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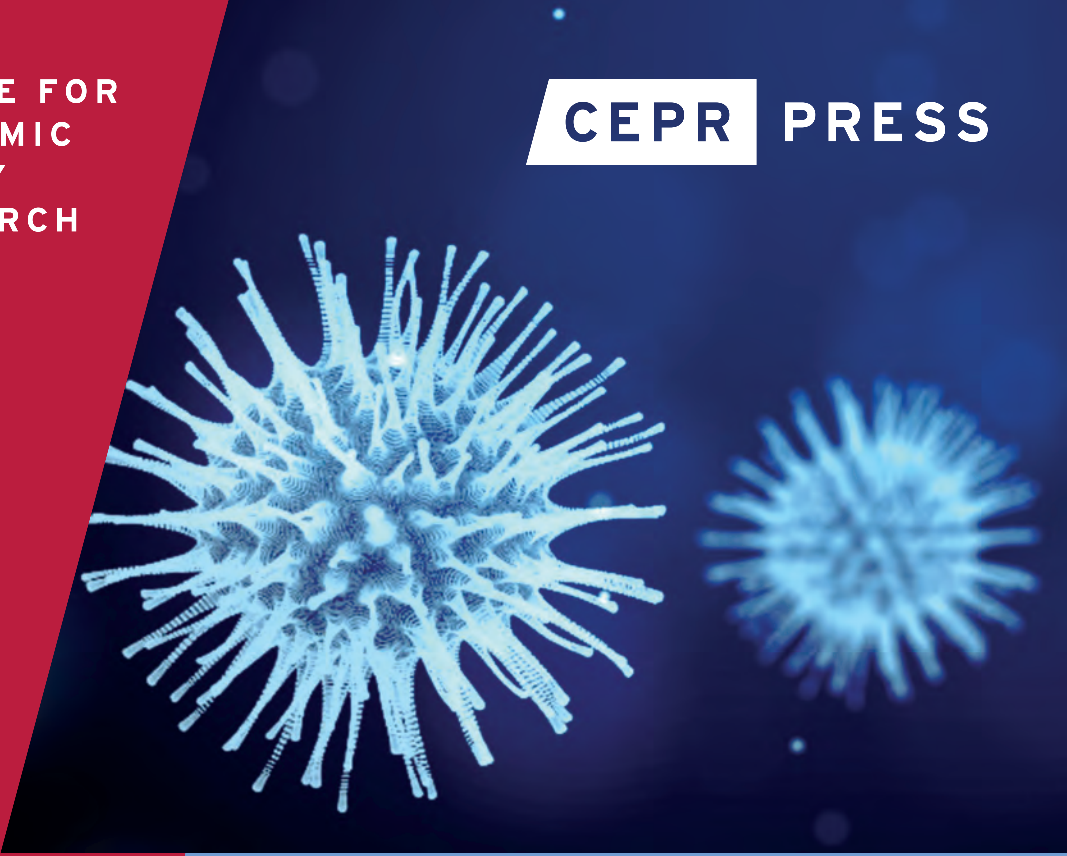

COVID ECONOMICS

VETTED AND REAL-TIME PAPERS

ISSUE 16
11 MAY 2020

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Benjamin Born, Alexander M. Dietrich and Gernot J. Müller

GENDER (IN)EQUALITY
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CONFLICTS WORLDWIDE
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GETTING PEOPLE BACK INTO WORK
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HERD IMMUNITY
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STRATEGIC BEHAVIOUR
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MEASUREMENT WITHOUT TESTING
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Covid Economics
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Covid Economics **Issue 16, 11 May 2020**

Do lockdowns work? A counterfactual for Sweden[1]

Benjamin Born,[2] Alexander M. Dietrich[3] and Gernot J. Müller[4]

Date submitted: 5 May 2020; **Date accepted:** 7 May 2020

Is a lockdown an effective means to limit the spread of the COVID-19 pandemic? We study the case of Sweden – one of the few countries without a lockdown – and use synthetic control techniques to develop a counterfactual lockdown scenario. First, we use a "donor pool" of European countries to construct a doppelganger that behaves just like Sweden in terms of infections before the lockdown. Second, we find that infection dynamics in the doppelganger since the lockdown do not systematically differ from the actual dynamics in Sweden. Third, we study Google mobility data and find that Swedes adjusted their activities in similar ways as in the doppelganger, although to a somewhat lesser extent.

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[1] We thank Christian Bayer, Hartmut Egger, Zeno Enders, Philip Jung, Willi Kohler, Kris Nimark, Julia Peters, and Harald Uhlig for very useful comments and discussions. Lennart Fischer provided valuable research assistance. The usual disclaimer applies.

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> “And when countries do all the wrong things and still end up seemingly not as battered by the virus as one would expect, go figure.” (New York Times, May 3, 2020)

1 Introduction

As the COVID-19 pandemic spread around the globe in early 2020, many countries shut down their economies in order to limit social interactions. In China, the Hubei province was put under lockdown for more than two months, starting in late January 2020. In Europe, Italy imposed a lockdown on March 9, followed by the large majority of countries in Europe and elsewhere. A widely discussed exception is Sweden, which opted against a lockdown in its approach towards the COVID-19 pandemic. And while the Swedish authorities advised citizens to adjust their behavior in the face of the pandemic, one may ask if the spread of the pandemic would have been more limited, if the government had imposed a proper lockdown instead?[1]

From a theoretical point of view, the answer seems obvious because, as it constrains social interactions, a lockdown is bound to limit the transmission of the disease. It is important to recognize, however, that even in the absence of a lockdown, (economic) activities will slow down because people reduce social interactions voluntarily out of sheer self interest. Eichenbaum et al. (2020) put forward and formalize this notion. They also show that because people fail to internalize the costs they impose on others as they become infectious—in the presence of an infection externality—government restrictions on social interaction will generally be optimal (see also Alvarez et al., 2020; Farboodi et al., 2020). Still, Krueger et al. (2020) stress that actual economies offer a lot of possibilities to shift (economic) activities towards sectors where the risk of infection is small(er). As a result, voluntary adjustment is relatively easy and goes a long way towards containing the spread of the virus.

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[1] For instance, “everyone” was “advised to avoid unnecessary traveling and social events, to keep distance to others, and to stay at home” if they had any symptoms. In addition, as “age is a risk factor, those above 70” were “advised to avoid social contact and visits to retirement homes are banned”. Quoted from website: https://www.krisinformation.se/en/hazards-and-risks/disasters-and-incidents/2020/official-information-on-the-new-coronavirus.

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Against this background we take up the issue empirically and ask whether the spread of COVID-19 infections in Sweden would have been more limited, if a lockdown had been imposed. To answer this question, we develop a counterfactual scenario based on a variant of the synthetic control method (Abadie and Gardeazabal, 2003; Abadie et al., 2010, 2015). Ideally, in order to assess the effectiveness of a lockdown, we would like to compare the developments in a country that imposed a lockdown to a synthetic control group of countries where no lockdown is imposed. And indeed, Friedson et al. (2020) benchmark infection dynamics after California's Shelter-in-place order against those in other US states. However, in this case—like elsewhere—the comparison is complicated by the fact that the control unit is composed of states that also imposed a lockdown, if only somewhat later than California.

In our analysis of the Swedish case, we turn things upside down: we compare actual infection dynamics in the absence of a lockdown to a counterfactual outcome for which we assume that a lockdown is imposed. In order to develop this counterfactual, we also rely on the synthetic control approach and construct a "doppelganger" for Sweden (Born et al., 2019). We then compare the outcome in Sweden and its doppelganger while subjecting the doppelganger to a lockdown "treatment" and not Sweden. To the extent the doppelganger is behaving like Sweden prior to treatment, any difference in outcomes after the lockdown treatment may be attributed to it. Hence, this counterfactual experiment should inform us about what would have happened in Sweden had a lockdown been imposed.

We construct the doppelganger as a weighted average of the countries in a donor pool of European countries. Because infections do not start spreading simultaneously in all countries, we initialize observations for each country: day 1 is when the number of infections surpasses a threshold of one infection per one million inhabitants. After day 1 it took all countries in our donor pool at least 13 days to impose a lockdown. We select the weights for the doppelganger by matching infection dynamics within the 13 days window between day 1 and the first lockdown in our donor pool. At the same time, as we select the weights, we make sure that the doppelganger equals Sweden in terms of population size and urbanization rate.

We find that the (almost) perfect doppelganger of Sweden is a weighted average of the Netherlands (weight of 0.39), Denmark (0.26), Finland (0.19), Norway (0.15), and Portugal (0.01). By construction the doppelganger behaves like Sweden during the 13 day window prior to the lockdown in terms of infection dynamics. Yet, and this is our main result, it also behaves not systematically different from Sweden after the lockdown is imposed in the doppelganger (which happens to be at day 18). This result suggests that the infection dynamics in Sweden would not have been different in case it had imposed a lockdown. Importantly, our analysis is not speaking to the question if the lockdown was effective in the countries that make up the doppelganger.

But we can verify that our result for Sweden does not depend on any individual country that enters the doppelganger. In a robustness exercise we exclude, in turn, each of the five countries from the donor pool and, as we construct new doppelgangers on the basis of the restricted donor pool, obtain very similar results as in the baseline, even though the composition of the doppelganger is necessarily somewhat different in each case. Moreover, we also compare the number of tests for COVID-19 and find that Sweden conducted fewer tests than the doppelganger. However, this is unlikely to be the (only) cause for our result, because we find that the number of COVID-19 deaths in Sweden has not been higher than in the doppelganger.

In sum, we find that a lockdown would not have helped much in Sweden. In order to account for this apparently puzzling result, we analyze Google mobility reports. We find that—even in the absence of a lockdown—Swedes adjusted their activities considerably, and in similar ways as in the doppelganger. Yet, by and large, the adjustment has been somewhat weaker. This suggests that voluntary social restraint goes some way in resolving the “lockdown puzzle”.

One may object that this is merely about semantics. If all that matters is that people adjust their activities, why do we care if this is happening on a voluntary basis, because of a government recommendation, or because of a full-fledged lockdown? The answer is twofold:

First, from a theoretical point of view, it is interesting to learn whether people adjust their behavior voluntarily. Second, from a practical angle, it seems preferable if the necessary adjustment comes about voluntarily and does not need to be enforced. More importantly, still, it is conceivable that the benefits of social restraint (voluntary or due to a lockdown) are declining in the scope of the measures that are taken and, hence, a moderate restraint as observed in Sweden may already be sufficient to limit the spread of infections considerably.

The remainder of this note is organized as follows. Section 2 details our approach, notably the construction of the donor pool and the doppelganger. Section 3 presents results for the baseline. It also discusses our robustness exercises. A final section concludes. The appendix provides further details.

2 The approach

We develop a counterfactual scenario for Sweden in order to assess whether a lockdown would have helped to contain the spread of COVID-19 infections. For this purpose, we construct a "doppelganger" for Sweden based on synthetic control methods. Ideally, the doppelganger behaves just like Sweden before the lockdown such that any difference after the lockdown may be attributed to the "treatment" to which the doppelganger is subjected while Sweden is not.

2.1 The donor pool

The doppelganger is a weighted average of the countries in the "donor pool". To ensure a high degree of homogeneity between Sweden and its doppelganger, we restrict the donor pool to Norway and western EU countries with more than 1 million inhabitants. In total it includes 13 countries. Table 1 provides details on when and what type of lockdown measures where imposed in the countries of the donor pool as well as in Sweden. The first lockdown was imposed in Italy on March 9, the last in the Netherlands on March 24. These lockdowns typically involved the closing of non-essential shops as well as a ban on gatherings of more

Table 1: Donor pool vs. Sweden

Country	Lockdown Start	Lockdown End	Note on containment measures	Day 1	Days to Lockdown
Austria	16.03.	-	non-essential shops closed, ban on gatherings >5	29.02.	16
Belgium	18.03.	-	non-essential shops closed, ban on gatherings >2	03.03.	15
Denmark	18.03.	-	non-essential shops closed	03.03.	15
Finnland	16.03.	-	governm. agencies closed, ban on gatherings >10	01.03.	15
France	17.03.	-	non-essential shops closed, ban on gatherings >2	29.02.	17
Germany	23.03.	-	non-essential shops closed, ban on gatherings >2	01.03.	22
Greece	23.03.	-	non-essential shops closed, stay-at-home-order	05.03.	18
Ireland	28.03.	-	non-essential shops closed, stay-at-home-order	04.03.	24
Italy	09.03.	-	non-essential shops closed, stay-at-home-order	22.02.	16
Netherlands	24.03.	-	non-essential shops closed, ban on gatherings	02.03.	22
Norway	13.03.	-	restaurants, bars closed, ban on gatherings >5 (24.03)	28.02.	14
Portugal	19.03.	-	no shops closed, governm. agencies closed, stay-at-home advice	06.03.	13
Spain	14.03.	-	non-essential shops closed, stay-at-home-order	01.03.	13
Sweden	-	-	No Lockdown imposed, ban on gatherings >50	29.02.	-

Notes: Donor pool includes western EU countries with population size of at least one million and Norway. Day 1 is the day when the number of infections surpasses a threshold of one infection per one million inhabitants. Sources for lockdown dates and details are provided in the appendix.

than two people. In some instances, the ban applies only to gatherings of 10 people or more. In Sweden only gatherings of more than 50 people were banned.

In our analysis we use daily observations for the number of infections up to May 1, 2020. Our data source for infections (as well as for the number of COVID-19 deaths) is the Johns

Hopkins University (Dong et al., 2020).[2] In order to assess the impact of the lockdown, it is essential to ensure that infection dynamics are comparable across countries prior to the lockdown. As the virus arrived at possibly different dates in each country, one should not compare the infection dynamics on a calender-day basis. Therefore, we initialize observations for each country using a common reference point: day 1 is when the number of infections surpasses a threshold of one infection per one million inhabitants. Day 1 varies from country to country, see Table 1. For instance, in Sweden it is February 29, in Norway February 28, and in Denmark March 3.

In the rightmost column, Table 1 also reports the number of days between that date and the day the lockdown was imposed.[3] Note that no country in the donor pool imposed a lockdown within the first 13 days after day 1. For the construction of the doppelganger, we require it to track the infection dynamics in Sweden during the first 13 days as closely as possible, that is, before any country in the donor pool imposed a lockdown. Since the number of infections are initially very low, we target the log of infections rather than the level. In this way, we make sure that the early observations within the 13-day window play a non-negligible role for the construction of the doppelganger.

We also require the doppelganger to be comparable to Sweden in terms of population size and in terms of the urban population share because these factors may play an important role for infection dynamics. In total, we target 15 observations in order to construct the doppelganger: log infections at daily frequency within the 13 day window prior to the first lockdown, population size, and the urbanization rate.

2.2 Constructing the doppelganger

We construct the doppelganger by selecting weights on the countries in the donor pool for which we obtain the best match between the doppelganger and Sweden for the 15 target

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[2] Observations are available at daily frequency. They are assembled using national (e.g. ministry of health, government) as well as international (e.g. WHO, European Centre for Disease Prevention and Control) official sources. For further Information see the website: `https://coronavirus.jhu.edu/us-map-faq`.

[3] Figure A.1 in the appendix displays the number of infections in each country per calendar date.

observations. Formally, we let $\mathbf{x_1}$ denote the (15×1) vector of observations in Sweden and let $\mathbf{X_0}$ denote a (15×13) matrix with observations in the countries included in the donor pool. Finally, we let $\mathbf{w}$ denote a (13×1) vector of country weights w_j, $j = 2, \ldots, 14$. Then, the doppelganger is defined by $\mathbf{w}^*$ which minimizes the following mean squared error:

$$(\mathbf{x_1} - \mathbf{X_0 w})' \mathbf{V} (\mathbf{x_1} - \mathbf{X_0 w}) \ , \tag{1}$$

subject to $w_j >= 0$ for $j = 2, \ldots, 14$ and $\sum_{j=2}^{14} w_j = 1$. In this expression, $\mathbf{V}$ is a (15×15) symmetric and positive semidefinite matrix.[4]

3 Results

We now turn to the results. First, we compare the infection dynamics in Sweden and the doppelganger. Afterwards, we suggest a tentative explanation of our findings based on data from Google's mobility reports.

3.1 Infection dynamics

Figure 1 shows the main result. The vertical axis measures cumulative infections in logs, the horizontal axis measures time in days since the number of infections exceeds one per one million inhabitants (day 1). The solid (blue) line represents data for Sweden. The dashed (red) line represents the doppelganger. It is a weighted average of the following countries: Netherlands (weight of 0.39), Denmark (0.26), Finland (0.19), Norway (0.15), and Portugal (0.01). By construction, that is by minimizing expression (1), the number of infections in the doppelganger tracks the dynamics in Sweden up to day 13 very closely. Still, the

---

[4] $\mathbf{V}$ is a weighting matrix assigning different relevance to the characteristics in $\mathbf{x_1}$ and $\mathbf{X_0}$. Although the matching approach is valid for any choice of $\mathbf{V}$, it affects the weighted mean squared error of the estimator (see the discussion in Abadie et al. (2010), p. 496). Following Abadie and Gardeazabal (2003) and Abadie et al. (2010), we choose a diagonal $\mathbf{V}$ matrix such that the mean squared prediction error of the outcome variable (and the covariates) is minimized for the pre-treatment period. Including the covariates in the optimization differs from Kaul et al. (2018) who have raised concerns about including all pre-intervention outcomes together with covariates when using the SCM.

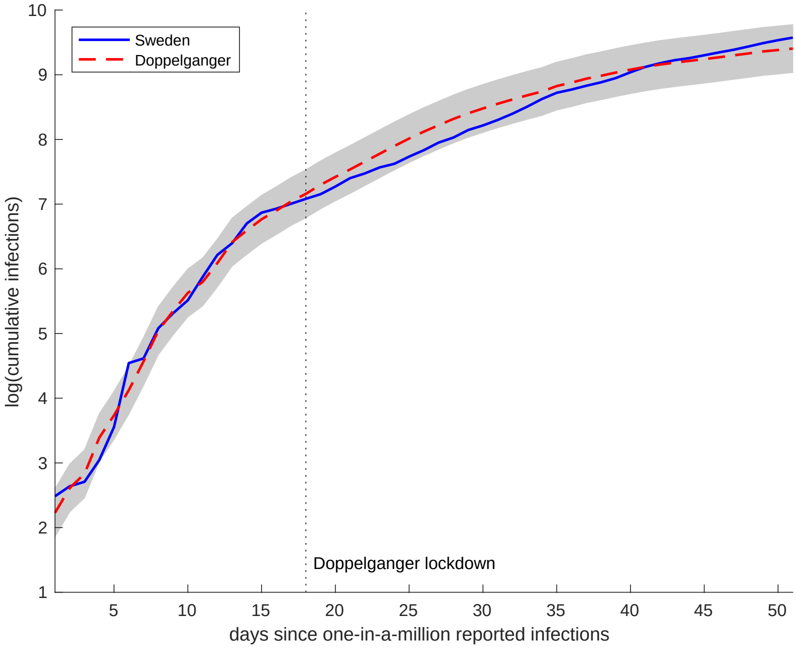

Figure 1: Cumulative infections in Sweden (blue solid line) and in its doppelganger (red dashed line) since day 1 (in logs). *Notes:* Doppelganger is weighted average of the Netherlands (0.39), Denmark (0.26), Finland (0.19), Norway (0.15), and Portugal (0.01). Targeted observations are log infections during the first 13 days as well as population size and urbanization rate. Shaded areas represent two standard deviations of the difference between infections in Sweden and its doppelganger during the first 13 days. Dotted line indicates the time of the lockdown in the doppelganger. Data source: Johns Hopkins University (Dong et al., 2020).

match is not perfect and the shaded area indicates two standard deviations of the difference between infection growth in Sweden and the doppelganger in the matching period. Recall that we also match the population size and the urbanization rate: it is 10.2 million and 0.87, respectively—both in Sweden and its doppelganger.[5]

Given that the doppelganger behaves like Sweden in terms of infection dynamics during the first 13 days, is of equal size and has the same urbanization rate, it provides a meaningful counterfactual for Sweden. The average number of days until a lockdown was imposed in the countries that make up the doppelganger is 18 days. It is indicated by the dotted

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[5] The precise numbers for the urbanization rate are 0.87431 for Sweden and 0.87756 for the Doppelganger. For population they are 10.175 and 10.187 million, respectively.

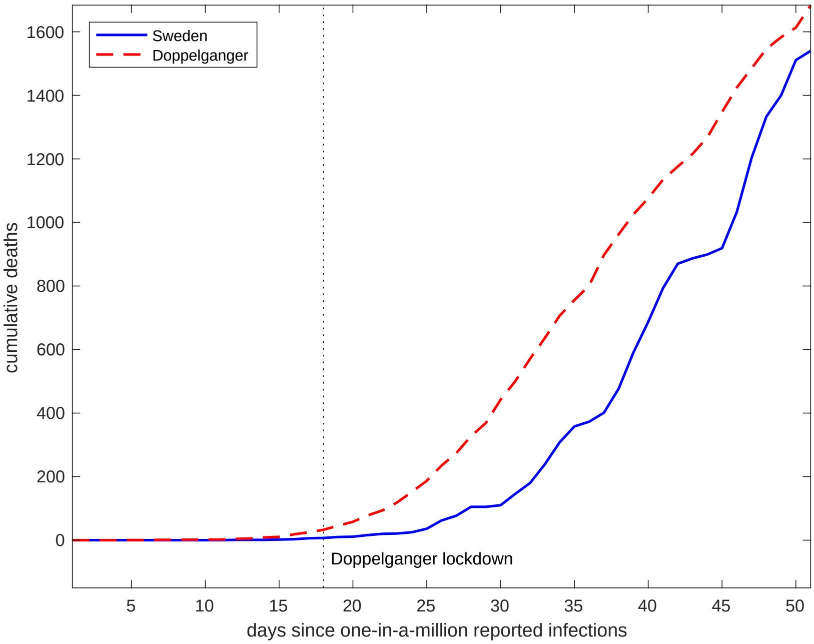

Figure 2: Cumulative COVID-19 deaths in Sweden (blue solid line) and in its doppelganger (red dashed line) since day 1. *Notes:* Based on the country weights used in Figure 1. See the notes to Figure 1 for additional details.

vertical line in Figure 1. We interpret the infection dynamics in the doppelganger afterwards as the outcome that would have been observed in Sweden, had a lockdown been imposed. Our identification assumption is that given pre-lockdown trends as well as other country characteristics, the probability of a lockdown was the same for Sweden and the doppelganger. The "treatment" was, in other words, random.

