month (n=116 countries). The solid line in the box indicates the median, with boxes at the interquartile range. Whiskers are either at 1.5*(interquartile range) outside the box, or at the extreme value.

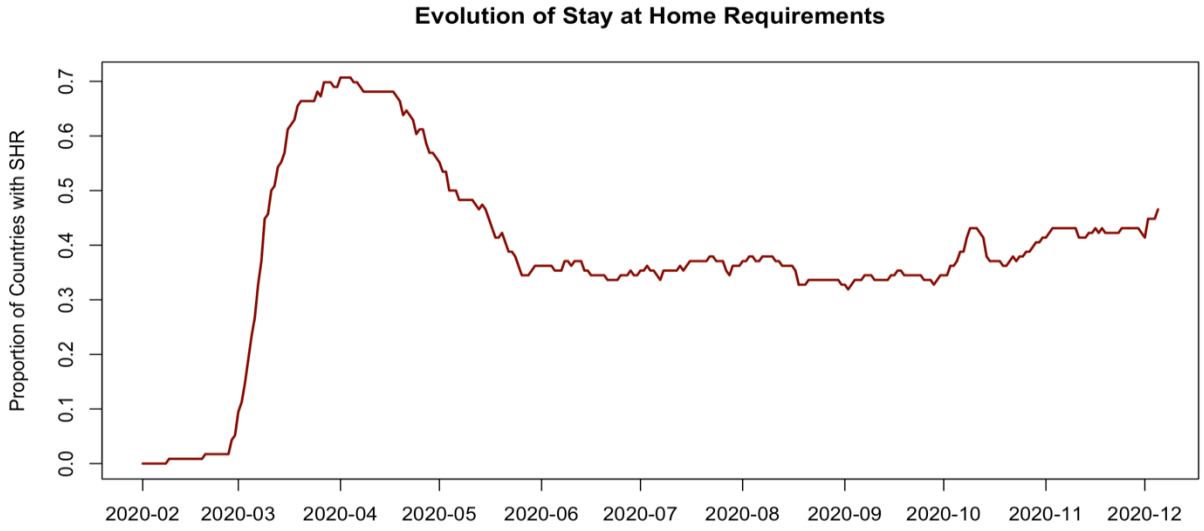

Fig. 2: The proportion of countries with a lockdown. The daily fraction of countries that have an active stay-at-home order for its general population (n=116 countries).

Lockdowns have a strong initial impact and then fatigue sets in: While at a macro level the prior two figures may suggest that lockdowns are effective, a closer look at the evolution of mobility levels during lockdown periods for each country reveals a more nuanced story. Figure 3 shows that lockdowns achieve a strong initial reduction in mobility but then are followed by a wear out period suggesting that lockdown fatigue is setting in. Across 93 countries that had a lockdown, the median mobility is reduced to 36% below the baseline at the start of a lockdown, and then by another 18% two weeks later. Nevertheless, this initial impact exhibits a wear out effect, as mobility gradually rises by approximately 3 percentage points with each additional week that the lockdown stays in effect. After 52 days of lockdown, the median mobility levels rise to 35% below the baseline, effectively erasing all impact of the lockdown, even though the lockdown continues to stay in effect.

The duration for which lockdowns are imposed varies across countries. Hence, it could be hypothesized that the fatigue observed in Figure 3 (black dots) might arise due to a selection effect if countries for which a lockdown is less effective at reducing mobility lift the lockdown earlier. However, an analysis focusing only on those 50 countries where the lockdown was in place for at least 60 days (red triangles in Figure 3) reveals a similar pattern of fatigue.