Under these assumptions, Figure 1 leaves little room for doubt: it shows that a lockdown would not have altered infection dynamics in Sweden in a meaningful way, at least not during the first four weeks after the lockdown. Given the available data at the time of writing we can not analyze the effect of the lockdown in the longer run. We expect this will be the subject of further analyses in the time to come.

However, for now we can make sure that our results are not driven by any individual country that contributes to the doppelganger. To do so, we construct doppelgangers again on the basis of objective (1), but exclude from the donor pool one country at a time that has a non-zero weight in the baseline doppelganger. Table A.2 in the appendix reports the results. We obtain new weights in each instance, but the countries that enter the baseline are generally important (except, of course, if they are excluded from the pool). Figure A.4 shows the infection dynamics for each of the five alternative doppelgangers. They are close to the baseline doppelganger and, hence, close to the actual dynamics observed in Sweden.

A widely discussed shortcoming of the available data is that the number of reported infections is not independent of the number of tests, since infections may go undetected if symptoms are mild or even absent. Figure A.3 in the appendix shows that there where fewer tests conducted in Sweden than in the doppelganger and increasingly so in the second half of the sample. Still the change is moderate and it is hard to say to what extent this matters for reported infections, notably since testing strategies differ across countries.

Against this background we also compare the number of COVID-19 deaths in Sweden and the doppelganger because the statistics are arguably less distorted in this case. Figure 2 displays the time series for the cumulative number of deaths. The figure is organized in the same way as Figure 1 above. The solid (blue) line represents data for Sweden. The dashed (red) line represents the outcome for the doppelganger. Note that we do not construct a new doppelganger but use exactly the same country weights as above. In the figure we display absolute numbers rather than logs, because initially there were no deaths reported, neither in Sweden nor in the doppelganger.

We observe that Sweden did not suffer more COVID-19 deaths than the doppelganger, even though the doppelganger and Sweden are of equal population size. Still, during the last two weeks in the period under consideration, we observe faster growth of COVID-19 deaths in Sweden than in the doppelganger. It remains to be seen whether Sweden will eventually suffer a larger number of deaths. Still, we note that a similar pattern emerges for the five alternative doppelgangers that we obtain for the restricted donor pool. Results are shown in Figure A.5 in the appendix.

3.2 Voluntary social restraint

On the basis of the available data, we find that a lockdown in Sweden would not have limited the number of infections or the number of COVID-19 deaths. Theory suggests that this may be the result of people maintaining a larger social distance even in the absence of a lockdown—there could be, in other words, voluntary social restraint. Krueger et al. (2020), in particular, show this in the context of a formal model and suggest that this may be the relevant case for Sweden.

In order to assess this hypothesis, we rely on the Google COVID-19 Community Mobility Reports (Google, 2020). They are available for each country in our donor pool and provide a measure for how long and how frequently certain types of locations are visited.[6] Locations are classified according to six distinct categories: Grocery and pharmacy, Parks, Residential, Retail and recreation, Transit stations, and Workplaces. The reports measure the change in the number and the length of stays at these locations relative to the median value of the same weekday between January 3 and February 6, 2020.

Figure 3 displays mobility dynamics for each category, contrasting once more data for Sweden (blue solid line) and the doppelganger (red dashed line). As before, the horizonal axis measures time since day 1. The dotted line indicates the lockdown in the doppelganger. A number of findings stand out. First, we observe a pronounced decline for the locations retail and recreation, transit, and work. At the same time, there is an increase in domestic activities (residential) as well as for parks. Second, the adjustment starts to take place about 10 days before the lockdown and, importantly, both in the Sweden and the doppelganger. Last, we observe that while the adjustment of activities follows roughly the same pattern in Sweden and the doppelganger, it is somewhat more pronounced in the doppelganger. Hence, social restraint does seem to take place voluntarily but not to the same extent as in case of a lockdown. Still, since our counterfactual lockdown scenario for Sweden shows no improvement

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[6] Google collects location data in various ways using mobile phone positions (via mobile networks or GPS data), a user's IP address, search queries, or navigation requests. Google uses this information only if users actively agree to share their "Location History".

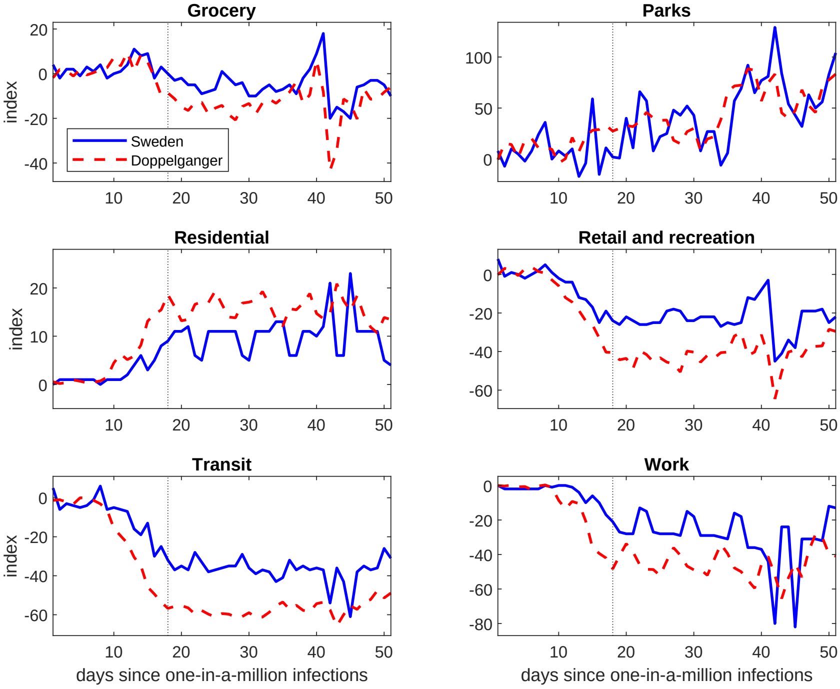

Figure 3: Mobility in Sweden (blue solid line) vs. doppelganger (red dashed line) since day 1. Dotted line: lockdown in doppelganger, see Figure 1 for details. Data source: Google (2020).

in terms of infection outcomes, it seems conceivable that the benefits of social restraint decline as its scope increases.

4 Conclusion

In this paper, we take up the question of whether lockdowns work, that is, whether they limit the spread of COVID-19. We develop a counterfactual for Sweden, one of the few countries where no lockdown was imposed. The counterfactual is based on data from other European countries, selected in such a way as to mimic key aspects of Sweden before any of those countries imposed a lockdown.

We find that a lockdown would not have helped in terms of limiting COVID-19 infections or deaths in Sweden. As we analyze Google mobility reports, we find that Swedes have adjusted their activities in the absence of a lockdown in ways similar to what we observe for the counterfactual lockdown scenario. This suggests that voluntary social restraint plays an important role when it comes to accounting for our result. Against this background it is natural to ask whether voluntary social restraint implies significantly lower economic costs than a full-blown lockdown. We leave this question for future research.

Instead, in concluding, we stress some caveats. First, we use data on COVID-19 infections and deaths even though there are serious issues related to measurement, not least the fact that the number of reported infections depends on the number of tests. Still, our analysis is based on the same data that informs public discussions and actual policy design. Second, our results are necessarily preliminary because it is based on data up to May 1, 2020 only. We cannot know whether our results change as more data comes in.

Last, there is the issue of external validity: we have developed a counterfactual for Sweden and cannot be sure that results carry over to other contexts and countries—just because we find a lockdown would not have made a big difference for Sweden does not mean that it didn't work elsewhere. For it seems that for the COVID-19 pandemic to impact a country strongly, several conditions are required to be met at the same time (New York Times, 2020). In our view, the present study is but one of many that can advance our understanding of whether and how lockdowns work.

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A Appendix

Table A.1: Lockdown measures in Europe: sources

Country	Source
Austria	*www.parlament.gv.at*
Belgium	*www.belgium.be*
Denmark	*politi.dk*
Finnland	*valtioneuvosto.fi*
France	*www.diplomatie.gouv.fr*
Germany	*www.bundesregierung.de*
Greece	*gr.usembassy.gov/covid-19-information*
Ireland	*www.gov.ie*
Italy	*www.trovanorme.salute.gov.it*
Netherlands	*www.government.nl*
Norway	*www.helsedirektoratet.no*
Portugal	*www.acm.gov.pt*
Spain	*www.gov.uk/foreign-travel-advice/spain/coronavirus*

Table A.2: Doppelganger weights: restricted donor pool

	Baseline	I	II	III	IV	V
Austria	< 0.01	< 0.01	0.43	< 0.01	0.10	< 0.01
Belgium	< 0.01	< 0.01	< 0.01	0.19	< 0.01	< 0.01
Denmark	0.26	NA	0.24	0.31	0.33	0.26
Finland	0.19	0.13	NA	0.14	0.18	0.19
France	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Germany	< 0.01	< 0.01	< 0.01	0.04	< 0.01	< 0.01
Greece	< 0.01	< 0.01	< 0.01	0.05	0.04	< 0.01
Ireland	< 0.01	0.01	0.01	< 0.01	< 0.01	< 0.01
Italy	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Netherlands	0.39	0.41	0.27	NA	0.35	0.40
Norway	0.15	0.46	0.05	0.27	NA	0.15
Portugal	0.01	< 0.01	< 0.01	< 0.01	< 0.01	NA
Spain	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Notes: doppelganger weights in baseline and for restricted donor pool. In column I to V we exclude, in turn, one of the five countries that receive a positive weight in our doppelganger of the baseline specification.

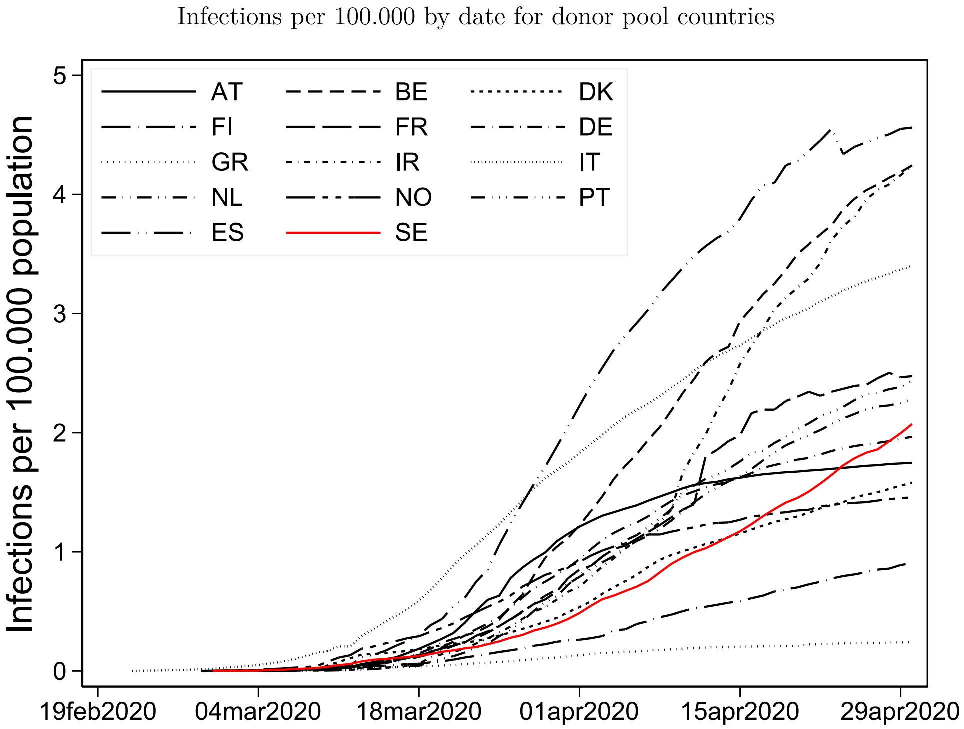

Figure A.1: Infections per 100.000 population for european countries vs. Sweden (red line). Countries grouped by region.

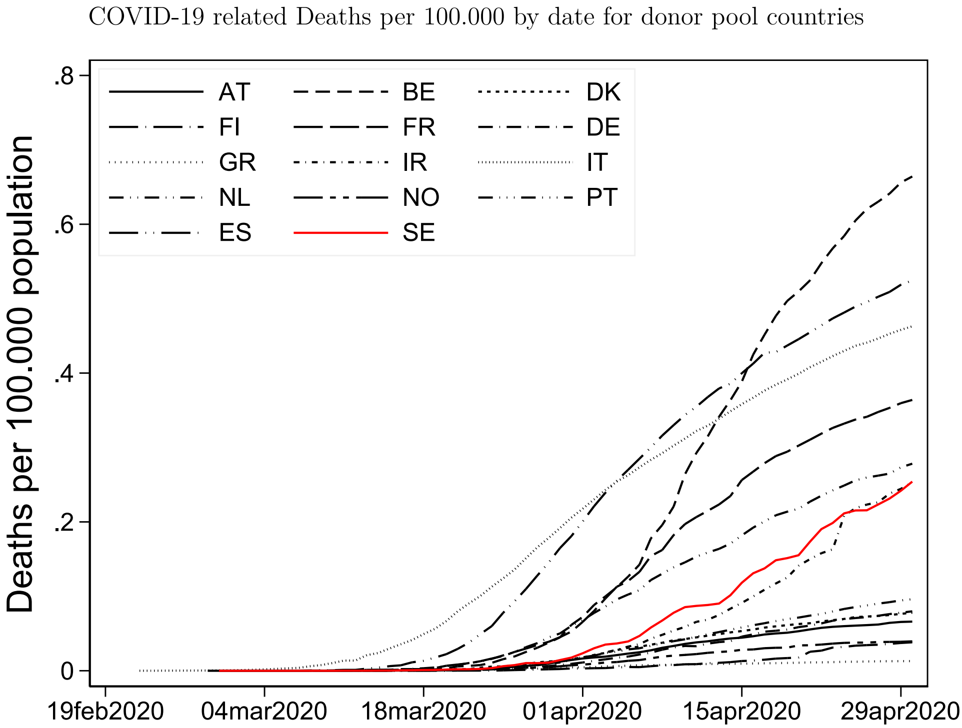

Figure A.2: Deaths per 100.000 population for european countries vs. Sweden (red line). Countries grouped by region.

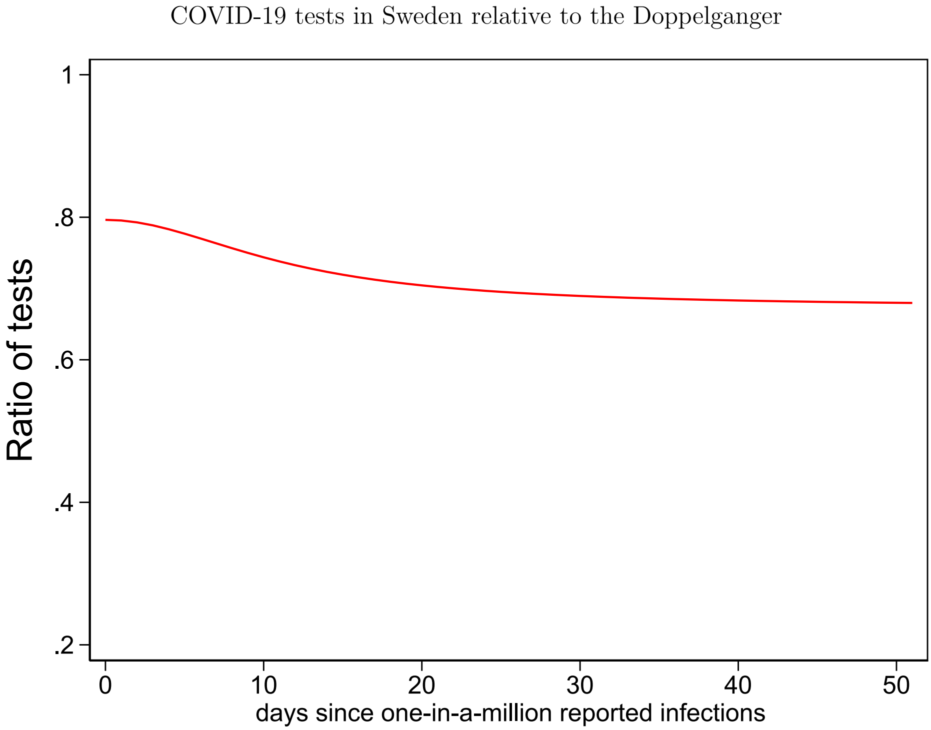

Figure A.3: Number of COVID-19 tests in Sweden relative to the Doppelganger. Source: Hasell et al. (2020). Observations on the number of tests are not reported at daily frequency both for Sweden and the countries that make up the doppelganger. We compute the ratio based on interpolated data after fitting a quadratic trend on the available observations.

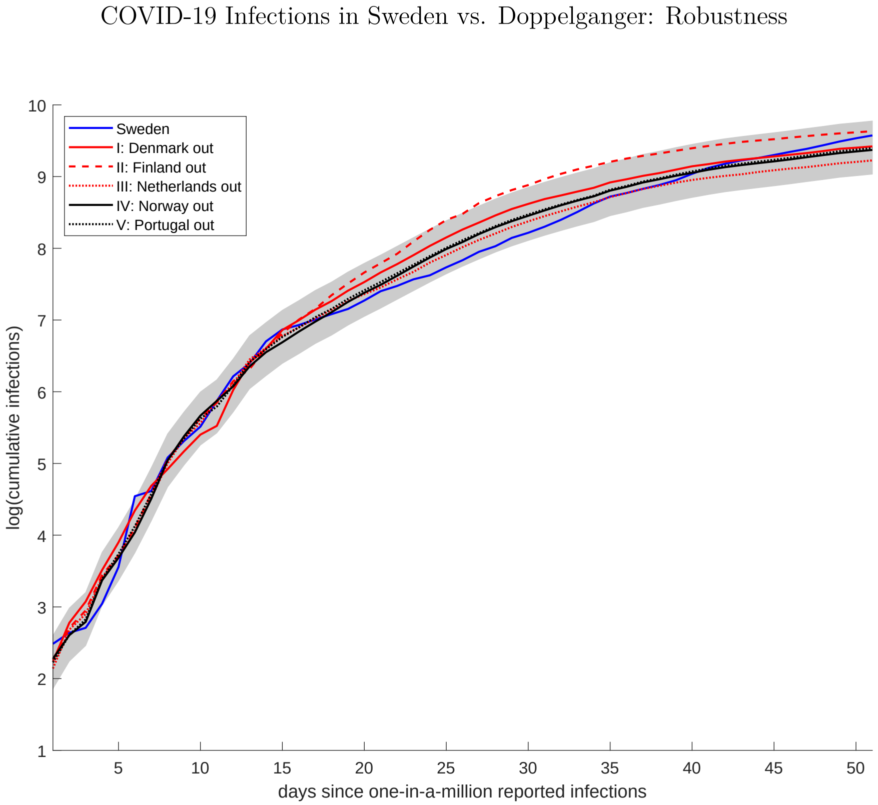

Figure A.4: Cumulative infections in Sweden (blue solid line) and in five doppelgangers since day 1 (in logs). *Notes:* Doppelganger are constructed as each country that contributes to the baseline doppelganger is, in turn, excluded from the donor pool. Table A.2 reports country weights. Shaded areas represent two standard deviations of the difference between infections in Sweden and the baseline doppelganger during the first 13 days. Data source: Johns Hopkins University (Dong et al., 2020).

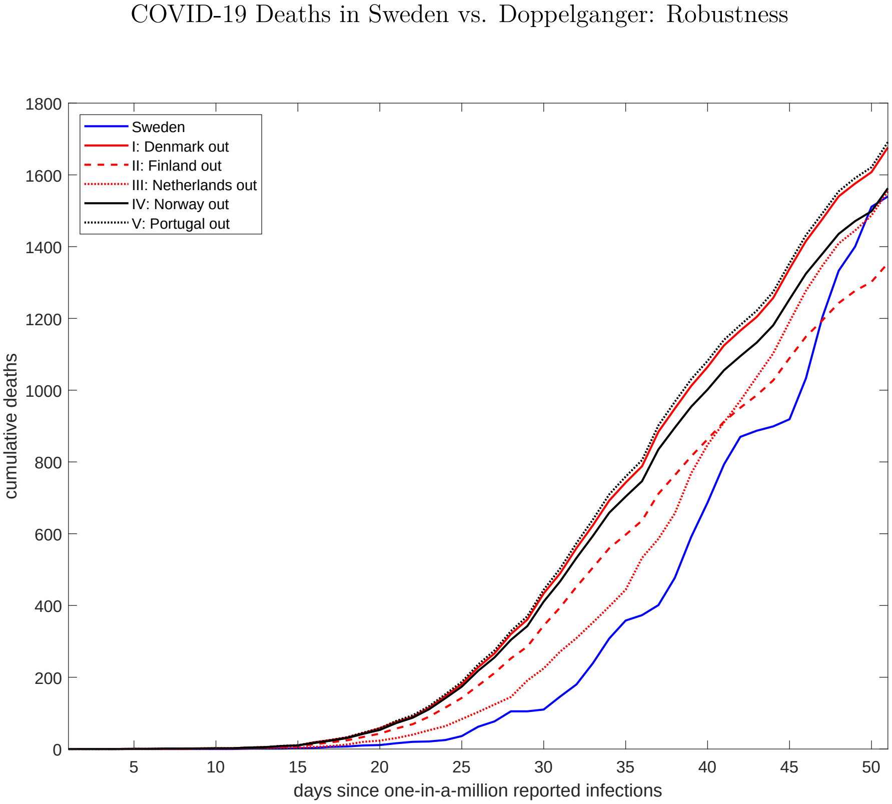

Figure A.5: Cumulative Deaths in Sweden (blue solid line) and in five doppelgangers since day 1 (in logs). *Notes:* Doppelganger are constructed as each country that contributes to the baseline doppelganger is, in turn, excluded from the donor pool. Table A.2 reports country weights. Data source: Johns Hopkins University (Dong et al., 2020).

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Gender equality in work and Covid-19 deaths[1]

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On average, women comprise a smaller share of deaths from Covid-19. However, variation in the share of Covid-19 deaths for women across countries and US States suggests that biological factors cannot fully account for this gender difference. I hypothesize that women's participation in the workforce is related to women's share of Covid-19 deaths. I show that the percent of the full-time workforce comprised by women is positively related to the percent of female Covid-19 deaths across countries. I also show that the percent of the full-time workforce comprised by women is positively related to the incidence of various diseases associated with a more severe impact of Covid-19 and the percent of medical doctors and nurses who are women. My results suggest that in countries where women participate more fully in the workforce, women may be more susceptible to Covid-19 due to increased exposure to the virus and a higher risk of developing comorbidities. Future research should be careful to consider social factors when examining gender differences in health outcomes.

Covid Economics 16, 11 May 2020: 23-60

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1. Introduction

On average, women comprise a smaller share of deaths from Covid-19 (The Gender and COVID-19 Working Group, 2020; Jin et al., 2020). So far, explanations for this gender difference center on biological or genetic differences between men and women and gender differences in behaviour (Moalem, 2020; GlobalHealth 50/50, 2020). As men appear more vulnerable to infection, some ask whether Covid-19 treatments should be different for men and whether extra care is necessary to protect them (Rabin, 2020; Hastings, 2020). At the same time, other commentators have pointed to the fact that women face a higher risk of exposure due to the fact that they constitute the majority of health care and essential workers (Gupta, 2020; Robertson, 2020). Moreover, evidence from the 1918 flu pandemic suggests that social factors may be important in explaining differences in mortality rates (Paskoff, and Sattenspiel, 2020). As Quinn and Smith (2018) recognize, the state of the literature on women's work and their health outcomes is still underdeveloped. To add to this literature and contribute to the discussion around the gendered impact of Covid-19, I examine whether gender difference in Covid-19 deaths across countries and US States are related to gender differences in work patterns.

To date, the discussion around gender differences in Covid-19 mortality has focused on average effects. The fact that the % of female deaths due to Covid-19 varies across countries has been ignored, even though the variation is considerable. In the April 22 data from Global Health 50/50, the % of female deaths due to Covid-19 ranges from 19% in Thailand to 50% in Portugal. Variation can also exist within a country. For US States with gender disaggregated data, as of April 24 the % of female deaths due to Covid-19 ranged from 39% in North Carolina to 55.6% in Alaska. Presumably, sex cannot explain the cross- or within-country variance in the share of women's deaths due to Covid-19. This raises the question whether differences in work patterns can help explain the variation in mortality rates, particularly across country.

Work patterns are a natural candidate for study because occupational risks are associated with a substantial part of the burden of chronic diseases, some of which are linked to increased susceptibility to the coronavirus, e.g. asthma (GlobalHealth 50/50, 2020). Work may also be associated with increased exposure to the coronavirus, which is why the closing of non-essential businesses has played a key role in most countries' efforts to combat the coronavirus. Since women's participation in the workforce varies substantially across countries, women's work may help explain the variation in women's share of Covid-19 deaths across countries.

Using data on female Covid-19 outcomes from Globalhealth 50/50 and country-level data from a variety of other sources, I show that the % of female deaths due to Covid-19 is higher in countries in which women comprise a greater share of the full-time workforce. I also show that the share of women in the full-time workforce is associated with a higher incidence among women of some diseases and injuries, as well as a higher share of female medical doctors. These results lend support to the idea that women's share of Covid-19 deaths increases when they are subject to greater occupational health risks and greater exposure to the virus. While causal attribution is difficult due to the evolving nature of the phenomenon, the results highlight that caution needs to be exercised in attributing gender differences in Covid-19 deaths entirely to biological factors. Societal factors may also be important.

2. Methods

Data Sources

I obtain data on the share of Covid-19 deaths (Deathsfemale) and cases (Casesfemale) and the ratio of male to female deaths among confirmed Covid-19 cases (Genderratio) from the April 7, 15 and 22, 2020 updates of the GlobalHealth 50/50 COVID-19 sex-disaggregated data tracker. According to its protocol, GlobalHealth 50/50 COVID-19 compiles all national and international/global surveillance data relating to Covid-19 infection from the 60+ countries with the highest number of reported cases and updates its data every week. GlobalHealth 50/50 reports data for England and Wales, Scotland and Northern Ireland separately. I aggregate these to a UK level number. I also collect all available gender disaggregated data on Covid-19 fatalities and cases in US States as of April 24. As of that date, only 14 states provided gender-disaggregated data, one of which is Rhode Island which had no reported deaths due to the coronavirus on the day that it reported a breakdown by gender (March 6, 2020). Links to state-level statistics were obtained from the list in Schumaker (2020).

I obtain the latest available country-level data on the share of women in the full-time workforce (% full-time workers – female) from the OECD and the International Labor Organization (ILO). Data for US States is from the US Census. The latest data on the share of female medical doctors (% medical doctors – female) and nurses (% Nurses – female) in a country are from the World Health Organization (WHO). From the World Economic Forum I obtain country-level data on Economic Participation and Opportunity scores and Health and Safety scores for 2019. I obtain data for the incidence of disease and injury among women measured in DALY’s (disability-adjusted life year) per 100,000 (population) from the 2017 Global Burden of Disease Study. GDP Per Capita comes from the World Bank (for countries) and the US Bureau of Economic Analysis (for US states). The Appendix (Tables A1-A4) provides summary statistics and correlation matrices for the data.

Data analysis

I plot the data to analyze potential outliers in the data. Visual inspection suggests that data for countries outside the OECD is of poorer quality than for OECD countries, so I focus the analysis on OECD countries. I conduct most of the analysis using the April 22 version of the GlobalHealth 50/50 data as it has broader coverage than earlier versions of the data and data quality increases over time. However, I also analyze the April 7 and April 15 releases of GlobalHealth 50/50 data in the Appendix.

In the OECD sample, I run multivariate OLS regressions of Deathsfemale on % full-time workers – female and GDP per capita (the base regression). As a robustness check, I also run regressions of Casesfemale and Genderratio on % full-time workers – female and GDP per capita. To examine the hypothesis that work might increase women's susceptibility to Covid-19, I examine how women's incidence of disease is related to % full-time workers – female and other controls in the Appendix. I conduct the analysis for the full country-level GBD dataset with available data on control variables and for US States (Tables A5 and A6). I also examine how women's share of the health workforce varies with % full-time workers – female.

I examine potential mechanisms driving the relation between Covid-19 outcomes and % full-time workers by first adding the Health and Safety Scores and the incidence of Female Cardiovascular diseases, Female Chronic respiratory diseases and Female Substance use disorders to the base regression and then replacing % full-time workers – female with % medical doctors – female in the base regression. I focus on cardiovascular and respiratory diseases and substance abuse as there is evidence these exacerbate the impact of Covid-19.

Since the Health and Safety Score is highly correlated with GDP (correlation of -0.553, p-value 0.002), I leave GDP per capita out of the regressions with health measures. Since the variation in % Nurses - female is small, I do not include this measure in the regression analysis. I correct all standard errors for heteroskedasticity using Eicker-Huber-White standard errors. The results are in Table 1.

In Table 2, I replicate the Deathsfemale regressions in Table 1 for the full sample. I exclude Iran because of potential misreporting due to stigma (Rubin, 2020). Since the quality of labor market data is worse outside the OECD, I add a specification in which I replace % full-time workers – female with Economic Participation and Opportunity scores (column IV).

I restrict my analysis of the US data to visual inspections because the sample is so small.

3. Results

Figure 1 provides a scatterplot of Deathsfemale and Casesfemale for the full sample. Lines indicate the linear fit between Deathsfemale and Casesfemale for OECD and non-OECD countries separately. In the figure, most counties fall below the 45-degree line, which is the reason why women are viewed as being less susceptible to Covid-19. However, it is also clear that there is considerable variation in the data across countries, which would be difficult to attribute to sex differences. Figure 1 also highlights that there is a stronger relation between cases and deaths in OECD countries. Similar patterns are observable in the plot of Deathsfemale and Genderratio (Figure A1 in the Appendix). It is possible that the weaker relation outside the OECD is driven by differences in testing which is why I do not include Casesfemale and Genderratio in the multivariate analysis for the full sample.

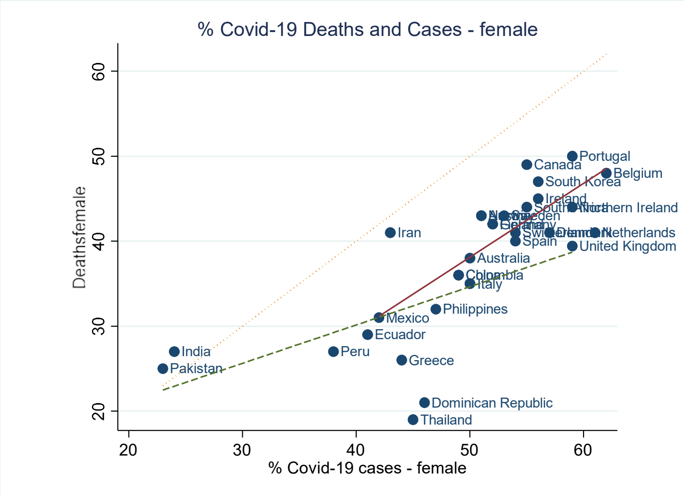

Figure 1 Female Covid-19 Deaths and Cases

Figure 1 uses the April 22 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the % of Covid-19 deaths that are female. The solid line fits Deathsfemale and % of Covid-19 cases that are female among OECD countries. The dashed line fits Deathsfemale and the % of Covid-19 cases that are female among non-OECD countries. The dotted line indicates the 45-degree line.

Figure 2 provides a scatterplot of Deathsfemale and Casesfemale for US states. The figure highlights that gender differences in Covid-19 outcomes can vary even within a country. Again, this variation would be difficult to attribute to sex differences.

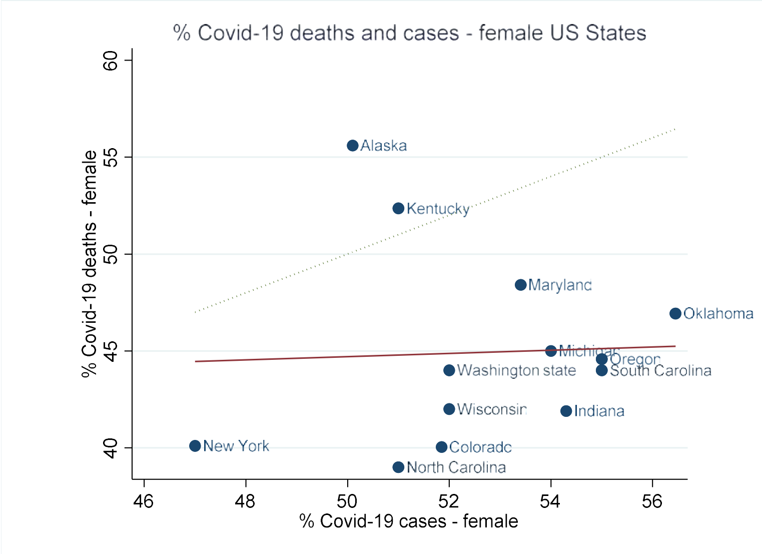

Figure 2 Female Covid-19 Deaths and Cases – US States

Figure 2 uses all available sex-disaggregated data for US States as of April 24, 2020. The solid line fits % of Covid-19 deaths that are female and % of Covid-19 cases that are female. The dotted line indicates the 45-degree line.

Figure 3 provides a scatterplot of Deathsfemale and % full-time workers – female for the OECD sample. The positive relation between the two variables is striking. As a robustness check, I plot Genderratio and % full-time workers – female in Figure 4. Consistent with Figure 3, the relation between Genderratio and % full-time workers – female is negative. The Appendix provides a similar robustness check for the full sample and Casesfemale (Figures A2 and A3).

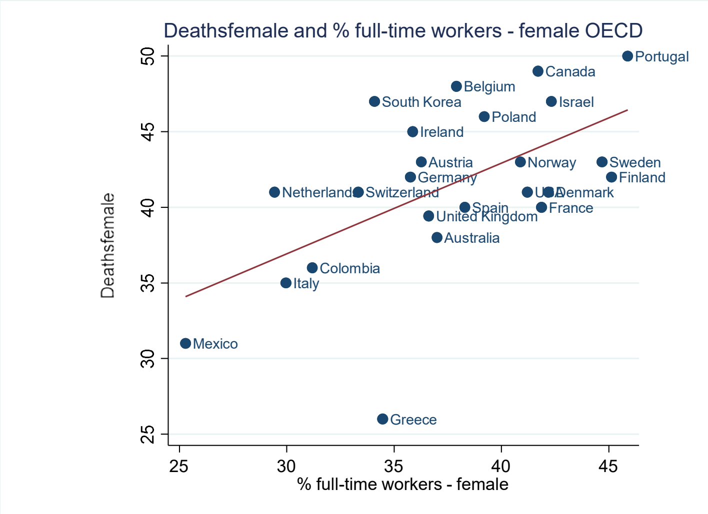

Figure 3 Female Covid-19 Deaths and Full-time Employment - OECD

Figure 3 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the percent of female deaths. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018.

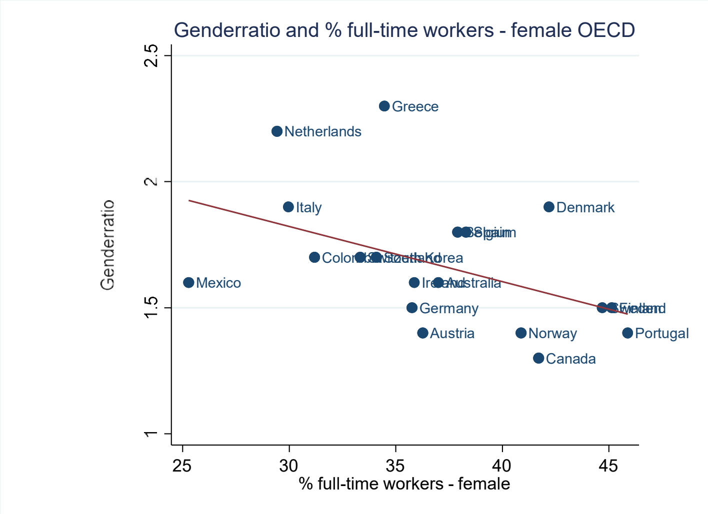

Figure 4 Gender ratio of confirmed Covid-19 deaths and Female Full-Time Employment – OECD

Figure 4 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Genderratio is the ratio of male to female deaths among confirmed cases of Covid-19. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018.

The results in columns I, V and IX of Table 1 show that the relations in Figures 3, 4 and A3 hold after accounting for variation in GDP. The p-values in these specifications range from 0.002 (column I) to 0.096 (column V). In countries in which women participate more equally in the workforce, gender differences in Covid-19 outcomes appear to be lower.

VARIABLES	Deathsfemale				Casesfemale				Genderratio			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
% full-time workers - female	0.56	0.60	0.67		0.40	0.42	0.41		-0.02	-0.02	-0.03	
	(0.002)	(0.002)	(0.002)		(0.096)	(0.047)	(0.096)		(0.056)	(0.010)	(0.059)	
% medical doctors - female				0.27				0.56				-0.01
				(0.261)				(0.036)				(0.444)
Health and Safety score		141.82				-515.88				-23.61		
		(0.571)				(0.098)				(0.039)		
Female Cardiovascular diseases			-0.00099				-0.00136				0.00002	
			(0.469)				(0.169)				(0.781)	
Female Chronic respiratory diseases			-0.00133				0.00862				0.00039	
			(0.690)				(0.048)				(0.080)	
Female Substance use disorders			-0.00029				-0.00356				-0.00055	
			(0.925)				(0.634)				(0.117)	
GDP Per Capita	41.16			91.83	39.04			76.10	-0.81			-5.32
	(0.368)			(0.326)	(0.422)			(0.172)	(0.749)			(0.174)
Constant	18.73	-119.14	21.22	23.83	35.46	538.88	32.52	22.57	2.48	25.49	2.27	2.57
	(0.005)	(0.626)	(0.006)	(0.117)	(0.000)	(0.079)	(0.001)	(0.124)	(0.000)	(0.024)	(0.000)	(0.008)
Observations	24	24	23	18	24	24	23	17	19	19	18	14
Adjusted R-squared	0.286	0.272	0.251	0.0460	0.115	0.218	0.205	0.231	0.124	0.251	0.344	0.00967

Table 1 Covid-19 Outcomes for Women and Female Employment – OECD countries

Table 1 shows the results of heteroskedasticity corrected OLS regressions of Covid-19 outcomes for women on % full-time workers – female and various control variables. The sample of Covid-19 outcomes is from the April 22, 2020 update of the GlobalHealth 50/50 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for OECD countries. Deathsfemale (Casesfemale) is the percent of Covid-19 deaths (cases) that are female. Genderratio is the ratio of male to female deaths among confirmed Covid-19 cases. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018 (Source: OECD). % medical doctors - female is the percent of doctors in a country who are female (Source: WHO Global Health Workforce Statistics 2018 update). Health and Safety score is from the World Economic Forum's Global Gender Gap 2020 Report. Female Cardiovascular diseases, Female Chronic respiratory diseases and Female Substance use disorders are measured in DALY's (disability-adjusted life year) per 100,000 (population) and measured in 2017 (Source: Global Burden of Disease Study, 2017). GDP Per Capita is as of 2018 (Source: The World Bank). P-values are in parentheses.

The results in Tables A5 and A6 suggest that women's incidence of some diseases may increase with their greater workforce participation. The coefficients on % full-time workers – female in the regressions for cardiovascular and respiratory diseases in Table A5 are positive with p-values ranging from 0.041 to <0.000. Similar patterns hold for US States in Table A6. Nevertheless, including health related measures in the base regression does not reduce the magnitude of the coefficient on % full-time workers – female in Table 1.

To examine whether work may be associated with increased exposure, I plot % medical doctors – female and % Nurses – female against % full-time workers – female in Figure 5. The figure suggests that the more women work, the greater the share of front-line health professionals they comprise. Figures 6 and 7 suggests that there is a positive relation between Deathsfemale and % medical doctors – female and % Nurses – female. Figures A4 and A5 for the full sample suggests a similar relation between Deathsfemale and % medical doctors – female in the full sample, but both figures also highlight that women's participation in the healthcare sector is unlikely to fully explain variation in Deathsfemale. This is particularly evident from Figure A5 which highlights the lack of variation in % Nurses – female across countries.

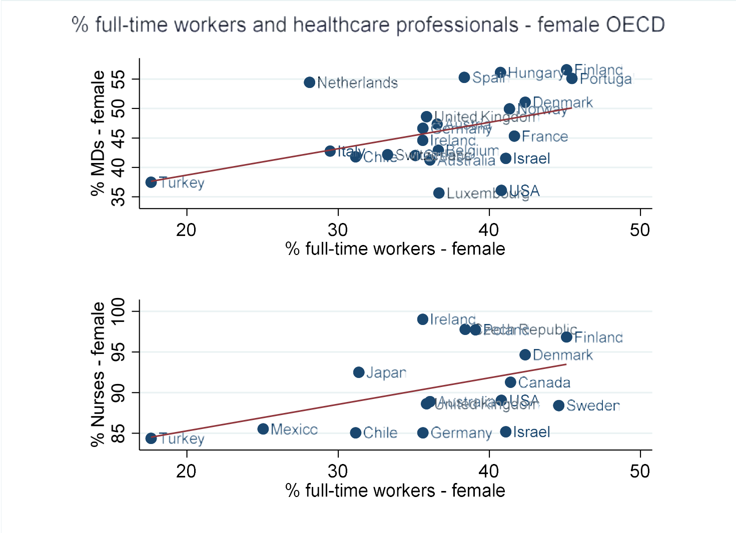

Figure 5 Healthcare Professionals and Female Full-Time Employment – OECD

% MDs – female (% Nurses – female) is the percent of medical doctors (Nurses) that are female in a country. Data is from the WHO Global Health Workforce Statistics 2018 update. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2016.

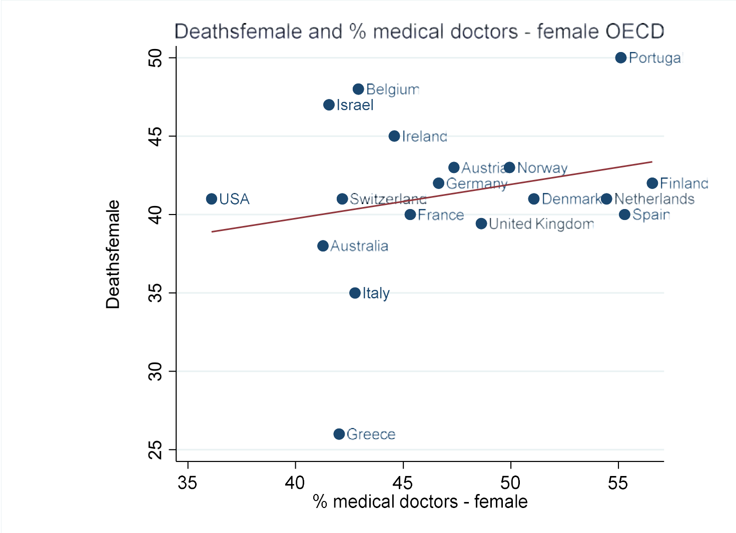

Figure 6 Female Covid-19 Deaths and Women's Share of Medical Doctors - OECD

Figure 6 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. % medical doctors - female is the percent of doctors in a country who are female.