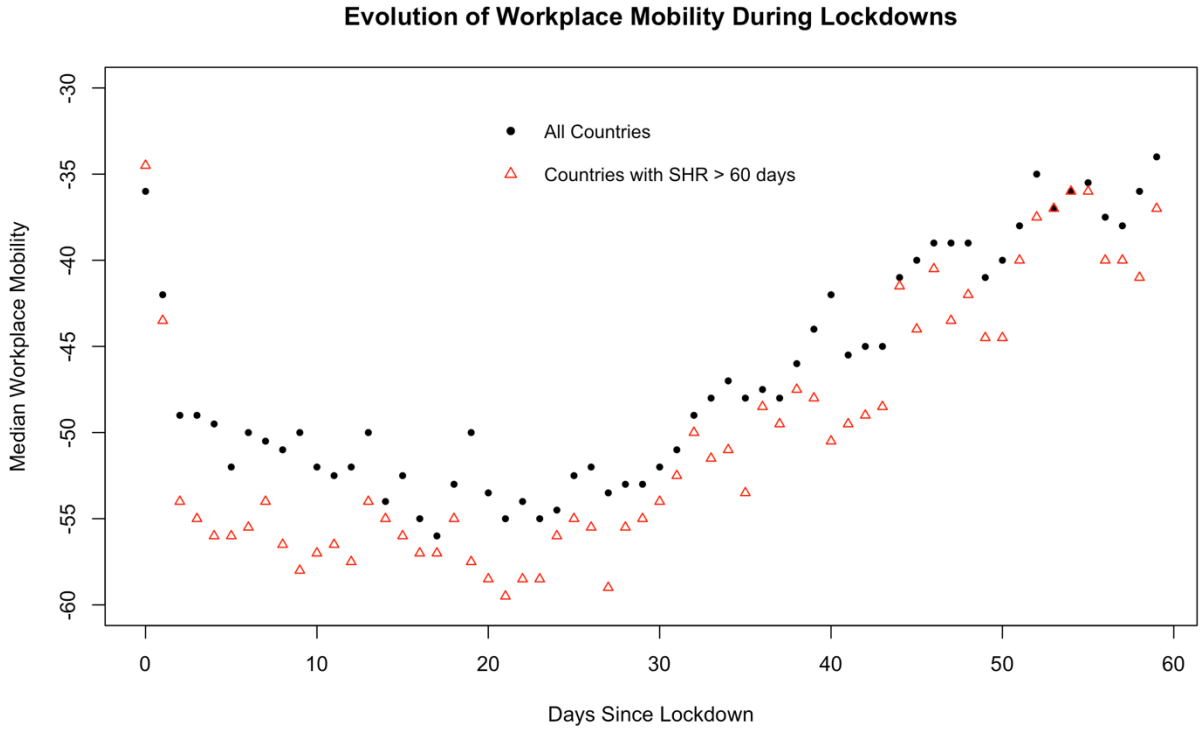

Fig. 3: Evolution of workplace mobility during lockdowns. For each country (n=93, solid dots), we identify the date when the first lockdown requirement was imposed over its general population. During the lockdown period, for each day since the start of the lockdown we determine the median workplace mobility across countries for that day. As a robustness test, this

analysis is repeated for countries where the first lockdown lasted for more than 60 days (n=50, hollow triangles).

Lockdowns significantly reduce mobility: To better understand the dynamic effects of imposing a lockdown on mobility at the country level, we focus on 79 countries where lockdowns lasted at least four weeks. Out of these 79 countries, 70 exhibit a significant mobility reduction ($p<0.01$) in the first two weeks of the lockdown compared to the two weeks before the lockdown. The median value of this reduction is 40 percentage points. The data exhibits strong day of the week seasonality; hence we compute a seven day moving average of mobility level during the lockdown to better understand lockdown dynamics. Based on this metric, the minimum level of mobility is achieved 18.0 days into the lockdown for the median country. Comparing this minimum mobility to the average mobility two weeks before the lockdown, we observe a median reduction of 50 percentage points. These observations indicate that lockdowns are effective in reducing mobility.

30% of the effectiveness of a lockdown is lost in four weeks: For 59 of the 70 countries mentioned above, lockdowns were extended for at least four weeks after reaching the minimum mobility level. For the median country, we find that 30.1% of the mobility reduction achieved from imposing a lockdown is lost within four weeks after reaching this minimum level. We then specify regression models to explain the observed daily mobility level within a country as a function of the days since the lockdown was imposed, after controlling for day of the week effects (additional details provided under Materials and Methods). For 96% of these countries, we observe a significant rebound in mobility during the lockdown period. For these countries, we used the fitted models to estimate the number of days it would take a lockdown to reach the average mobility levels observed during the two weeks before the start of the lockdown. This calculation reveals that lockdowns would lose all their effectiveness in 112.1 days for the median country.

Greater mobility reductions are associated with greater lockdown fatigue: There are important differences across countries in terms of the magnitude of the fatigue they exhibit. This is shown in Figure 4, which displays for each country the average mobility level one week before the start of the lockdown and four weeks after reaching the minimum mobility level during the lockdown. We obtain a marginally significantly negative correlation between both metrics (correlation = -0.23, p-value = 0.08), which suggests that countries that achieved lower mobility levels prior to the start of a lockdown exhibited a greater rebound in mobility.

Similarly, Figure 5 replaces the horizontal axis in Figure 4 by the reduction in mobility achieved between the start of a lockdown and the date when the minimum mobility level is reached during the lockdown. We obtain a significantly positive correlation between both metrics (correlation = 0.25, p-value = 0.05), which suggests that countries that achieved a greater reduction in mobility from the start of a lockdown exhibited a greater rebound in mobility.