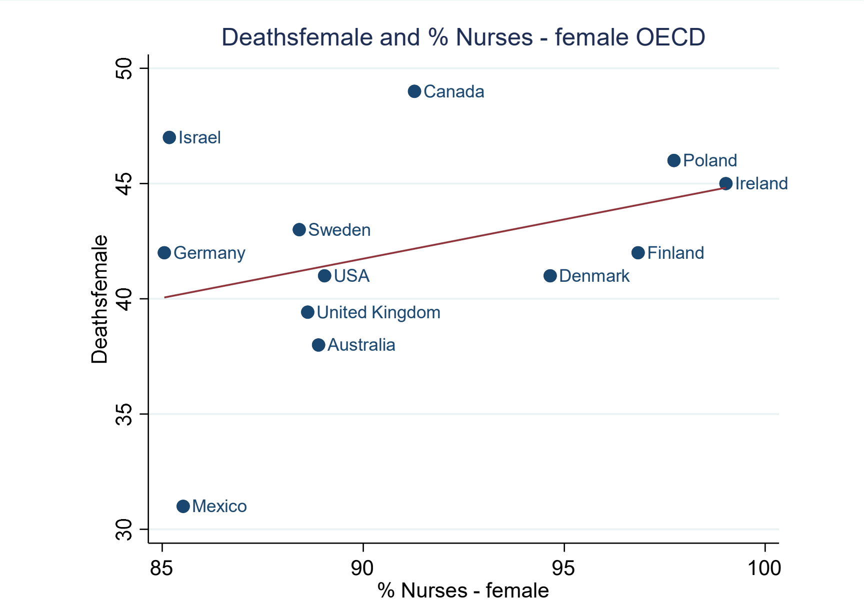

Figure 7 Female Covid-19 Deaths and Women's Share of Nurses- OECD

Figure 7 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. % Nurses - female is the percent of nurses in a country who are female.

Columns IV, VIII and XII of Table 1 display the same signs on the coefficients for % medical doctors – female as for % full-time workers – female. The results in column VIII are particularly consistent with the idea that women are more likely to become ill the more they work in front-line health positions (coefficient on % medical doctors – female of 0.56 with a p-value of 0.036).

The results in Table 2 are broadly consistent with those in Table 1. As with % full-time workers – female, the coefficient on the Participation and Opportunity Score is positive (p-value 0.009). But there are also some notable differences. In the full sample, the incidence of Female Chronic respiratory diseases in column III is positively associated with Deathsfemale (p-value of 0.047) and the coefficient on % full-time workers – female is smaller in column III (coefficient of 0.39, p-value 0.068) than in column II (coefficient of

0.60, p-value 0.017), which suggests that some of the positive relation between % full-time workers – female and Deathsfemale may be due to increased health problems associated with women's greater participation in the workforce. In the full sample, Deathsfemale is also more significantly related to % medical doctors – female (coefficient of 0.41, p-value 0.90) which is consistent with the idea that the more women work, the more they may be exposed to the coronavirus. It is plausible that greater variation in some of the explanatory variables across countries and the increase in sample size explains the differences in results in Tables 1 and 2.

VARIABLES	Deathsfemale				Casesfemale				Genderratio			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
% full-time workers - female	0.56	0.60	0.67		0.40	0.42	0.41		-0.02	-0.02	-0.03	
	(0.002)	(0.002)	(0.002)		(0.096)	(0.047)	(0.096)		(0.056)	(0.010)	(0.059)	
% medical doctors - female				0.27				0.56				-0.01
				(0.261)				(0.036)				(0.444)
Health and Safety score		141.82				-515.88				-23.61		
		(0.571)				(0.098)				(0.039)		
Female Cardiovascular diseases			-0.00099				-0.00136				0.00002	
			(0.469)				(0.169)				(0.781)	
Female Chronic respiratory diseases			-0.00133				0.00862				0.00039	
			(0.690)				(0.048)				(0.080)	
Female Substance use disorders			-0.00029				-0.00356				-0.00055	
			(0.925)				(0.634)				(0.117)	
GDP Per Capita	41.16			91.83	39.04			76.10	-0.81			-5.32
	(0.368)			(0.326)	(0.422)			(0.172)	(0.749)			(0.174)
Constant	18.73	-119.14	21.22	23.83	35.46	538.88	32.52	22.57	2.48	25.49	2.27	2.57
	(0.005)	(0.626)	(0.006)	(0.117)	(0.000)	(0.079)	(0.001)	(0.124)	(0.000)	(0.024)	(0.000)	(0.008)
Observations	24	24	23	18	24	24	23	17	19	19	18	14
Adjusted R-squared	0.286	0.272	0.251	0.0460	0.115	0.218	0.205	0.231	0.124	0.251	0.344	0.00967

Table 1 Covid-19 Outcomes for Women and Female Employment – OECD countries

Table 1 shows the results of heteroskedasticity corrected OLS regressions of Covid-19 outcomes for women on % full-time workers – female and various control variables. The sample of Covid-19 outcomes is from the April 22, 2020 update of the GlobalHealth 50/50 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for OECD countries. Deathsfemale (Casesfemale) is the percent of Covid-19 deaths (cases) that are female. Genderratio is the ratio of male to female deaths among confirmed Covid-19 cases. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018 (Source: OECD). % medical doctors - female is the percent of doctors in a country who are female (Source: WHO Global Health Workforce Statistics 2018 update). Health and Safety score is from the World Economic Forum’s Global Gender Gap 2020 Report. Female Cardiovascular diseases, Female Chronic respiratory diseases and Female Substance use disorders are measured in DALY’s (disability-adjusted life year) per 100,000 (population) and measured in 2017 (Source: Global Burden of Disease Study, 2017). GDP Per Capita is as of 2018 (Source: The World Bank). P-values are in parentheses.

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Figures A6 and A7 show that the positive relation between Deathsfemale and % full-time workers – female plotted in Figure 3 also appears to exist in the April 7 and April 15 data from GlobalHealth 50/50. It is noticeable that countries move closer together with each update. Presumably, this is because countries start reaching a similar stage in the spread of the coronavirus and the data becomes more accurate. Table A7 replicates Table 1 in the earlier data sets. While the results are less statistically significant, they are broadly consistent with the results in Table 1.

Figure A8 shows the plot of Deathsfemale and % full-time workers – female for US states. The slope of the fitted line between the two variables is slightly positive. But there are also notable outliers (Alaska and Kentucky). As better data becomes available, further research needs to be conducted to explain the cross-state pattern in Deathsfemale in the US.

4. Discussion

I highlight the fact that there is considerable variation in Covid-19 outcomes for women using data across countries and US States. Since the argument that biological sex differences vary considerably across countries and US States is presumably indefensible, this variation challenges the idea that the only reason women fare better than men in the coronavirus crisis is because of innate biological or behavioural differences. I hypothesize that women's participation in the workforce can help explain this variation because work may be associated with a higher incidence of pre-existing conditions and greater exposure to the coronavirus. My results are broadly consistent with this hypothesis. Even though the evolving nature of the pandemic and the data makes the identification of a causal channel problematic, the striking nature of the simple relations I document here should serve as a starting point for additional research into social dimensions related to Covid-19 outcomes.

The results suggest that the more equal societies are, the more gender equal treatment and policies to combat Covid19 should be. At the same time, it should be recognized that although women may suffer less from Covid-19 in more gender unequal countries, they experience worse quality of lives than men along other dimensions. Thus, lower mortality rates for women in these countries should not be used as an excuse to discriminate further.

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Appendix for Adams, Renée (2020) Gender Equality in Work and Covid-19 Deaths

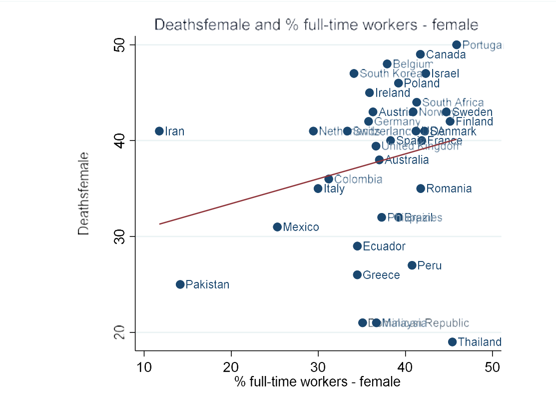

Figure A2 Female Covid-19 Deaths and Full-time Employment

Figure A2 uses the April 22 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676). Deathsfemale is the % of Covid-19 deaths that are female. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country, measured in 2018. The line fits Deathsfemale and % full-time workers – female.

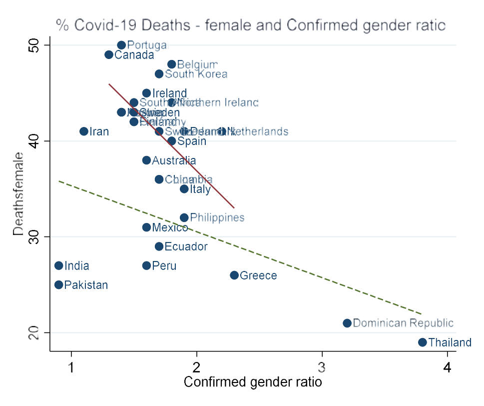

Figure A1 Female Covid-19 Deaths and Confirmed Gender Ratio

Figure A1 uses the April 22 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the % of Covid-19 deaths that are female. The Confirmed gender ratio is the ratio of male to female deaths among confirmed cases of Covid-19. The solid line fits Deathsfemale and the Confirmed gender ratio among OECD countries. The dashed line fits Deathsfemale and the Confirmed gender ratio among non-OECD countries.

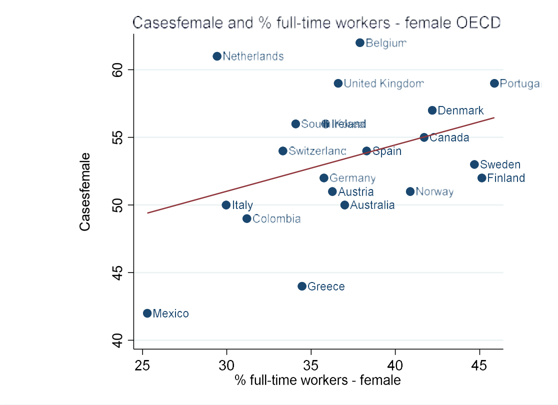

Figure A3 Female Covid-19 Cases and Full-time Employment - OECD

Figure A3 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Casesfemale is the percent of Covid-19 cases that are female. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country, measured in 2018.

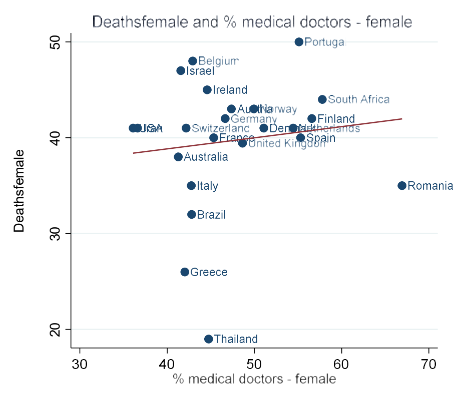

Figure A4 Female Covid-19 Deaths and Women’s Share of Medical Doctors

Figure A4 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. % medical doctors - female is the percent of doctors in a country who are female.

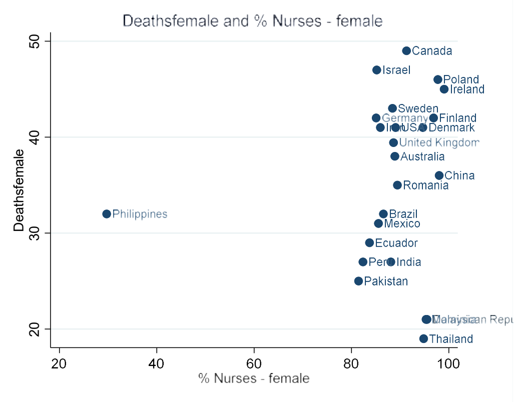

Figure A5 Female Covid-19 Deaths and Women's Share of Nurses

Figure A5 uses the April 22, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676). % Nurses - female is the percent of nurses in a country who are female.

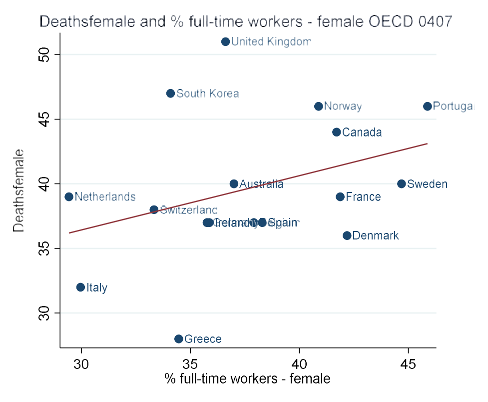

Figure A6 Female Covid-19 Deaths as of April 7, 2020 and Full-time Employment - OECD

Figure A6 uses the April 7, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the percent of Covid-19 deaths that are female. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country, measured in 2018.

Figure A7 Female Covid-19 Deaths as of April 15, 2020 and Full-time Employment - OECD

Figure A7 uses the April 15, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the percent of Covid-19 deaths that are female. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018.

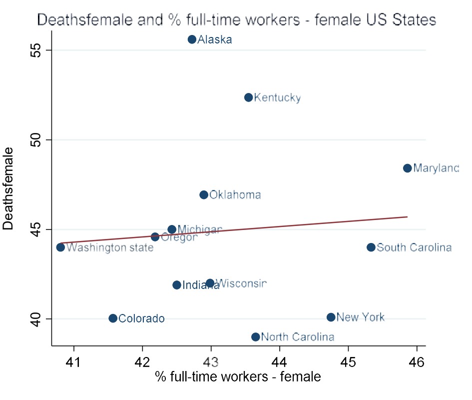

Figure A8 Female Covid-19 Deaths and Full-time Employment – US States

Figure A8 uses all available sex-disaggregated data for US States as of April 24, 2020. Deathsfemale is the % of Covid-19 deaths that are female. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country, measured in 2019. The line fits Deathsfemale and % full-time workers – female.

Variable	Obs	Mean	Std. Dev.	Min	Max
Panel A: Countries with Deaths, Cases or Gender in April 22 Globalhealth 5050 data					
Deathsfemale	41	37.986	8.249	19.000	50.000
Genderratio	30	1.730	0.577	0.900	3.800
Casesfemale	41	47.537	10.759	11.000	62.000
% full-time workers - female (2018)	42	36.447	7.020	11.729	45.877
% full-time workers - female (2017)	42	35.936	7.515	12.579	45.673
Participation and Opportunity Score	48	0.667	0.113	0.327	0.798
% medical doctors - female	28	47.518	8.216	35.654	66.911
% Nurses - female	32	84.821	17.464	19.461	99.021
Health and Safety Score	48	0.972	0.010	0.926	0.980
Female Cardiovascular diseases	49	3923.080	2240.587	1488.049	13754.730
Female Chronic respiratory diseases	49	1140.769	422.519	467.892	2455.460
Female Substance use disorders	49	351.334	235.287	123.014	1503.543
GDP Per Capita (2017) (millions)	48	28602.320	25325.610	1464.993	17361.300
GDP Per Capita (2018) (trillions)	47	0.031	0.027	0.001	0.117
OECD	51	0.549	0.503	0.000	1.000
Panel B: OECD Countries with Deaths, Cases or Gender in April 22 GlobalHealth 50/50 data					
Deathsfemale	24	41.434	5.579	26.000	50.000
Genderratio	19	1.674	0.266	1.300	2.300
Casesfemale	24	52.000	5.942	40.000	62.000
% full-time workers - female (2016)	28	0.368	0.052	0.250	0.455
% full-time workers - female (2017)	28	0.370	0.051	0.249	0.453
% full-time workers - female (2018)	28	37.259	5.100	25.285	45.877
% medical doctors - female	20	46.059	6.158	35.654	56.571
% Nurses - female	15	91.037	5.074	85.055	99.021
Health and Safety Score	28	0.974	0.004	0.968	0.980
Female Cardiovascular diseases	27	3531.781	1207.991	1715.370	6506.650
Female Chronic respiratory diseases	27	1174.323	329.247	700.024	1841.371
Female Substance use disorders	27	355.749	264.172	123.014	1503.543
GDP Per Capita (2017) (millions)	28	42388.580	23034.710	6375.932	17361.300
GDP Per Capita (2018) (trillions)	28	0.045	0.025	0.007	0.117
Panel C: US States					
Deathsfemale	13	44.917	4.892	39.000	55.600
Casesfemale	13	1.242	0.225	0.799	1.564
% full-time workers - female (2019)	13	52.547	2.514	47.000	56.450
% full-time workers - female (2017)	13	43.170	1.449	40.804	45.860
South	13	43.044	1.429	40.863	45.516
Female Cardiovascular diseases	13	0.385	0.506	0.000	1.000
Female Chronic respiratory diseases	13	4084.656	919.376	2643.168	5405.458
Female Substance use disorders	13	1953.516	426.563	1411.228	2837.120
GDP Per Capita (2017) (millions)	13	1715.970	478.178	883.968	2750.504

Table A1 Summary statistics for full sample, OECD sub-sample and US state sample

Table A1 provides summary statistics for the data. The sample in panel A consists of all available data for countries with at least one of Deathsfemale, Casesfemale or Genderratio reported in the April 22, 2020 update of the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676). The sample in Panel B consists of OECD subsample of the data in Panel A. The sample in Panel C consists of all available data for US States with gender disaggregated data on Covid-19 fatalities and cases as of April 24. Links to state-level statistics were obtained via https://abcnews.go.com/Health/coronavirus-map-tracking-spread-us-world/story?id=69415591. Deathsfemale (Casesfemale) is the percent of Covid-19 deaths (cases) that are female. Genderratio is the ratio of male to female deaths among confirmed Covid-19 cases. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country (Sources: OECD, the International Labor Organization (for non-OECD countries) and the US Census (for US states)). In the OECD data % full-time workers – female is calculated as follows: Female Working Age Population Female Employment Rate (1-Female Incidence of Part-time Employment)/(Total Working Age Population Total Employment Rate (1-Total Incidence of Part-time Employment). For countries not in the OECD, % full-time workers – female is calculated as Female employment(100-incidence of female part-time employment)/Total employment(100-incidence of part-time employment). Not all countries report data on part-time employment, thus % full-time workers – female is missing for them. For US States, % full-time workers – female=Number of Female workers (16-64) who worked full-time/ Total number of workers (16-64) who worked full-time. % medical doctors - female (% Nurses – female) is the percent of medical doctors (Nurses) in a country who are female (Source: WHO Global Health Workforce Statistics 2018 update). The Participation and Opportunity Score and the Health and Safety score is from the World Economic Forum's Global Gender Gap 2020 Report. Female Cardiovascular diseases, Female Chronic respiratory diseases and Female Substance use disorders are measured in DALY's (disability-adjusted life year) per 100,000 (population) and measured in 2017 (Source: Global Burden of Disease Study, 2017). GDP Per Capita comes from The World Bank (for countries) and the US Bureau of Economic Analysis https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1 (for US states).

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Deathsfemale	1.000														
(2) Genderratio	-0.466	1.000													
	(0.009)														
(3) Casesfemale	0.746	0.192	1.000												
	(0.000)	(0.309)													
(4) % full-time workers - female	0.232	0.290	0.325	1.000											
	(0.179)	(0.142)	(0.057)												
(5) % full-time workers - female (2017)	0.170	0.173	0.448	0.996	1.000										
	(0.337)	(0.398)	(0.007)	(0.000)											
(6) Participation and Opportunity Score	0.317	0.399	0.488	0.828	0.836	1.000									
	(0.052)	(0.032)	(0.001)	(0.000)	(0.000)										
(7) % medical doctors - female	0.200	-0.083	0.393	0.387	0.236	0.187	1.000								
	(0.348)	(0.752)	(0.071)	(0.056)	(0.226)	(0.339)									
(8) % Nurses - female	0.124	0.105	0.041	0.166	0.282	0.123	-0.123	1.000							
	(0.565)	(0.689)	(0.843)	(0.398)	(0.154)	(0.504)	(0.662)								
(9) Health and Safety Score	0.137	0.330	0.335	0.464	0.428	0.446	0.249	-0.119	1.000						
	(0.414)	(0.081)	(0.035)	(0.002)	(0.005)	(0.001)	(0.201)	(0.516)							
(10) Female Cardiovascular diseases	0.121	-0.018	0.233	0.102	0.227	0.130	0.519	0.038	0.068	1.000					
	(0.462)	(0.925)	(0.147)	(0.524)	(0.153)	(0.384)	(0.006)	(0.835)	(0.647)						
(11) Female Chronic respiratory diseases	0.217	-0.276	0.241	0.233	0.255	-0.024	-0.020	0.024	-0.366	0.125	1.000				
	(0.185)	(0.147)	(0.134)	(0.143)	(0.107)	(0.871)	(0.922)	(0.896)	(0.011)	(0.393)					
(12) Female Substance use disorders	0.336	-0.301	0.372	0.148	0.163	0.217	-0.072	0.104	0.106	0.336	0.320	1.000			
	(0.036)	(0.112)	(0.018)	(0.357)	(0.308)	(0.143)	(0.722)	(0.570)	(0.479)	(0.018)	(0.025)				
(13) GDP Per Capita (2017) (millions)	0.534	-0.121	0.302	0.280	0.264	0.453	-0.342	0.298	0.010	-0.267	0.194	0.169	1.000		
	(0.001)	(0.532)	(0.058)	(0.073)	(0.091)	(0.001)	(0.075)	(0.098)	(0.949)	(0.070)	(0.192)	(0.255)			
(14) GDP Per Capita (2018) trillions)	0.554	-0.163	0.298	0.228	0.218	0.439	-0.412	0.328	-0.006	-0.266	0.179	0.166	0.999	1.000	
	(0.000)	(0.408)	(0.066)	(0.152)	(0.170)	(0.002)	(0.033)	(0.072)	(0.967)	(0.074)	(0.235)	(0.269)	(0.000)		

(15) OECD	0.503	-0.130	0.499	0.166	0.204	0.322	-0.286	0.340	0.181	-0.195	0.089	0.021	0.651	0.644	1.000
	(0.001)	(0.492)	(0.001)	(0.295)	(0.195)	(0.026)	(0.140)	(0.057)	(0.218)	(0.178)	(0.544)	(0.886)	(0.000)	(0.000)	

Table A2 Correlation matrix – Full sample

The sample consists of all available data for countries with at least one of Deathsfemale, Casesfemale or Genderratio reported in the April 22, 2020 update of the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676). Data is described in Table A1. OECD is a dummy variable that is equal to 1 if the country is in the OECD and 0 otherwise. P-values are in parentheses.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) Deathsfemale	1.000													
(2) Genderratio	-0.572	1.000												
	(0.011)													
(3) Casesfemale	0.757	-0.003	1.000											
	(0.000)	(0.990)												
(4) % full-time workers - female (2016)	0.528	-0.469	0.392	1.000										
	(0.008)	(0.043)	(0.058)											
(5) % full-time workers - female (2017)	0.548	-0.466	0.405	0.998	1.000									
	(0.006)	(0.044)	(0.050)	(0.000)										
(6) % full-time workers - female (2018)	0.571	-0.466	0.407	0.992	0.997	1.000								
	(0.004)	(0.044)	(0.048)	(0.000)	(0.000)									
(7) % medical doctors - female	0.243	-0.167	0.473	0.291	0.279	0.239	1.000							
	(0.331)	(0.568)	(0.055)	(0.213)	(0.233)	(0.310)								
(8) % Nurses - female	0.362	0.220	0.400	0.345	0.340	0.317	0.518	1.000						
	(0.247)	(0.601)	(0.197)	(0.209)	(0.215)	(0.250)	(0.154)							
(9) Health and Safety Score	0.091	-0.312	-0.389	-0.065	-0.079	-0.077	0.106	0.223	1.000					
	(0.673)	(0.194)	(0.060)	(0.742)	(0.691)	(0.697)	(0.658)	(0.425)						
(10) Female Cardiovascular diseases	-0.115	0.162	-0.028	0.225	0.212	0.198	0.103	0.469	0.193	1.000				
	(0.601)	(0.522)	(0.899)	(0.258)	(0.288)	(0.323)	(0.676)	(0.077)	(0.334)					
(11) Female Chronic respiratory diseases	-0.025	0.204	0.486	0.265	0.278	0.261	0.024	0.020	-0.406	0.315	1.000			
	(0.910)	(0.416)	(0.019)	(0.182)	(0.161)	(0.189)	(0.922)	(0.942)	(0.036)	(0.109)				
(12) Female Substance use disorders	0.088	-0.485	0.183	0.249	0.262	0.253	-0.369	-0.001	0.033	0.034	0.475	1.000		
	(0.688)	(0.041)	(0.403)	(0.210)	(0.187)	(0.202)	(0.120)	(0.997)	(0.869)	(0.865)	(0.012)			
(13) GDP Per Capita (2017) (millions)	0.296	-0.215	0.274	0.239	0.271	0.279	-0.331	0.161	-0.560	-0.191	0.351	0.289	1.000	
	(0.160)	(0.376)	(0.194)	(0.221)	(0.164)	(0.150)	(0.153)	(0.566)	(0.002)	(0.339)	(0.073)	(0.143)		
(14) GDP Per Capita (2018) (trillions)	0.297	-0.207	0.281	0.234	0.266	0.275	-0.314	0.211	-0.553	-0.182	0.347	0.276	0.998	1.000
	(0.159)	(0.396)	(0.184)	(0.231)	(0.171)	(0.157)	(0.178)	(0.451)	(0.002)	(0.364)	(0.076)	(0.164)	(0.000)	

Table A3 Correlation matrix – OECD sub sample

The sample consists of all available data for OECD countries with at least one of Deathsfemale, Casesfemale or Genderratio reported in the April 22, 2020 update of the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676). Data is described in Table A1. P-values are in parentheses.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Deathsfemale	1.000									
(2) Genderratio	0.583	1.000								
	(0.029)									
(3) Casesfemale	-0.776	-0.745	1.000							
	(0.001)	(0.002)								
(4) % full-time workers - female (2018)	-0.021	-0.085	-0.010	1.000						
	(0.943)	(0.771)	(0.974)							
(5) % full-time workers - female (2017)	-0.261	-0.178	0.215	0.936	1.000					
	(0.367)	(0.542)	(0.459)	(0.000)						
(6) South	0.266	0.065	-0.032	0.590	0.594	1.000				
	(0.358)	(0.826)	(0.914)	(0.026)	(0.025)					
(7) Female Cardiovascular diseases	0.091	0.015	0.157	0.335	0.464	0.607	1.000			
	(0.757)	(0.959)	(0.591)	(0.242)	(0.094)	(0.021)				
(8) Female Chronic respiratory diseases	0.131	-0.036	0.134	0.100	0.229	0.481	0.906	1.000		
	(0.656)	(0.904)	(0.648)	(0.735)	(0.432)	(0.082)	(0.000)			
(9) Female Substance use disorders	0.170	-0.337	0.157	-0.309	-0.282	0.205	0.406	0.653	1.000	
	(0.561)	(0.239)	(0.591)	(0.282)	(0.328)	(0.481)	(0.150)	(0.011)		
(10) GDP Per Capita (2017) (billions)	0.123	0.060	-0.420	-0.111	-0.278	-0.464	-0.718	-0.721	-0.448	1.000
	(0.674)	(0.839)	(0.135)	(0.705)	(0.336)	(0.095)	(0.004)	(0.004)	(0.109)	

Table A4 Correlation matrix – US States

The sample consists of all available data for US States with at least one of Deathsfemale, Casesfemale or Genderratio as of April 24, 2020. Data is described in Table A1. P-values are in parentheses.

	VARIABLES	% full-time workers - female	P-value	Participation and Opportunity Score	P-value	GDP per capita	P-value	Health and Safety score	P-value	Constant	P-value	Obs.	Adj. R-squared
1	Cardiovascular diseases	121.99	(0.000)			-32,133.39	(0.001)			661.71	(0.366)	89	0.186
2		123.12	(0.000)					24,177.57	(0.419)	-23,537.02	(0.422)	86	0.123
3				4,329.16	(0.002)			9,451.39	(0.612)	-7,973.43	(0.660)	150	0.0364
4	Chronic respiratory diseases	8.57	(0.020)			3,528.79	(0.039)			675.63	(0.000)	89	0.0669
5		7.75	(0.041)					-1,063.64	(0.815)	1,813.00	(0.680)	86	0.0104
6				475.49	(0.050)			-8,780.84	(0.088)	9,257.11	(0.065)	150	0.0209
7	Diabetes and kidney diseases	-0.77	(0.899)			-9,433.54	(0.000)			1,701.32	(0.000)	89	0.0584
8		-2.83	(0.666)					11,676.67	(0.274)	-9,777.00	(0.341)	86	-0.00792
9				-193.31	(0.665)			13,593.23	(0.058)	-11,615.08	(0.088)	150	0.00673
10	Digestive diseases	10.49	(0.001)			-3,569.80	(0.007)			532.38	(0.000)	89	0.138
11		9.99	(0.006)					8,765.23	(0.042)	-8,049.29	(0.054)	86	0.110
12				569.09	(0.012)			5,374.11	(0.099)	-4,748.80	(0.141)	150	0.0646
13	Enteric infections	0.34	(0.950)			-11,778.79	(0.013)			624.46	(0.043)	89	0.0389
14		2.42	(0.661)					755.69	(0.854)	-521.93	(0.896)	86	-0.0215
15				9.90	(0.990)			-14,852.32	(0.264)	15,412.62	(0.229)	150	-0.00659
16	HIV/AIDS and sexually transmitted infections	23.46	(0.033)			-12,954.05	(0.016)			-180.53	(0.340)	89	0.0300
17		22.89	(0.037)					26,086.41	(0.161)	-25,814.64	(0.158)	86	0.0107
18				1,522.12	(0.147)			54,455.13	(0.014)	-52,716.77	(0.013)	150	0.0261
19	Maternal and neonatal disorders	-5.97	(0.597)			-27,836.81	(0.000)			2,026.83	(0.000)	89	0.211
20		-2.52	(0.862)					5,374.97	(0.653)	-3,960.65	(0.734)	86	-0.0224
21				-1,499.71	(0.333)			-22,972.29	(0.325)	25,617.35	(0.257)	150	0.00315
22	Mental disorders	-6.55	(0.074)			11,818.04	(0.000)			1,848.96	(0.000)	89	0.482
23		-6.79	(0.082)					-2,898.84	(0.628)	4,928.79	(0.396)	86	0.00681
24				-88.49	(0.691)			-1,071.53	(0.695)	2,841.98	(0.282)	150	-0.0116

25	Musculoskeletal disorders	10.36	(0.191)			25,736.62	(0.000)			1,563.40	(0.000)	89	0.443
26		8.59	(0.303)					-6,448.37	(0.599)	8,448.42	(0.477)	86	-0.0126
27				1,244.36	(0.007)			-5,465.83	(0.332)	6,556.66	(0.224)	150	0.0178
28	Neglected tropical diseases and malaria	7.56	(0.269)			-11,358.23	(0.044)			250.50	(0.465)	89	0.0193
29		10.17	(0.112)					2,539.10	(0.703)	-2,658.16	(0.684)	86	4.48e-05
30				1,781.83	(0.105)			-28,011.36	(0.157)	26,971.15	(0.156)	150	0.00712
31	Neoplasms	63.54	(0.000)			22,349.58	(0.000)			469.00	(0.140)	89	0.353
32		62.56	(0.000)					13,819.03	(0.308)	-12,467.42	(0.343)	86	0.190
33				4,188.35	(0.000)			8,211.43	(0.381)	-7,930.18	(0.385)	150	0.179
34	Neurological disorders	16.35	(0.009)			16,413.94	(0.000)			1,198.18	(0.000)	89	0.366
35		15.92	(0.013)					-84.03	(0.992)	1,641.57	(0.840)	86	0.0268
36				1,271.53	(0.000)			2,760.40	(0.449)	-1,656.01	(0.637)	150	0.0620
37	Nutritional deficiencies	0.18	(0.954)			-8,562.90	(0.000)			560.81	(0.000)	89	0.206
38		0.80	(0.834)					1,296.30	(0.722)	-921.81	(0.794)	86	-0.0226
39				-378.81	(0.521)			-8,794.66	(0.270)	9,605.45	(0.213)	150	-0.00170
40	Other infectious diseases	2.06	(0.525)			-7,458.04	(0.006)			335.51	(0.042)	89	0.0550
41		3.50	(0.327)					40.17	(0.990)	36.64	(0.990)	86	-0.0135
42				167.39	(0.746)			-10,999.24	(0.214)	11,194.13	(0.187)	150	-0.00308
43	Other non-communicable diseases	-4.94	(0.173)			-7,807.93	(0.000)			1,800.52	(0.000)	89	0.207
44		-4.29	(0.376)					-930.03	(0.841)	2,509.16	(0.578)	86	-0.0109
45				-339.94	(0.454)			-6,017.50	(0.347)	7,831.11	(0.204)	150	-0.00282
46	Respiratory infections and tuberculosis	15.16	(0.053)			-17,340.64	(0.000)			672.41	(0.024)	89	0.126
47		16.65	(0.067)					-2,673.85	(0.804)	2,800.41	(0.789)	86	0.0117
48				1,210.73	(0.263)			-10,280.17	(0.526)	10,877.03	(0.484)	150	-0.00635
49	Self-harm and interpersonal violence	-11.91	(0.333)			-3,346.29	(0.024)			910.32	(0.076)	89	0.0781
50		-12.63	(0.362)					9,971.77	(0.007)	-8,835.03	(0.009)	86	0.0749
51				-2,604.61	(0.091)			16,591.28	(0.110)	-13,957.08	(0.127)	150	0.152
52	Sense organ diseases	10.04	(0.000)			-2,279.39	(0.014)			581.54	(0.000)	89	0.152
53		9.23	(0.000)					5,854.12	(0.059)	-5,125.45	(0.088)	86	0.125
54				395.57	(0.005)			2,756.90	(0.262)	-2,107.96	(0.376)	150	0.0471

55	Skin and subcutaneous diseases	2.68	(0.021)			4,716.10	(0.000)			454.07	(0.000)	89	0.547
56		2.72	(0.044)					-269.92	(0.899)	808.81	(0.694)	86	0.00372
57				349.85	(0.000)			213.97	(0.833)	204.09	(0.834)	150	0.125
58	Substance use disorders	2.89	(0.216)			2,105.21	(0.108)			185.65	(0.019)	89	0.0392
59		2.97	(0.238)					1,755.93	(0.247)	-1,482.15	(0.328)	86	-0.00508
60				182.68	(0.123)			1,570.20	(0.072)	-1,335.32	(0.122)	150	0.0117
61	Transport injuries	-1.10	(0.680)			-2,203.41	(0.002)			514.08	(0.000)	89	0.0720
62		-1.89	(0.513)					1,727.46	(0.454)	-1,182.04	(0.599)	86	-0.00750
63				-307.09	(0.117)			-390.20	(0.842)	1,064.04	(0.571)	150	0.0205
64	Unintentional injuries	22.69	(0.000)			2,213.55	(0.160)			216.96	(0.138)	89	0.173
65		22.78	(0.000)					5,266.62	(0.324)	-4,870.16	(0.349)	86	0.159
66				1,004.19	(0.000)			232.03	(0.952)	177.12	(0.962)	150	0.0704

Table A5 Cause of death or injury and % full-time workers – female

Table A5 shows results of heteroskedasticity corrected OLS regressions of Causes of death or injury for women measured in DALYs (disability-adjusted life year) per 100,000 (population) on % full-time workers – female and control variables. Causes of death or injury is as of 2017 (source: the Global Burden of Disease Study, 2017). % full-time workers – female is the percent of full-time workers who are female and is measured as of 2017 (source: OECD and the International Labor Organization, ILO). GDP per capita is as of 2017 (Source: The World Bank). Participation and Opportunity Score and Health and Safety Score are from the World Economic Forum's Global Gender Gap 2020 report. P-values are in parentheses.

	VARIABLES	% full-time workers - female	P-value	South	P-value	GDP per capita	P-value	Constant	P-value	Adjusted R-squared
1	Cardiovascular diseases	267.58	(0.000)			-2.10	(0.001)	-6,292.44	(0.001)	0.404
2		227.74	(0.000)	417.10	(0.100)	-1.80	(0.008)	-4,849.34	(0.016)	0.431
3	Chronic respiratory diseases	86.35	(0.000)			-1.36	(0.000)	-1,062.64	(0.221)	0.386
4		84.47	(0.002)	19.66	(0.875)	-1.35	(0.000)	-994.62	(0.323)	0.374
5	Diabetes and kidney diseases	88.89	(0.000)			-0.80	(0.000)	-1,776.75	(0.007)	0.416
6		77.52	(0.000)	119.09	(0.119)	-0.71	(0.003)	-1,364.72	(0.051)	0.432
7	Digestive diseases	21.84	(0.000)			-0.22	(0.015)	176.47	(0.479)	0.191
8		21.80	(0.002)	0.40	(0.991)	-0.22	(0.025)	177.85	(0.514)	0.174
9	Enteric infections	4.62	(0.000)			-0.03	(0.001)	-32.79	(0.457)	0.196
10		4.72	(0.001)	-0.99	(0.869)	-0.03	(0.005)	-36.20	(0.465)	0.179
11	HIV/AIDS and sexually transmitted infections	18.96	(0.000)			0.23	(0.000)	-858.80	(0.000)	0.705
12		15.23	(0.004)	39.07	(0.010)	0.26	(0.000)	-723.62	(0.001)	0.743
13	Maternal and neonatal disorders	22.02	(0.001)			0.19	(0.001)	-483.78	(0.074)	0.495
14		16.00	(0.027)	62.96	(0.003)	0.24	(0.000)	-265.94	(0.351)	0.570
15	Mental disorders	-8.44	(0.467)			-0.04	(0.580)	2,919.22	(0.000)	-0.00172
16		-10.24	(0.409)	18.79	(0.529)	-0.03	(0.730)	2,984.22	(0.000)	-0.0172
17	Musculoskeletal disorders	22.59	(0.386)			-0.82	(0.000)	2,948.95	(0.007)	0.225
18		20.94	(0.510)	17.28	(0.875)	-0.81	(0.001)	3,008.75	(0.019)	0.209
19	Neglected tropical diseases and malaria	-1.51	(0.245)			0.00	(0.736)	79.39	(0.146)	-0.00759
20		-1.44	(0.324)	-0.81	(0.885)	0.00	(0.813)	76.57	(0.200)	-0.0286
21	Neoplasms	177.90	(0.000)			-1.32	(0.000)	-2,627.78	(0.061)	0.357
22		189.35	(0.000)	-119.82	(0.491)	-1.41	(0.000)	-3,042.35	(0.058)	0.350
23	Neurological disorders	39.27	(0.014)			-0.27	(0.020)	1,045.48	(0.100)	0.139
24		47.25	(0.015)	-83.53	(0.159)	-0.33	(0.027)	756.49	(0.301)	0.154
25	Nutritional deficiencies	-0.66	(0.746)			-0.07	(0.003)	180.62	(0.041)	0.253
26		-2.42	(0.245)	18.46	(0.037)	-0.06	(0.018)	244.47	(0.006)	0.320
27	Other infectious diseases	2.89	(0.002)			-0.00	(0.988)	-46.97	(0.216)	0.244

28		2.24	(0.023)	6.80	(0.051)	0.00	(0.681)	-23.46	(0.557)	0.299
29	Other non-communicable diseases	30.10	(0.000)			-0.16	(0.164)	158.16	(0.643)	0.162
30		20.16	(0.019)	104.00	(0.014)	-0.08	(0.494)	517.98	(0.134)	0.255
31	Respiratory infections and tuberculosis	28.80	(0.000)			-0.22	(0.003)	-592.55	(0.037)	0.288
32		22.60	(0.007)	64.88	(0.068)	-0.17	(0.031)	-368.06	(0.242)	0.336
33	Self-harm and interpersonal violence	0.77	(0.940)			-0.04	(0.755)	499.38	(0.265)	-0.0370
34		-6.19	(0.558)	72.79	(0.029)	0.01	(0.905)	751.23	(0.099)	0.0216
35	Sense organ diseases	14.19	(0.007)			-0.13	(0.001)	139.48	(0.499)	0.232
36		18.75	(0.002)	-47.83	(0.012)	-0.16	(0.001)	-25.99	(0.908)	0.321
37	Skin and subcutaneous diseases	11.46	(0.073)			0.14	(0.057)	349.73	(0.178)	0.135
38		8.94	(0.194)	26.43	(0.324)	0.16	(0.035)	441.16	(0.114)	0.130
39	Substance use disorders	30.54	(0.271)			-0.48	(0.223)	552.66	(0.644)	0.00544
40		20.13	(0.488)	108.98	(0.515)	-0.40	(0.332)	929.72	(0.447)	-0.00574
41	Transport injuries	11.23	(0.236)			-0.35	(0.007)	322.27	(0.413)	0.174
42		5.23	(0.656)	62.79	(0.166)	-0.30	(0.031)	539.53	(0.254)	0.190
43	Unintentional injuries	19.15	(0.007)			-0.24	(0.002)	384.11	(0.182)	0.212
44		21.35	(0.004)	-23.07	(0.418)	-0.25	(0.002)	304.30	(0.301)	0.204

Table A6 Cause of death or injury and % full-time workers – female (US States)

Table A6 shows results of Heteroskedasticity corrected OLS regressions of Causes of death or injury for women measured in DALYs (disability-adjusted life year) per 100,000 (population) on % full-time workers – female and control variables for US States. Causes of death or injury is as of 2017 (source: The Global Burden of Disease Study, 2017). % full-time workers – female is the percent of full-time workers who are female and is measured as of 2017 (source: US Census). GDP per capita is as of 2017 (source: US Bureau of Economic Analysis https://apps.bea.gov/iTable/iTable.cfm?reqid=70&step=1&isuri=1). P-values are heteroskedasticity robust. P-values are in parentheses.