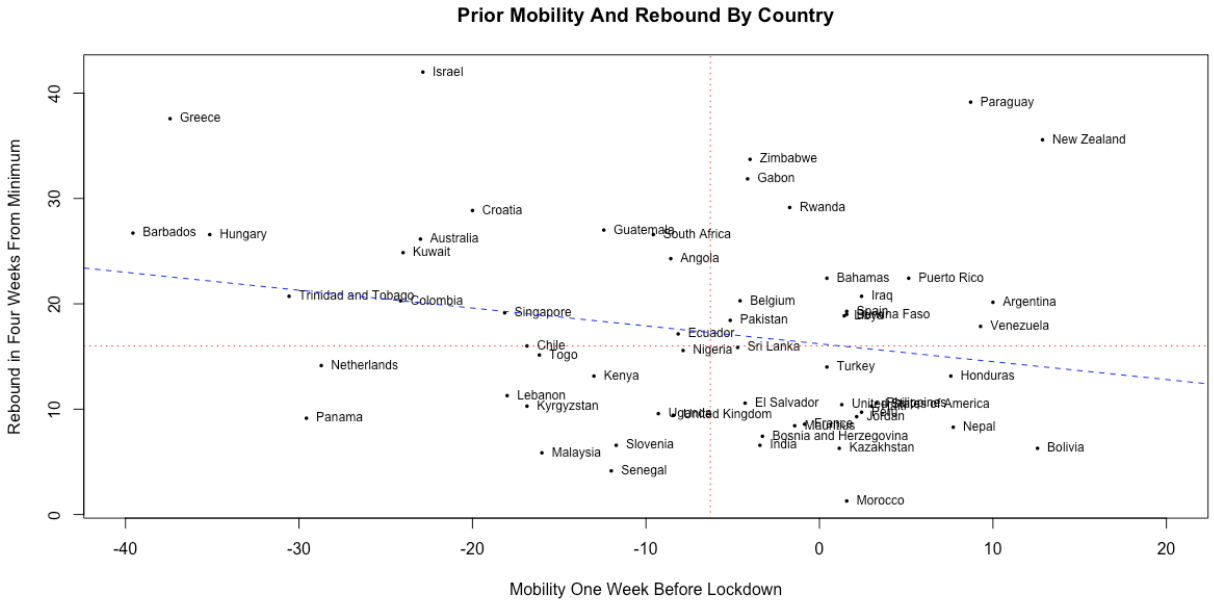

Fig. 4: Prior mobility and rebound across n=59 countries. The horizontal axis represents the average mobility level one week before the start of the lockdown. The vertical axis represents the rebound in mobility in four weeks starting from the day when minimum mobility levels were achieved during the lockdown.

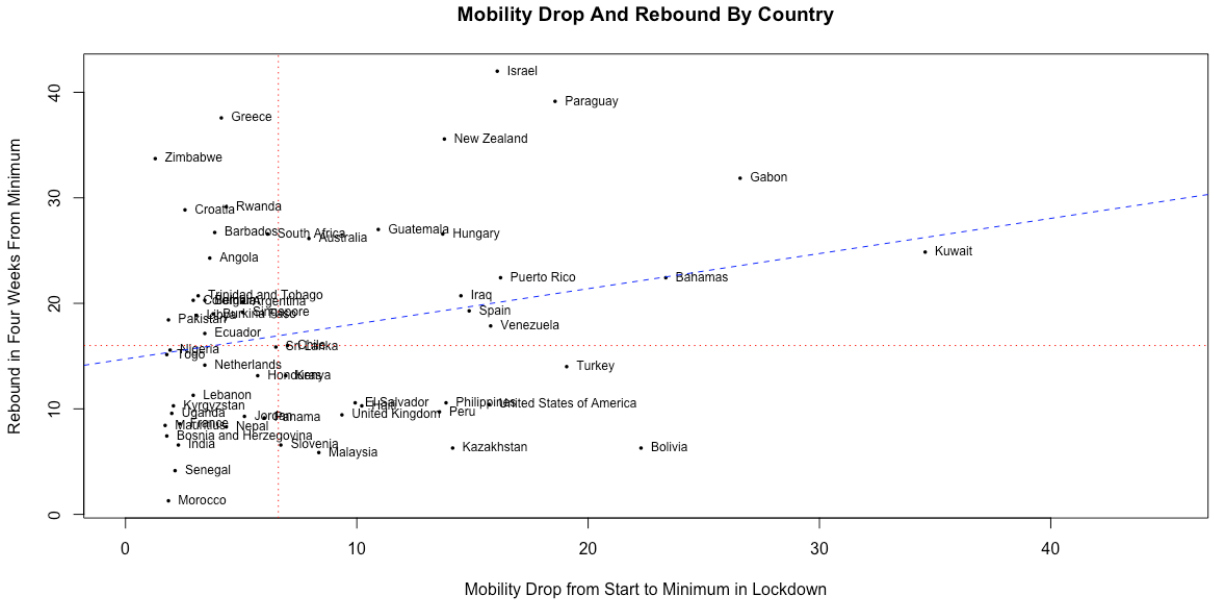

Fig. 5: Mobility drop and rebound across n=59 countries. The horizontal axis represents the mobility drop from the start of the lockdown until reaching the minimum mobility level during the lockdown. The vertical axis represents the rebound in mobility in four weeks from the day when minimum mobility levels were achieved during the lockdown.