VARIABLES	Deathsfemale				Casesfemale				Genderratio			
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	April 15, 2020											
% full-time workers - female	0.33	0.42	0.51241		0.34	0.39	0.44190		-0.00	-0.00	-0.00277	
	(0.275)	(0.175)	(0.080)		(0.118)	(0.057)	(0.082)		(0.897)	(0.851)	(0.907)	
% medical doctors - female				0.12				0.35				0.02
				(0.725)				(0.097)				(0.343)
Health and Safety score		37.11				-144.04				1.89		
		(0.930)				(0.640)				(0.937)		
Female Cardiovascular diseases			-0.00315				-0.00143				0.00011	
			(0.074)				(0.183)				(0.394)	
Female Chronic respiratory diseases			0.00459				0.00338				-0.00031	
			(0.401)				(0.388)				(0.629)	
Female Substance use disorders			-0.00292				-0.00151				-0.00004	
			(0.403)				(0.831)				(0.956)	
GDP Per Capita	63.19			102.86	44.71			51.65	-1.05			-2.09
	(0.265)			(0.268)	(0.286)			(0.318)	(0.741)			(0.730)
Constant	24.71	-11.70	26.97569	28.63	37.24	177.72	36.86282	32.98	1.84	-0.00	1.76927	0.70
	(0.019)	(0.977)	(0.015)	(0.103)	(0.000)	(0.555)	(0.000)	(0.007)	(0.017)	(1.000)	(0.013)	(0.573)
	0.33	0.42	0.51241		0.34	0.39	0.44190		-0.00	-0.00	-0.00277	
Observations	22	22	21	22	23	23	22	23	19	19	18	19
Adjusted R-squared	0.0867	0.0400	0.153	-0.0499	0.128	0.107	0.119	-0.00554	-0.116	-0.120	-0.169	-0.124
	April 7, 2020											
% full-time workers - female	0.42	0.31	0.33024		0.24	0.23	0.33542		-0.02	-0.02	-0.02462	
	(0.102)	(0.175)	(0.270)		(0.255)	(0.320)	(0.118)		(0.051)	(0.090)	(0.079)	
% medical doctors - female				0.55				0.25				-0.01
				(0.062)				(0.139)				(0.448)
Health and Safety score		573.19				72.88				-5.92		
		(0.110)				(0.852)				(0.589)		

Female Cardiovascular diseases			-0.00306				-0.00131				0.00002	
			(0.063)				(0.190)				(0.797)	
Female Chronic respiratory diseases			0.00358				0.00067				0.00028	
			(0.553)				(0.885)				(0.448)	
Female Substance use disorders			0.00338				-0.00296				-0.00032	
			(0.638)				(0.679)				(0.246)	
GDP Per Capita	30.23			84.87	9.14			30.36	-1.99			-2.99
	(0.691)			(0.194)	(0.819)			(0.428)	(0.591)			(0.509)
Constant	22.25	-528.93	32.05558	8.39	41.55	-28.77	43.08625	37.53	2.71	8.32	2.32241	2.44
	(0.090)	(0.125)	(0.027)	(0.543)	(0.000)	(0.939)	(0.001)	(0.000)	(0.000)	(0.428)	(0.001)	(0.010)
Observations	17	17	16	17	20	20	19	20	15	15	14	15
Adjusted R-squared	0.00794	0.0980	0.163	0.149	-0.0308	-0.0280	-0.0318	-0.0701	0.0978	0.0756	0.0277	0.188

Table A7 Covid-19 outcomes and Female Employment – OECD countries using April 7 and 15 data

Panel A of Table A7 uses the April 15, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Panel B of Table A7 uses the April 7, 2020 update of data from the GlobalHealth 5050 COVID-19 sex-disaggregated data tracker (http://globalhealth5050.org/covid19/#1586263312717-c89130f0-8676) for countries in the OECD. Deathsfemale is the percent of Covid-19 deaths that are female. Casesfemale is the percent of Covid-19 cases that are female. Genderrratio is the ratio of male to female deaths among confirmed cases of Covid-19. % full-time workers – female is the number of women working full-time divided by the total number of people working full-time in a country measured in 2018 (Source: OECD). % medical doctors - female is the percent of doctors in a country who are female (Source: (Source: WHO Global Health Workforce Statistics 2018 update). Health and Safety score is from the World Economic Forum’s Global Gender Gap 2020 Report. Female Cardiovascular diseases, Female Chronic respiratory diseases and Female Substance use disorders are measured in DALY’s (disability-adjusted life year) per 100,000 (population) and measured in 2017 (Source: Global Burden of Disease Study, 2017). GDP Per Capita is as of 2018 (Source: The World Bank). P-values are in parentheses.

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Shutdown policies and worldwide conflict[1]

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We provide real-time evidence on the impact of Covid-19 restrictions policies on conflicts globally. We combine daily information on conflict events and government policy responses to limit the spread of coronavirus to study how conflict levels vary following shutdown and lockdown policies. We use the staggered implementation of restriction policies across countries to identify their effect on conflict incidence and intensity. Our results show that imposing a nation-wide shutdown reduces the likelihood of daily conflict by around 9 percentage points. The reduction is driven by a drop in the incidence of battles, protests and violence against civilians. Across actors the decline is significant for conflicts involving political militias, protesters and civilians. We also observe a significant cross-country heterogeneity in the effect of restriction policies on conflict: no conflict reduction is observed in low income countries and in societies more fractionalized along ethnic or religious lines. We discuss the potential channels that can explain this heterogeneity.

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COVID ECONOMICS
VETTED AND REAL-TIME PAPERS

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1 Introduction

On March 31st, 2020 the U.N. Secretary General, Antonio Guterres, cautioned that the coronavirus epidemic could lead to “enhanced instability, enhanced unrest, and enhanced conflict”. The ongoing epidemic can exacerbate conflict by upending social and political protections. The effect could be severe for the vulnerable populations: those caught up in war and persecution, or those living in densely populated areas with dismal state capacity.[1] Critically, countries have responded with varying degree of restrictions to limit the spread of coronavirus. The policy response to Covid-19 can itself have a bearing on conflict situations.

Anecdotal evidence suggests that restrictions on mobility to flatten the epidemic curve, that raise the cost of mobilization, have a direct and negative effect on conflict. For example, violent crime across major cities in the United States has fallen sharply following the lockdown[2] and India’s lockdown has terminated nationwide protests against the mistreatment of Muslims.[3] The flipside is rising scapegoating of minorities or vulnerable groups, especially when state resources are diverted to combat the pandemic.[4] Moreover, the authoritarian regimes may also use the global preoccupation with coronavirus as an opportunity to crush opposition. For example, the Myanmar military has stepped up its offensive against ethnic armed rebel groups in Rakhine, Chin, Karen and northern Shan state[5], while the United Nations appeal for a global ceasefire to countervail the escalation in violence.[6] Some regimes have also used the global epidemic as an opportunity to stifle democratic opposition. In Azerbaijan, members of the opposition have been locked up for allegedly violating a lockdown.[7]

The Covid-19 pandemic and the restriction policies have also negatively affected economic activity. For example, the contraction of China’s economy has been estimated to be 6.8% in the first quarter of 2020.[8] In United States, a staggering 22 million people were rendered unemployed in a month since coronavirus was declared a national emergency.[9] The effect of restrictions through the income mechanism is a priori ambiguous. On the one hand, the current economic downturn may lead to more conflict, by reducing the individual opportunity cost of violence, protests and rebellions (Becker, 1968; Grossman, 1991; Dal Bó and Dal Bó, 2011), and by hampering the capacity of the state to fight opponents or buy off opposition (Berman et al., 2011, Fearon and Laitin, 2003a). On the other hand, states with more limited resources are less attractive “prizes” to be seized, which may lead to a decrease in conflict intensity (Bates et al., 2002; Besley and Persson, 2010).[10]

In this paper, we provide real-time evidence on how enforcing restrictions to limit the spread of coronavirus

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[1] Shared responsibility, global solidarity: Responding to the socio-economic impacts of Covid-19 (UNSDG, March 2020, url).

[2] Domestic violence has increased during coronavirus lockdowns (The Economist, April 22th, 2020, url).

[3] Would-be autocrats are using Covid-19 as an excuse to grab more power (The Economist, April 23th, 2020, url).

[4] For example, there have been a few incidents of physical violence against Muslims, in addition to hateful messages on social media, since it was discovered that a Muslim religious gathering was the source of many coronavirus cases (The Economist, April 23th, 2020, url). Among Rohingya refugee camps in Bangladesh coronavirus is being attributed as divine punishment for women’s “dishonorable acts" and not observing *Purdah* (veiling) (International Organization of Migration, April 19th, 2020, url).

[5] Myanmar military steps up attacks as coronavirus spreads (AlJazeera, April 16th, 2020, url).

[6] While some warring groups have responded to a call for ceasefire, in many of the most fragile situations there has not been any let up in fighting, and in some cases the fighting has intensified (UN.org, April 3rd, 2020), url).

[7] Would-be autocrats are using Covid-19 as an excuse to grab more power (The Economist, April 23th, 2020, url).

[8] CRU: China’s First Ever Negative Quarterly GDP Growth, Yahoo Finance (April 21th, 2020, url).

[9] U.S. now has 22 million unemployed, wiping out a decade of job gains, Washington Post (April 16th, 2020, url).

[10] One of the consequences of the current slowdown in economic activity is a collapse of the market for commodities, from agricultural to oil and mineral prices. Such drop of commodity prices may have multiple effects on conflict. Studying such effects is beyond the scope of this paper, in which we focus on the specific impact of Covid-19 related shutdown and lockdown policies.

affects conflicts globally and how conflict dynamics may vary across types of events, actors and may also crucially depend on socio-economic context. We take advantage of the joint release of daily information on conflict events by the *Armed Conflict Location and Event* dataset, on the one hand, and on government policy responses by the Oxford Covid-19 Government Response Tracker, on the other hand, to estimate how conflict levels vary following shut- and lockdown policies. In our baseline estimations, we focus on policies imposing the closing of workplaces and schools, and restricting internal movements. We also consider in our robustness exercises "stay-at-home" policies specifically. Our results show that imposing a nation-wide restriction on mobility reduces the likelihood of daily conflict by 9 percentage points. We further explore the dynamics of conflict in response to a restriction and find that the reduction in likelihood is progressive, and stronger three to four weeks after the policy is implemented. We exploit additional information in our dataset to assess whether restrictions affect conflict events differently, based on their nature and on the type of actors involved. We find that such policies negatively affect battles, protests and violence against civilians. The negative effect is most conspicuous for protests. Across actors, the decline is significant for events that involve political militias, protesters or civilians. On the other hand, conflict involving state forces, rebel groups or identity militias do not show any significant decline. These results are robust across various measures of mobility restrictions policies, and hold when considering either conflict incidence or intensity (number of reported events).

We finally investigate whether country level characteristics mediate the effectiveness of restriction policies. We consider different characteristics that are identified in the literature as important features explaining conflict: ethnic and religious fractionalization, institutions (democracy, rule of law) and income (GDP per capita). Two main results emerge. First, conflict does not appear to significantly decrease post-restriction in countries with low GDP per capita, while it does in countries with relatively high income per capita. This difference appears to be mostly driven by a stronger drop in protests in the latter case. Second, and consistent with the scapegoating narrative mentioned above, we find that conflict does not decrease in countries with high religious fractionalization. This effect is mostly driven by events involving civilians, political militias and state forces. These results suggest that the negative effect of mobility restriction on conflict could be tempered by a rise in violence against the religious minorities.

We believe that our estimates of the extent of conflict reduction following shutdown policies are likely to be an upper bound. Collecting and reporting data on conflict events might become more difficult during shutdown periods, especially if states use these contexts to further repress the media. We would in this case overestimate the reduction in violence in repressive states. We consider this possibility explicitly by testing how the effect of shutdown policies varies with press and media freedom indices. We find no heterogeneous effect in that dimension; in addition, controlling for media freedom leaves unchanged our results on country characteristics. Hence, though the overall conflict reduction might be overestimated, such bias does not appear to be driving the cross-country heterogeneity we uncover.

Our paper contributes to the literature in several ways. We contribute to research on the consequences of Covid-19. Ongoing research has assessed the macroeconomic implications of Covid-19 (Atkeson, 2020; McKibbin and Fernando, 2020; Guerrieri et al., 2020), the role of climate, or mass media in spreading Covid-19 (Carleton and Meng, 2020; Bursztyn et al., 2020). Notably, Chinazzi et al. (2020) study the effect of travel restrictions on the spread of Covid-19. In contrast, we provide first evidence for the effect of Covid-19 related mobility restrictions on global conflicts' level. Next we contribute to the literature on infectious diseases and civil conflicts, which shows that health shocks due to infectious diseases can potentially cause civil conflicts (Cervellati et al., 2017). We instead highlight that policy response to an epidemic can have an unintended consequence for civil conflicts. We also contribute to the literature on the opportunity cost of organized political activity. These papers find that bad weather hampers political demonstrations by increasing the cost of individual participation (Madestam et al., 2013; Kurrild-Klitgaard, 2013). In a similar vein, we find that restriction policies have a particularly significant effect on reducing protests. Finally, our work relates to the literature on scapegoating of minorities during epidemics. Jedwab et al. (2019) find that Black Death mortality increased Jewish persecution, while Voigtländer and Voth (2012) show that Black Death pogroms created anti-Jewish sentiment that persisted over centuries. We provide suggestive evidence that the reduction in violence against civilians due to mobility restrictions may have been countervailed by a rise in violence against religious minorities in some countries.

The next section presents the data and our baseline research design. Section 3 discusses the results and their robustness, and section 4 concludes.

2 Data and empirical strategy

2.1 Data and stylized facts

Conflict. We use conflict event data from the *Armed Conflict Location and Event* dataset (Raleigh et al., 2010, ACLED), as available on the ACLED webpage on April 28th, 2020. The data contain daily information on conflict events with specific details on the nature and the actors on both sides of the conflicts. Events are compiled from various sources, including press accounts from regional and local news, humanitarian agencies, and research publications.[11] For the purpose of our analysis, we end up with 105 countries (see Online Appendix Table A1.1 for a full list of countries) from January 1st, 2016 to April 18th, 2020. We do not consider the last week of data (April 19-25, 2020), as it is likely that reporting of events for that week is still incomplete at the time we retrieved the data.[12] We consider all types of conflict events in our estimations, regardless of whether they are described or not by ACLED as being directly related to the Covid-19.[13]

In our baseline estimates, we consider the daily incidence of any violent event, as well as the total number of violent events observed in each country. We also make use of two crucial features of the ACLED dataset. First, the data informs us on the nature of violence, i.e. whether the event is related to battles, remote violence, protests, riots, strategic development, and violence against civilians. Second, information are released on the different actors that are involved, such as state forces, rebel groups, political militias, identity militias, rioters, protesters, and civilians. Note that the ACLED data do not include information on who initiated the attack.

Figure 1(a) displays the weekly number of events since January 1st, 2019. The total number of events

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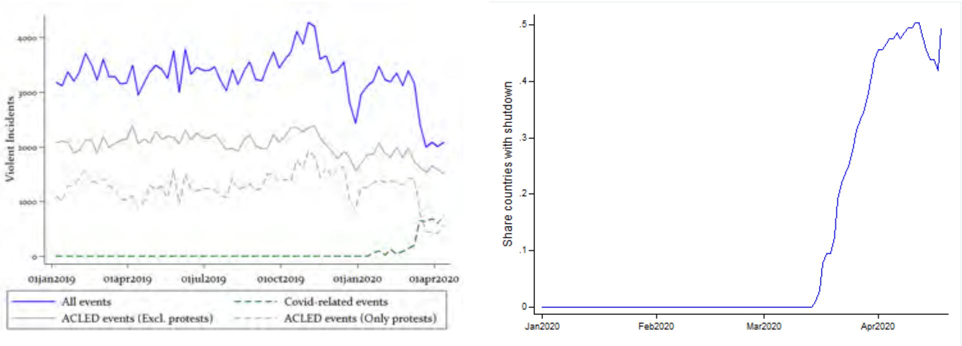
[11] These data have been widely used in recent conflict literature, see for instance Besley and Reynal-Querol (2014), Michalopoulos and Papaioannou (2016), and Berman et al. (2017).

[12] ACLED is updated on a daily basis, but events are added retrospectively if they did not yet appear in the various sources immediately after they occur.

[13] Though they account for a very small share of the observations, ACLED also reports information on ceasefire and peace agreement (ACLED sub-category "agreements" in the category "Strategic developments") and other events which are not conflictual (ACLED sub-category "other" in the category "Strategic developments"; the example provided by ACLED for this type of event is the following: "President of Russia Vladimir Putin inaugurates the newly constructed bridge that connects Russia with the Kerch City of Crimea, four years after the annexation of Crimea"). We drop these events from the data before computing our conflict measures. In our period of study, they represent only 0.66% of the total number of events.

dramatically declines from March 2020 onward. Mid-March 2020, it is 25% lower than the number of events at the same period of the previous year; in the first half of April 2020, it is 30 to 35% lower than in the first half of April 2019. The drop appears to be partly driven by protests, though even after excluding protests the conflict events fall by almost 25% in March-April 2020 compared to the previous year. Figure 1(a) also plots the number of events that ACLED identifies as being related to Covid-19: those for which the words "Covid" or "Coronavirus" appears in the ACLED event description. At the end of our sample period, such events represent more than a third of the total number of observed events.

Figure 1: Evolution of conflict events and shutdown policies



(a) Conflict

(b) Shutdowns

Source: Authors' computation from ACLED and OxGRT data.

Covid-19-related Policies. Information on the various governmental policies as a response to the Covid-19 outbreak are collected from the Oxford Covid-19 Government Response Tracker (OxCGRT) (Hale et al., 2020).[14] OxCGRT systematically assembles information on several policy responses governments have implemented, using public sources such as official government press releases and newspaper articles. Data include information on eight measures of public policy responses: the closings of school, workplaces and public transport, travel restrictions (internal and international), limitations of public gatherings, and stay-at-home requirements. Note that latter two categories have been added on April 28th, 2020 and are still incomplete at the time this paper is written. Measures are ranked on a scale ranging from 0 (no measure) to 2, 3 or 4: 0 means no measure in place, 1 means that the measure is a recommendation, and 2 to 4 denote required measure of different scale.[15] The OxCGRT data also contain information on whether the measure is a national or a regional one.[16]

In this paper, we focus on all Covid-19 related policy responses, with an emphasis on measures that restrict mobility. Our estimations are based on three measures. First, we construct a binary restriction measure, which switches to 1 when governments have implemented national school and workplace closings as well as

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[14] Data were downloaded on April 29th, 2020.

[15] For instance, in the case of schools, a value of 2 implies a required measure to close some part of the schooling system (only high schools, or only public schools), while a value of 3 implies a complete shutdown of the schools.

[16] OxCGRT also provides a composite measure of the 7 indicators, the "stringency index", including the seven government responses and their geographical coverage. The stringency index is built as the average measure of the eight policies, taking into account whether the policy is local or national, and rescaled between 0 and 100. We do not use this measure because some of the sub-categories are redundant for our research design. Finally, OxCGRT also includes some information about fiscal and monetary measures, and two Covid-19 related health policies (testing and contact tracing).

restrictions on internal movements. We label this measure *Shutdown*. Our sample includes 62 countries with the enforcement of restriction measures between March 15th and April 18th (see Online Appendix Table *A1.2* for the list of implementation dates by countries). On the other hand, 43 countries do not impose such measures (or only impose a part of these).

Second, we compute an index measure, hereafter labeled *Narrow Index*, which uses the same policy categories but takes into account the degree of requirement (no measure, recommended or required) as well as the geographical scope of the measure (local vs. national). We proceed in two steps. First, we recode each of the measure in the following order: i) recommendations, whether national or local, are coded as 1; ii) local requirements, are coded as 2; and iii) national requirements are coded as 3.[17] Our index is then computed as the sum of the three policy measures – closings of school, closing of workplaces and restrictions on internal movements – normalized on a scale between 0 and 1.

These two measures omit several categories available in the OxCGRT data: closing of public transport, restrictions to international travel, limitations of public gatherings and stay-at-home requirements. The closing of public transport is a redundant measure: when schools and workplaces are closed, and when there are restrictions on internal movements, public transport is already shut down. We also abstract from limitations on international travels as this measure entails some discrepancies. The last two measures – public gatherings and stay-at-home – are omitted from our baseline because they appear to be incomplete at the time of our data download (approximately 60% of the observations are missing). As a robustness, we therefore compute a more general index, labeled *Broad Index*, which takes into account all categories, with the exception of limitations on public gathering and stay-at-home measures. Also, we have recoded the stay-at-home measure to fill-in most of the missing observations[18] and we consider the effect of this measure separately in our sensitivity exercises. Figure 1(b) depicts the global move toward shutdown policies across the world in response of the COVID-19 crisis. Until mid-March, none of the countries in our sample have imposed a shutdown, based on our definition. Within a month since then, shutdown policies have affected about half of our sample of countries. Figures A1.1 in the Online Appendix show the evolution of our two indexes.

Country characteristics. In Section 3, we study how country characteristics may explain heterogeneous effect of restriction policies across countries. We mainly focus on five country characteristics from the Quality of Government dataset, which compiles several country indicators from various publicly available sources (Teorell et al., 2020). First, we use two indicators of fractionalization that reflect the probability that two randomly selected individuals from a given country will not share a certain characteristic. The fractionalization variables can capture the relationship between ethnic cleavages and political instability or conflict that could exist across countries (Esteban and Ray, 1994, 1999; Montalvo and Reynal-Querol, 2005). Based on the year 2000, we are specifically interested at ethnic and religious fractionalization (Alesina et al., 2003). Second, we use two scores on the quality of institutions, namely the rule of law and the level of democracy. The latter is approximated using a combined imputed Polity-Freedom House index which ranges from 0 (least democratic) to 10 (most democratic). Rule of law measures the confidence in the rules

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[17] We do not consider the distinction between the different scales of requirements, i.e. values 2 and 4 of the policy measures, but assign a value of 2 to the all required measures at the local level and a value 3 for the national level.

[18] More than 20% of the countries in OxCGRT contained a coded stay-at-home measure starting on April 18th, 2020 with missing observations beforehand. Sources provided by OxCGRT and online searches (newspaper articles and official sources retained) were used to assess the exact date of implementation of stay-at-home policies, without making changes to the OxCGRT coding.

of society by including perceptions on crime, the judiciary system and enforceability (Worldwide Governance Indicators, World Bank Group et al. (2010)). These variables capture any difference in conflict levels across countries that could be due to the underlying institutions (Fearon and Laitin, 2003b; Collier and Rohner, 2008). Last, we use GDP per capita as a measure of economic development (World Bank Group et al., 2010). All measures except the fractionalization ones are averaged between 2016 and 2019.

Descriptive statistics. Table A1.3 in the Online Appendix provides summary statistics for all variables used in the paper. Over the four conflict events that are reported daily in our sample period, protests are the most common form, followed by battles. This pattern is also reflected in the actor types: conflict events that involve state forces, protesters or rebel groups are most preponderant. Given that ACLED primarily focuses on developing countries, unsurprisingly, the countries included in our sample exhibit lower GDP per capita (about 6,800 current USD, compared to a world average of 14,000 over the period), democracy scores (4.9, as compared with a cross-country average of 6.4 at the world level), rule of law indexes (-0.46, -0.1 at the world level) than the world average; on the other hand, the levels of ethnic and religious fractionalization are more comparable to the world average (0.53 and 0.43 in our sample versus 0.44 and 0.44 at the world level).

2.2 Empirical strategy

Baseline equation. Our aim is to estimate how restriction policies in country i at day t contemporaneously affect conflict. We estimate the following baseline specification:

$$\text{Conflict}_{it} = \beta \text{Restrictions}_{it} + \eta_c + \mu_{ym} + \varepsilon_{it}, \tag{1}$$

where Conflict_{it} is our conflict variable at the country-day level, being measured in terms of incidence (i.e. a binary variable coding for non-zero events) in our baseline estimates. We also report results using conflict intensity, defined as the total number of violent events in a day. Restrictions_{it} is our measure of restrictions at country-level - the binary *Shutdown* measure is used as baseline, and we systematically check the results using the *Narrow Index* and *Broad Index* measures. Finally, η_c and μ_{ym} are country and year-month fixed effects, respectively. η_c accounts for any time-invariant or slow-moving country characteristics, such as political system, institutions, or culture, that may affect conflict; μ_{ym} captures common year-month shocks, in particular the global spread of COVID-19 that correlates with lockdown policies, and worldwide seasonality in conflict incidence. In our baseline estimates we use a linear probability model, with standard errors clustered at the country level. When using the number of conflict events as a dependent variable, we use a Poisson pseudo maximum likelihood estimator.

Additional exercises and robustness. We perform several additional exercises. First, we evaluate the post-shutdown dynamics of violence by including weekly leads and lags of our binary Restrictions_{it}. Second, we consider separately each of the ACLED category of events and actors (see Online Appendix Table A1.3 for a list of types of events and actors). Finally, we test whether our estimates of β vary across countries with different characteristics, by interacting our measure of COVID-19-related policies with binary indicators denoting that the country-specific indicator falls below or above the sample median.

3 Results

Baseline estimates. Table 1 displays the main estimates. Our binary measure of restrictions is negatively correlated to the incidence of conflict. The point estimate suggests that shutdowns are associated with a 9 percentage point drop in conflict incidence (column 1), and with 0.27 fewer events, e.g. a 6.5% drop in the total daily number of conflict events (column 2). Results are similar to the use of our alternative policy measures, *Narrow index* and *Broad index* (columns 3 and 4, respectively). Quantitatively, a one standard deviation increase in the indexes (-0.136 and -0.135, respectively) is associated with a decrease in conflict incidence range from 5.1 percentage points (column 3) to 5.5 percentage points (column 4). Overall, the results in Table 1 confirm the descriptive pattern shown in Figure 1: shutdown policies are associated with a lower incidence and intensity of conflict.

We perform two robustness exercises on these aggregate results. First, we control for linear country specific time trends to allow for unobserved country-specific conflict propensities to trend linearly over time. Despite our short-time period, this demanding specification leaves our results broadly unchanged (Table A2.4). Second, we perform a placebo analysis, by randomly permuting the dates of implementation of our restriction measure *Shutdown (binary)* for each country in the sample. We estimate equation (1) with our permuted restriction. Figure A2.2 plots the sampling distribution of our coefficient of interest, for which we repeat the estimation 1,000 times. Most of the estimates with permuted dates are not significant and far from our main estimate.

Table 1: Baseline Results

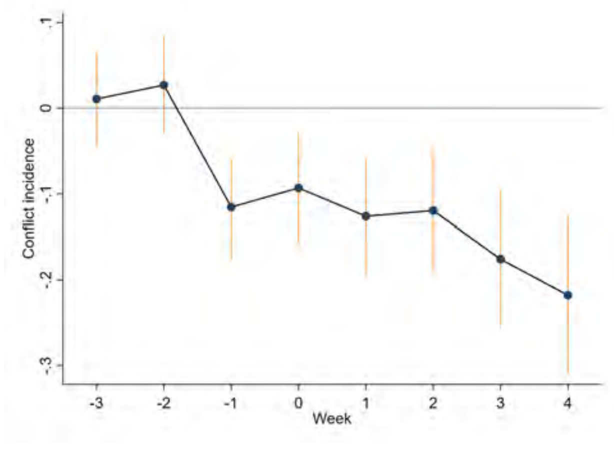
	(1)	(2)	(3)	(4)	(5)
Dep. var. (conflict)	Incidence	Intensity	——— Incidence ———		
Policy restrictions measure	Shutdown (binary)		Narrow index	Broad index	Shutdown
Policy restriction	-0.093*** (0.030)	-0.273* (0.165)	-0.185*** (0.034)	-0.201*** (0.036)	-0.149** (0.074)
× Press Freedom Index					-0.001 (0.002)
Observations	122,099	122,099	122,099	122,099	117,794
R-squared	0.482		0.482	0.482	0.478
Model	OLS	PPML	OLS	OLS	OLS
Country FE	——— Yes ———				
Month-year FE	——— Yes ———				

Note: * significant at 10%; ** at 5%; *** at 1%. Standard errors are clustered at the country level. Conflict incidence is a variable that takes the value 1 if at least one conflict event is recorded in the country a given day. Conflict intensity is the number of events observed in the country a given day. See main text for the definition of the various restriction measures. Table A1.3 in the online appendix contains descriptive statistics about each variable used in the estimation. Press Freedom Index is the average of the press freedom index from Reporters Without Borders over the 2016-2019 period, as provided in the Quality of Government dataset.

Freedom of press and reporting bias. Since the beginning of COVID-19 pandemic, Reporters Without Borders (RSF) have been monitoring the impact on journalism. Through anecdotal evidence, they document state censorship, disinformation, and negative consequences on the right to reliable news.[19] These effects are argued to be more prominent in countries where media independence and pluralism or respect for freedom of press was rather low before the pandemic.[20] Transposed to our research question, this might imply that countries with a low level of press freedom exhibit bias in the reporting, which would imply a downward bias in our estimates of the effect of restrictions policies: with fewer events reported, we would overestimate the conflict-reducing impact of shutdown policies. In column (5) of Table 1, we indirectly test for the existence of such reporting bias by interacting our baseline policy variable with a pre-shutdown measure of press freedom: the average of the press freedom index from Reporters Without Borders over the 2016-2019 period, as provided in the Quality of Government database.[21] The coefficient is negative – the opposite sign as the one we would expect according to the narrative above – and far from statistical significance (p-value of 0.44). Hence, the effect of shutdown policies on the quality of reporting does not appear to vary significantly across countries with different degrees of press freedom. Reporting bias may however still be an issue in our context, even if it is distributed homogeneously across countries. For this reason, our estimates are likely to be an upper bound of the conflict-reducing effect of shutdown policies, and should be considered as such.

Post-shutdown dynamics of violence. Our results of Table 1 are silent on the dynamic and the persistence of violence during the weeks following the implementation of the restrictions. We slightly modify equation 1 by allowing the effect of restrictions to vary across time, around the implementation date. Figure 2 displays the estimates. The specification is demanding because of the short period under consideration following the restrictions, still, a pattern emerges. There is a noticeable decline in violence a week before the restriction is imposed. This indicates that actors involved in violence were already adjusting their behavior due to the spread of Covid-19 (or in anticipation of the policy change). Following the restriction, the reduction in conflict incidence is gradual, and stronger three to four weeks after the policy is implemented.

Figure 2: Timing of Shutdown and Conflict Incidence



Note: This figure plots the coefficients of Table A2.5 in appendix, together with 90% confidence intervals.

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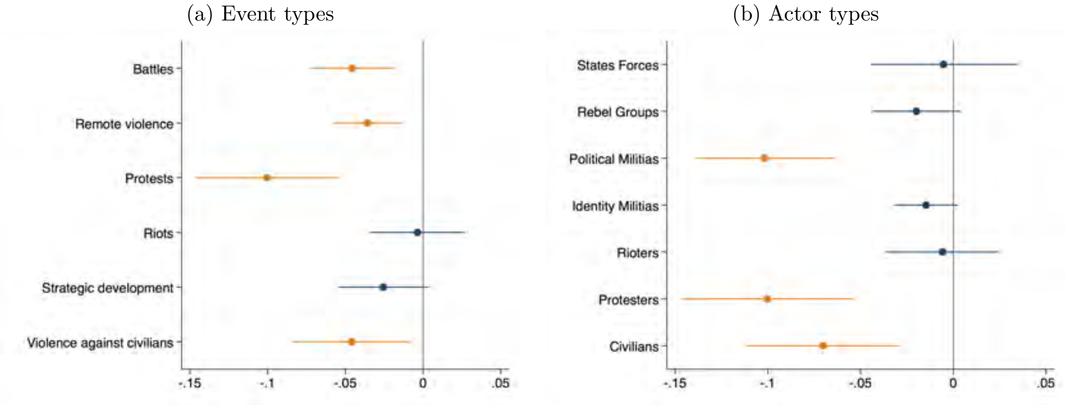
[19] A real time update of Covid-19 related violations are compiled here.

[20] Reporters Without Borders use anecdotal evidence in the 2020 World Press Freedom Index to highlight a correlation between press freedom violations related to the coronavirus epidemic and the ranking in the Index. url.

[21] The press freedom index measures countries on a scale of 0-100, with 100 representing countries with the least press freedom. We inverse the measure, a higher score indicating greater press freedom, to ease interpretation.

Types of events. A crucial feature of the ACLED data is to inform us on the nature of violent events. We replicate column (1) of Table 1 for every single type of events: battles, remote violence, protests, riots, strategic development, and violence against civilians. Figure 3(a) displays the point estimate for each category. Shutdown policies are negatively correlated to battles, remote violence, protests and violence against civilians. The effect is most significant for protests which decline by over 10 percentage points. The significant decline in protests is plausibly due to shutdown measures increasing the cost of individual participation in an activity where the benefit is shared by all sympathizers, irrespective of their participation (Kurrild-Klitgaard, 2013). Using of a PPML estimator and of our two alternative indexes of restrictions delivers similar results (Online Appendix Section A3).

Figure 3: Estimates across types of events and actors


(a) Event types

(b) Actor types

Note: These figures estimate the effect of our baseline measure of restriction policy (*Shutdown*) on different types of conflict events and on conflicts involving different types of actors. The OLS coefficients and standard errors appear in Tables A3.6 and A4.10 in the online appendix. The dependent variable is conflict incidence.

Type of Actors. ACLED data also records information on the types of actors that are involved in each of the violent event. We use this information to estimate equation 1, assessing the daily level of violence by actors. Strikingly, political militias, protesters and civilians are the actors for which there is a decrease of violence. For the other categories of actors – state forces, rebel groups, identity militias and rioters –, restrictions have a negative but statistically insignificant effect on the level of conflict. In the Online Appendix Section A4, we estimate whether these results are robust to using conflict intensity and our alternative policy indexes.

Country characteristics. We finally explore whether countries are heterogeneous in the way they react to the implementation of restriction policies. We define a binary variable equal to 1 when a country's pre-sample (2016-2019) characteristic is above the sample median. We estimate equation 1 allowing the effect of shutdowns to be heterogeneous for the two groups of countries, namely those above and below the sample median. Figure 4 plots the estimates and the p-value of the difference between the two.

First, countries with a higher level of ethnic fractionalization do not seem to behave significantly differently to those with lower level of fractionalization (though they do in a number of our robustness exercises, see below). However, countries with high level of religious fractionalization do not exhibit a reduction in the level of violence, but do for countries with a low level (the difference between the two is different from 0).

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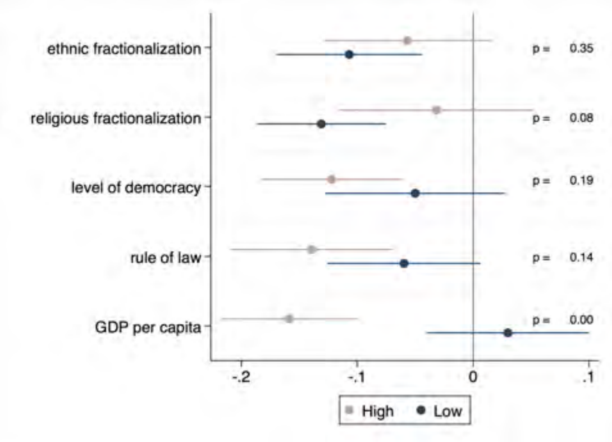
Figure 4: Country characteristics



Note: These figures estimate the effect of our baseline measure of restriction policy (*Shutdown*) on different overall daily conflict incidence, as a function of country characteristics. Lines represent 90% confidence bands. The *Shutdown* variable is interacted with a dummy which takes the value 1 if the country characteristic is above the sample median. The p-values of the difference in the coefficient between the high and low groups appear next to the coefficients. Table A5.14 in the online appendix provides the full estimates.

Second, the level of violence in countries below the median level of democracy score is not decreasing while it is in countries above the median (the difference between the two is different from 0). Third, we evaluate whether countries may react differently along a measure of rule of law. We fail to detect any significant differences between the two groups of countries. Last, we find that countries above the GDP per capita median are those for which the decrease of violence is the highest but positive and significant for those below.

Overall, countries with a higher level of religious fractionalization, lower level of democracy and higher poverty are those for which the restriction policies either do not reduce or in some cases even increase violence. These results are confirmed when using conflict intensity instead of incidence as a dependent variable, and the non-binary policies indexes, though in some cases, the effect of ethnic, rather than religious, fractionalization appears more significant.[22]

Next, we assess if restriction policies have a heterogeneous effect across countries depending on the nature of event or of the actors involved (Tables are displayed in Online Appendix Section A5.3). We find that countries with high level of religious fractionalization do not experience a reduction in violence against civilians, whereas countries with low levels of religious fractionalization experience a significant decline in such type of violence (Figure A5.19). This effect is mostly driven by events involving civilians, political militias and state forces. Further, the heterogeneity of conflict responses with respect to income (GDP per capita) is mostly driven by the dynamics of protests (Figure A5.22).

The impact of stay-at-home policies. We consider the specific effect of the stay-at-home policies on conflict. We construct a binary restriction measure, which switches to 1 when governments have implemented

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[22] We did not find evidence of cross-country heterogeneity in reporting bias using a press freedom index in Table 1, column (5), which suggest that these cross-country results are unlikely to be driven by differences in reporting. Still, we further show in the Online Appendix A5 that controlling for an interaction term between the shutdown measure and (demeaned) press freedom to account leaves the results of Figure 4 unchanged (Figure A5.10).

a nationwide stay-at-home policy. Further we adjust our *Broad index* variable to include that policy, taking into account, in the same way as for the other component, the severity of the home stay policy, based on the degree of requirement (no measure, recommended or required) and its geographical scope (local vs. national). The results are presented in Table A6.18 in the Online Appendix. The results broadly confirm that stay-at-home policies reduce violence, though the decline is smaller both in size and in statistical significance than in our baseline estimations. Consistent with our previous findings however, we find that protests decline significantly in response to stay-at-home restrictions (Figures A6.23 and Tables A6.19). Interestingly, cross-country differences appear more significant in this case: in countries with above median levels of religious fractionalization and in countries with low income per capita, we find that conflict levels actually *increase* significantly following such lockdown policies. This important cross-country heterogeneity explains the weaker average results found when averaging the effect across countries.

Discussion. Overall, our results can be summarized as follows. First, most of the conflict reduction following shutdown policies is observed for protests, though some significant effect is also found for violence against civilians and battles. Second, conflicts that are found to decline involve political militias, protesters and civilians, but we do not find any significant reductions in events involving state forces, rebel groups and identity militias. Third, the cross-country analysis reveals that differences in levels of fractionalization – mostly religious – and GDP per capita create different responses of conflict to restriction policies (and, to a lesser extent, rule of law): conflict declines more in countries with above median GDP per capita, and below median fractionalization measures. The underlying types of conflict are however quite different in each case: while GDP per capita appears to play a role mostly through protests events, fractionalization affect events involving state forces and civilians.

Overall these results points to several potential mechanisms through which COVID-19 related restrictions might be impacting conflict. First, by reducing mobility, such restrictions impact individual mobilization capacity, which explains the decline in the protests worldwide. However, this reduction in the number of protests is not observed in countries with very low income, which suggests that the economic effect of shut- and lockdown policies might trigger additional (mostly peaceful) conflict. This effect might also relate to the fact that shutdown policies limit the capacity of low-income states to fight against the opposition (Berman et al., 2011). Second, we find consistent evidence that shutdown policies have an ambiguous effect on violence against civilians in more fractionalized countries. This indicates that the negative effect of mobility restriction on violence could be tempered by a rise in inter-religious and inter-ethnic violence. This result is in line with the literature which suggests that epidemics can intensify underlying ethnic or religious tensions and lead to scapegoating of minorities (Jedwab et al., 2019; Voigtländer and Voth, 2012).

4 Conclusion

In this paper, we provide real-time evidence of how enforcing restrictions to limit the spread of coronavirus affects conflicts globally. Our results show that imposing nation-wide shutdown of economic activities and mobility restriction reduces the likelihood of daily conflict by 9 percentage points. The conflict reduction is particularly strong for protest, though other types of events – battles or violence against civilians – also decline to some extent. Interestingly, our results show that conflict has not reduced in every country, and that socio-economic characteristics play an important role in driving the conflict response to COVID-19 restrictions policies. In the most fractionalized countries, in particular, restriction policies have an ambiguous effect, and violence against civilians, involving political militias and state forces, show no decline.

Our work is only a first step to try to understand how Covid-related policies might impact conflict. Given the preliminary nature of the data, and the short time span currently available, more work is surely needed. Many important dimensions of the conflict-covid nexus are not considered in our analysis. For instance, future research could try to further explore cross-country heterogeneity in conflict responses, and consider within-country characteristics, such as urbanization and local income levels. Given the current collapse in many commodity markets, how natural resources rich regions react to the spread of the virus is surely an important question to study as well.

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Getting people back into work[1]

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Governments are starting to ease restrictions to economic activity. The risks of easing these measures too soon, or in misguided ways, are obvious, not only for public health but also for the economy. A world with no lockdown and a pandemic spreading rapidly through the population does not make for a healthy economy; nor, in all likelihood, does a world in which containment measures have to be repeatedly re-instated after being eased prematurely or in sub-optimal ways. We discuss some key economic issues that the UK government needs to face when thinking about how best to get people back into work: we assemble some basic empirical evidence, identify some challenges that policy-makers will need to confront, and discuss some policy considerations.

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1 Introduction

The COVID-19 pandemic has led to unprecedented social distancing measures around the world to contain the spread of the virus. The UK has, like many countries, effectively closed down entire sectors of its economy and severely limited activity in many other sectors. This curtailing of activity is likely to lead to a sharp recession. At the same time, the risks of easing these measures too soon, or in misguided ways, are obvious, not only for public health but also for the economy. A world with no lockdown and a pandemic spreading rapidly through the population does not make for a healthy economy either; nor, in all likelihood, does a world in which containment measures have to be repeatedly reinstated after being eased prematurely or in suboptimal ways.

The government faces these incredibly difficult trade-offs in deciding when and how to ease lockdown restrictions to restart the economy. It will have to take these decisions with limited knowledge of what is happening to firms, families and workers, what the health and economic consequences of alternative policies will be, and considerable uncertainty about how events will unfold and how best to promote inclusive economic recovery.

In this note, we discuss some key economic issues that should be considered when thinking about how best to get people back into work: we assemble some basic empirical evidence, identify some challenges that policymakers will need to confront, and discuss some policy considerations. Many of the specific issues that we overview could be examined in more detail, and we hope that this paper might make some contribution in setting the agenda for that.

When thinking about this highly unusual crisis, there are a few insights from economics that can be helpful in guiding policy thinking in relation to easing the lockdown and getting people back into work. These underlie a number of the more specific policy options that we discuss later, and it is useful to describe them up front.

The first is that pervasive economic uncertainty in itself typically dampens economic activity, and additional policy uncertainty can be particularly damaging. On some measures, economic uncertainty is now greater in magnitude than during the 2008 financial crisis (Baker et al., 2020). Restarting the economy while mitigating the rate of virus transmission will require firms to reorganise working and workplace arrangements, which will often involve costly investments. Many workers too may need to invest in new skills, and perhaps even relocate, in order to continue working. Neither firms nor workers will take these steps as much as would be ideal if it is unclear for how long those investments will be needed.

In other contexts, uncertainty – and policy uncertainty in particular – has been shown to discourage firms from taking action and from investing (e.g. Pindyck (1991), Bloom et al. (2007) and Baker et al. (2016)). Of course, flexibility and discretion over future policy is necessary in a situation where much of the relevant science remains unknown, as is currently the case – and claiming certainty now only to change guidance later would probably undermine certainty more than simply saying nothing. But there may be things on which basic ‘forward guidance’ can already be provided. For example, it seems safe to say that the desk-based economy will be expected to largely work from home, and that many workplaces will be expected to implement social distancing measures, for some time after the full lockdown is eased. Being clear about that now will help ensure that firms do not underinvest in making these things happen effectively, under the mistaken impression that things might soon return to normal for them once lockdown is eased. The damaging effects of uncertainty – particularly where this cannot be easily removed by government, given the inevitably uncertain environment – also highlight the importance of effective state insurance schemes, so that firms and workers do not bear all of the risks of further disruptions or lockdowns.

Second, the need for innovation will be a central feature of the post-lockdown, pre-vaccine period. Successfully navigating trade-offs between economic activity and rates of virus transmission will require adaptations to the ways in which work is organised, to reduce crowding in the workplace (both by enabling working from home and by increasing social distancing within the workplace) and on public transport as people commute. The appropriate innovations will tend to be different in different sectors and contexts, and it is industry – rather than government – that will be best placed to identify them. But there are crucial things that government can do to encourage and facilitate this type of innovation. Providing certainty where possible is one important example, as discussed. As with innovation in other areas, regulation, monitoring, and the sharing or publicising of best practice are all policies that potentially can encourage it. Fiscal policy instruments might also play a role to align firms' incentives with society's wider interests: the presence of a contagious virus creates obvious externalities meaning, for example, that many of the gains from innovations to enable workers to work from home will be felt by the rest of society (in the form of lower rates of virus transmission) rather than by those workers or firms themselves. There are also subtler reasons why firms' investments may fall short of what is socially optimal. Returns to the investments of one firm depend on similar investments being made by firms in its supply chain and by other businesses that purchase its output, so that they too can reopen normal activity. Here there is a useful analogy with the economics of climate change, where strategic complementarities mean that individual firms underinvest in adaptations towards cleaner energy, even in the presence of a carbon tax (Aghion et al., 2014). This market failure could be tackled through a combination of targeted subsidies, insurance schemes that reduce investment risk, and regulation establishing, for instance, minimum distance requirements in the workplace.