Country Characteristics and Mobility Dynamics: We observe substantial variation in mobility dynamics during the lockdown across countries. We next explore whether country characteristics help explain some of this variation. We focus on three mobility metrics: i) mobility levels observed prior to the lockdown; ii) the reduction in mobility achieved between the two weeks prior to the lockdown and the date when the minimum mobility is achieved; and iii) the rebound in the mobility levels observed four weeks after reaching the minimum mobility levels during the lockdown. We conduct regression analyses with each of these three metrics as a dependent variable and country characteristics as predictors (please refer to the methods and materials section for a list of the country characteristics used for each regression).

First, in terms of the analysis of mobility levels prior to the lockdown, we find that both the policies adopted by a country before a lockdown as well as its education levels are significant predictors for this metric. In particular, we obtain a significantly negative impact of the stringency index observed prior to the lockdown and the mean years of schooling of a country.

Second, considering the reduction of mobility achieved between the start of a lockdown until reaching the minimum mobility level, once again the policies implemented prior to the start of the lockdown significantly predict this mobility reduction. More specifically, more stringent policies prior to the lockdown are associated with a weaker drop in mobility. In addition, countries with populations enjoying a greater life expectancy are associated with stronger reductions in mobility.

Third, regarding the mobility rebound realized four weeks after reaching the minimum level, both the mobility levels observed prior to the start of the lockdown and the mobility reduction achieved during lockdown are significant predictors with opposite relationships. On the one hand, greater mobility levels prior to the start of a lockdown are associated with a weaker mobility rebound. On the other hand, a greater mobility reduction achieved during the lockdown is associated with a stronger mobility rebound.

Discussion: Overall, our global analysis suggests that lockdowns work, in that imposing a lockdown is associated with a significant reduction in the observed levels of mobility for most countries in our analysis. Interestingly though, mobility dynamics in response to a lockdown vary significantly across the world. We observe and quantify a global pattern of lockdown fatigue, as mobility levels slowly start rising the longer a lockdown stays in effect. In a relatively short of amount of time (e.g., four weeks), lockdown fatigue may eliminate one third of the gains achieved in terms of reduced mobility. A direct implication of this result may be that lockdown compliance might need to be reinforced by governments when lockdowns remain in effect for long periods of time.

In terms of the drivers of lockdown fatigue, the strongest predictor appears to be the reduction in mobility achieved during the lockdown: the greater this reduction, the stronger the fatigue.

Accordingly, these two appear to be compensatory. A similar association is observed between lockdown fatigue and the mobility levels prior to the start of the lockdown. Countries that had already achieved lower levels of mobility prior to a lockdown exhibit greater mobility rebounds during their lockdown periods. Interestingly, lower mobility levels prior to a lockdown are observed for countries with greater education levels. However, these countries are likely to experience greater lockdown fatigue.

The effectiveness of lockdowns is also associated with other country characteristics such as the life expectancy enjoyed by the population in each country. Countries with greater life expectancy show stronger mobility reductions during a lockdown. The opposite is observed for countries that had more strict policies prior to the implementation of a lockdown.

Our analysis has several limitations. First, we do not intend to make any causal claims; our findings are based on summarizing and regressing available data across sources to study the interplay between government policy and mobility. Second, our inferences of mobility are based on workplace mobility data, and while other mobility types have a strong positive correlation with this metric, it may be beneficial to further investigate the impact of lockdowns on other types of mobility. Finally, in this research we do not incorporate the explicit impact of case data on mobility. It is likely that beyond policy, observing actual cases in their communities may have a further impact on people's decisions to move around. Nevertheless, we hope that our findings above help inform policy makers on the nature of response they may expect when implementing lockdowns and incorporate these observations for more effective planning purposes.

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Data and materials Availability: The data that support the findings of this study are publicly available online at:

- Google: https://github.com/GoogleCloudPlatform/covid-19-open-data
- Oxford: https://github.com/OxCGRT/covid-policy-tracker
- UNDP: http://hdr.undp.org/sites/default/files/2020_statistical_annex_all.xlsx

Code Availability: Software used includes R (version 4.0.3) and RStudio (version 1.4.1103) for data analysis and model estimation. The code used in the analysis is available from the authors upon request.

Supplementary Materials: Provided in a separate file.