Third, there is an unusually strong case for the government to play an active role in helping the labour market adjust to the huge shock that it has gone through. The severity of this crisis, combined with the fast adoption of new technologies to facilitate social distancing in work, is already leaving many workers without a job as their firms shut down or their occupations become redundant; in all likelihood, more will follow. Other workers are being temporarily furloughed while their firms are in lockdown. Millions of workers may need to look for different sorts of work, in different firms and different sectors, either temporarily or permanently. In any given local labour market, there is no guarantee that the skill sets of workers looking for new jobs will match the new needs of firms, and – particularly in markets with lots of small firms – the logistical exercise in forming matches between large numbers of workers and firms can be slow and inefficient, as we have seen in the example of fruit pickers. More generally, we know that large mismatches in the labour market can hamper employment and economic growth (Sahin et al., 2014). To minimise such negative and long-lasting effects, there is a strong case for public intervention – not of the command-and-control type, but to minimise the frictions in the labour market by, for instance, providing platforms for job posting and matching in specific sectors or occupations. Policies to incentivise retraining on the job may also facilitate the formation of new high-quality matches. And there should be firm steps to remove obvious barriers to sensible labour market reallocation, such as exclusivity clauses which prevent some furloughed workers from taking up temporary work in sectors where there is demand for their labour. In some localities where private sector vacancies are poorly matched to the skill sets of unemployed or furloughed workers, there may be a case for more direct intervention – for example, by employing such workers to conduct valuable public investments that will pay off later. All of this will require good data (better than are currently available) on where vacancies are arising and the locations and characteristics of the furloughed and unemployed.

Fourth, the impacts of lifting the lockdown will depend on how individuals respond to the new rules. Individuals and families face very variable constraints and incentives to go back to work. Many workers will be incapable of returning to work, either because they have health vulnerabilities or because they live with vulnerable people or key workers. In addition, while schools and nurseries remain closed, many parents will find it difficult to return to work and support their children. We estimate that, among non-key workers who cannot easily work from home, two-thirds could have constraints that limit their participation in the labour market or have circumstances such that the risks of their participation are relatively high. Any strategy for easing lockdown that is based on letting some population groups go back to the workplace before others should be prepared for the fact that there will still be many difficult cases within those groups, and the need to ensure safety on public transport and in the workplace will still be paramount.

Another running theme is that the most appropriate policy in each case depends on the balance of information and know-how between the government and other economic agents. Where firms or workers have better information than government, policy should be designed to encourage them to take the best actions – for instance, through regulation, subsidies, or the (possibly temporary) removal of existing regulation, taxes or subsidies that provide disincentives. Where government has better information, it should be more directional.

Some caveats are in order before we proceed. First, there are important limitations to what we can say empirically now, as most of the information we have is from the pre-crisis period. The real-time data that already exist are limited and we comment on where we think this is a particularly important concern.

Second, we do not consider what tolerance society may have for infection risk and whether that changes as the crisis unfolds. These are clearly key inputs to decision-making, which we are not best placed to comment on. Tolerance to the risk of getting infected is likely to vary across individuals.

Third, there are important behavioural factors that we again are not well placed to comment on here. As the lockdown is eased, some individuals may behave more carelessly, possibly speeding up contagion and making the outside environment riskier for all and especially for the most vulnerable. Conversely, under continued strict restrictions, some may increasingly flout them. These should be important considerations when assessing different policies.

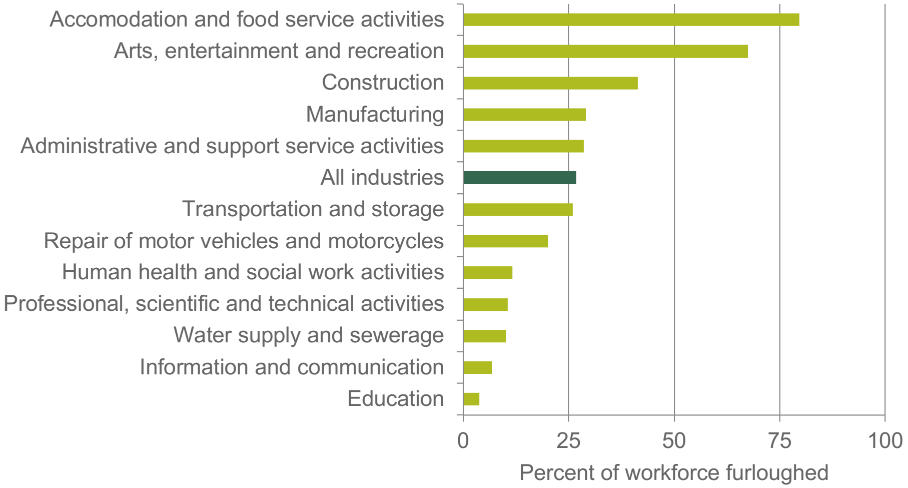
Fourth, scientific or practical advances, such as widespread testing or the rapid development and deployment of medical treatment, would have important consequences for how one views alternative policy avenues. A discussion of the economic policy implications of such developments is outside the scope of this paper.

In Section 2, we set the context with what we know about who is and is not working under lockdown. In Sections 3–6, we run through some of the key factors that we need to think about in order to restart the economy, covering working from home, commuting, safety in the workplace, and individual- or household-level constraints or risks to going out to work. In each section, we set out some key empirical facts and discuss the role for government, with reference to some of the key principles outlined above. In Section 7, we discuss which firms will want or be able to employ workers as we restart and issues around supply chains and productivity. In Section 8, we summarise and conclude.

2 Who is and is not working under lockdown

To set the scene for much of what is to come, it is useful to set out what we know about who is, and is not, working under the current lockdown. Figure 1 shows the percentage of workers who have been furloughed in different industries, among businesses that responded to a survey conducted by the Office for National Statistics (ONS) between 23 March and 5 April this year.[4] The survey is intended to cover firms that either continue to trade or have temporarily paused trading, not firms that have shut down completely (hence, it is possible that the 0.3% of firms that had ceased trading is a substantial underestimate of the true figure across the UK). These figures also do not include the self-employed or unincorporated businesses. More generally, there is no guarantee of representativeness. But it is perhaps the best information we have at present.

Figure 1. Share of workers furloughed by businesses responding to ONS survey, 23 March to 5 April 2020



Source: Office for National Statistics, 2020.

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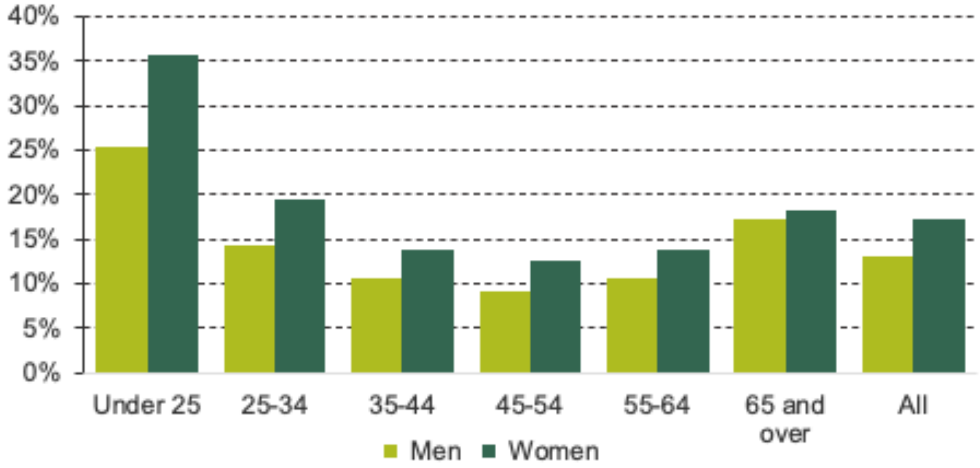
[4] The survey asks firms what proportion of their workforce they have furloughed and these figures are then weighted according to firm employment data taken from the Inter-Departmental Business Register. 6,150 businesses responded to the survey.

Figure 1 suggests that in late March and early April, 27% of employees had been furloughed. Furlough rates were greatest for businesses in the accommodation and food services sector and the arts, entertainment and recreation sector, which respectively furloughed 80% and 68% of their workers. The same survey indicates that 0.5% of employees had been made redundant over this period (again, note that this may exclude significant numbers of employees who are now without work because their firms have folded altogether).

Another approach to estimating the number of workers who have been furloughed or laid off is to survey individuals. Adams-Prassl et al. (2020) report the first available results from an online survey of 3,974 individuals taken on 25 March 2020. Their figures suggest much greater proportions of individuals no longer working, but largely corroborates the kinds of variations seen across sectors shown in Figure 1, and provides additional detail suggesting that younger workers and women are more likely to have lost work. This accords with ex-ante analysis of pre-crisis data by Joyce and Xu (2020), which shows that sectors that have been entirely shut down – such as hospitality – disproportionately employ those groups (see Figure 2).

The fact that the Adams-Prassl et al. survey includes the self-employed and people whose firms have gone bust would be one potential reason for the gloomier picture it paints when compared with the ONS survey, though it is also likely that surveys of this kind undersample people who still have plenty of work to do and hence less time to fill in surveys. Clearly, more real-time data will help. But, taken together, what these useful and timely analyses do reveal very clearly is that large fractions of the workforce are not currently doing productive work and that this varies greatly across sectors and hence types of people.

Figure 2. Share of workers in shut-down sectors by age group and gender



Source: Joyce and Xu (2020), based on Quarterly Labour Force Survey 2019.

These figures are crucial context to the challenge of easing lockdown. They provide a sense of scale for how far out of equilibrium the labour market will be as restrictions are eased, with huge numbers of people and firms looking to restart work and production at around the same time. As we discuss later, the potential role for government to help smooth this huge exercise in coordination and reallocation is unusually significant, as it could otherwise take a very long time and lead in the interim to inefficient labour markets – for example, unnecessary labour shortages in some sectors, as we have seen recently for fruit pickers – and needless hardship for unemployed workers. More specifically, one may look at some of these figures and discern with fairly high probability that a number of the furloughed or laid-off workers will not be able to return to their previous work for some time – for example, many of those furloughed in the accommodation and food services sector. It should be a priority to identify now where those workers are, and to ease barriers to them taking up alternative work, at least on a temporary basis, rather than simply accept that they will be furloughed and not doing productive work for many months. Moreover, this sector has space and other capital that are currently not being used. Repurposing such space for alternative uses that will be more compatible with social distancing as the lockdown is eased could maximise its value and allow more workers to restart their activities.

3 Working from home

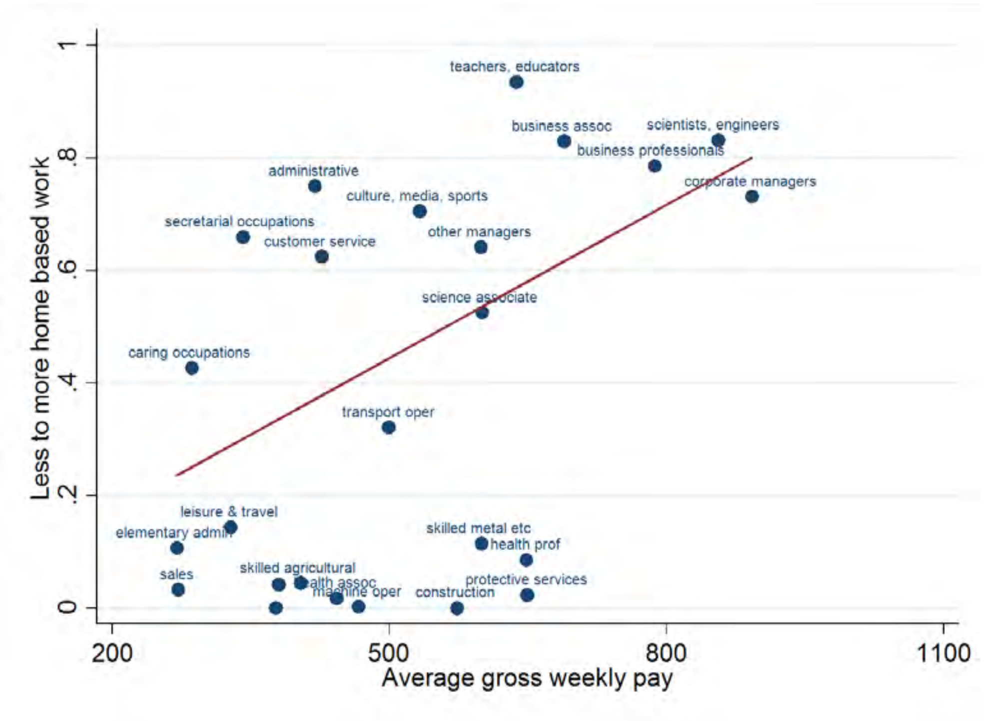
As lockdown is eased, ensuring that those who could work from home reasonably productively are doing so should be a policy priority. It dampens the trade-off between the level of economic activity and the rate of virus transmission. It benefits not only those who can work from home; it also enables more of those who *cannot* work from home to go to work, without society once again seeing a spike in virus infections large enough to precipitate the reintroduction of lockdown which would once again threaten their livelihoods. But there is obvious potential for market failure here resulting in insufficient working from home. Some of the benefits from doing so accrue not to the individuals or firms themselves but to others in society (through lower virus transmission); and working from home may require investments and adaptations that the uncertain environment could inhibit.

3.1 Ability to work from home

Figure 3 shows occupation-level estimates of the degree to which workers might be able to work from home, against average earnings in that occupation. To produce this, we have applied the approach of Avdiu and Nayyar (2020), which was based on the tasks involved in different occupations in the US (which itself utilised analysis of the O*NET task database undertaken by Dingel and Neiman (2020)). Each occupation at the four-digit level of the Standard Occupational Classification (SOC 2010, ONS) is classified as either amenable or not amenable to home working. For example, jobs that necessarily involve working with machinery, close contacts with customers or working outside will not be amenable to home working, all else equal. On the other hand, many desk-based occupations such as legal work, management and computer programming (shown towards the top of the graph) will be. There are two caveats to Figure 3. First, it is based on pre-crisis information on task content. This is not immutable, and the nature of some roles could be adapted (as discussed further below). Second, it assumes that the US-based classification of occupations by task content translates perfectly to the UK setting.

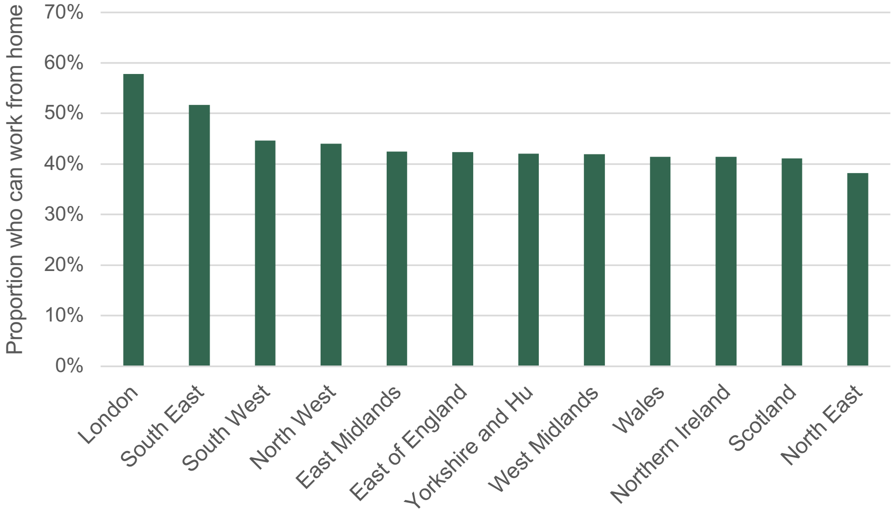
Figure 3 shows the proportion of occupations that can be worked from home within each two-digit-level SOC-2010 group against the average pay in that group of occupations. It demonstrates that lower-paid jobs are less likely to be amenable to doing from home. This emphasises the likely need for effective insurance from government for some time, to help those who cannot be accommodated safely in the workplace. Figure 4 splits the analysis instead by region and shows that the occupations of workers in London are on average considerably more amenable to home working than those in the rest of the country. For example, 58% of workers in London are in occupations amenable to home working compared with 38% in the North East of England. (Magrini (2020) provides information on the possibility of working from home at a more granular level.) This is actually a convenient fact in the context of mitigating virus transmission since, as we shall see, if Londoners do not work from home they are much more likely than others to commute by public transport, in which the risk of spreading the virus is relatively high. An emphasis on ensuring that home working happens wherever it can looks particularly appropriate in London.

Figure 3. Amenability of different occupations to home-based work against average earnings for different occupations



*Source: Labour Force Survey data for 2018–19. ‘Can work from home’ assessed on O*NET characteristics of jobs, including whether works outdoor every day, deals with safety equipment, machinery, deals with public, etc. Vertical axis measures the proportion of occupations that can be worked from home within each two-digit-level SOC-2010 group.*

Figure 4. Share of workers in occupations that could be done at home by region



Source: Authors' calculations using Quarterly Labour Force Survey 2019 and measures of whether occupations can be worked from home taken from Dingel and Neiman (2020). Calculations based on region of residence.

3.2 Ensuring that working from home happens as much as it should

The possibility of working at home given the tasks involved in one's job pre-crisis is not necessarily a good guide to whether one could do one's job from home after sufficient ingenuity and innovation to reorganise working practices or service delivery. Adaptation is possible. In the education sector, working from home was not the norm prior to the crisis, but universities were able to make the shift towards remote teaching relatively quickly and easily. Similarly, school teachers have to some extent been able to use existing technology to enable them to work from home, although potentially with diminished quality.

There may be longer-term benefits from innovations of this kind. In some industries, and at least when it is partly the worker's choice, working from home has been shown to improve productivity significantly (Bloom et al., 2015). In other contexts too, 'forced experimentation' of methods that would not otherwise have been tried has led to people discovering that they were not previously doing things optimally: namely, the 2014 London Tube strikes led to permanent changes in commuting behaviour as people were forced to discover commuting routes or methods that they preferred to what they were doing before (Larcom et al., 2017). It is certainly possible that this crisis does something similar for remote working as, for example, people re-evaluate the need to travel rather than use videoconferencing facilities.

However, the most basic case for policy action to encourage working from home is much simpler. There are negative externalities associated with travel and social contact in the workplace during a pandemic. Hence, there is a clear potential role for government in encouraging working from home and the innovations that facilitate it. And an uncertain environment may prevent firms from making the investments that are required, so there is a role for government in mitigating that uncertainty.

Potential policy levers include:

- **'Forward guidance' about the expectation of working from home in certain parts of the economy**. Despite all the uncertainties ahead, it seems highly likely that under any sensible and balanced approach to lifting lockdown, many people in desk-based occupations should be continuing to work from home for some time. Making this clear now could have real benefits. Company decision-makers who think they will be filling offices again as soon as lockdown is lifted are unlikely to be investing as much as they should be in innovation to enable productive working in a remote context.
- **Loans or grants to cover the up-front investment costs in remote working technologies**, perhaps targeted at smaller businesses where cash-flow issues are likely to be most significant. (Ideally, there would be monitoring to ensure that working from home is actually taking place for recipients of these – see below for wider benefits of monitoring.)
- **Sharing of best practice**. Firms and sectors will tend to be best at figuring out how to most effectively conduct remote working in their particular context. But the government could play a role in helping new innovations and best practices to spread as quickly as possible.
- **Subsidies for firms or workers who are operating from home**. The theoretical case for these is clear, given the externalities, though the practical design could be challenging – for example, to avoid large deadweight.
- **Norm setting**. Simply sending a strong signal that certain sectors or occupations are expected to work from home, and that failing to do so is deemed unacceptable and irresponsible, may have a significant effect. The government could play its part in making it reputationally or psychologically costly to flout this societal expectation, effectively internalising the externality without the cost or design challenges of a financial subsidy to working from home.
- **Regulation and monitoring**. As well as the direct benefits, this can help spur innovation in working from home.

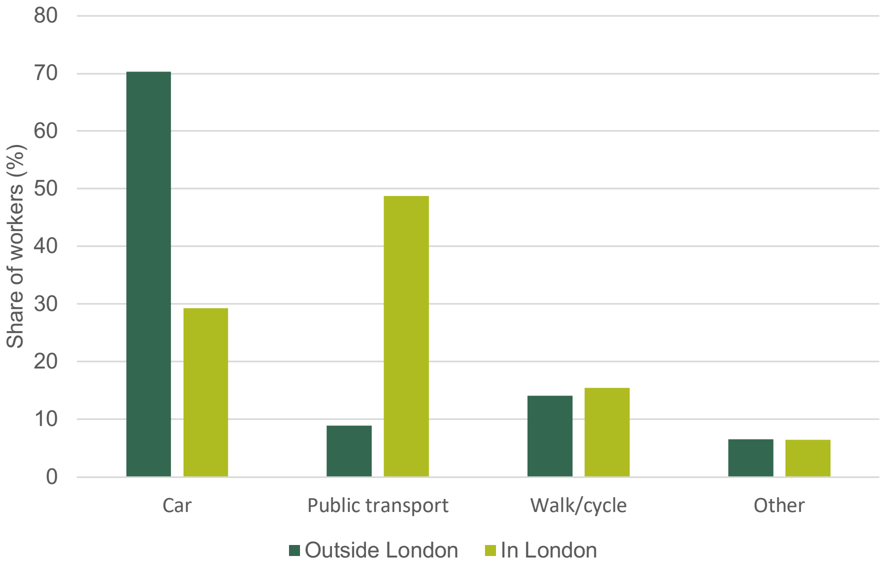
4 Commuting

The crisis has turned normal assessments of the social desirability of different forms of transport on their head. The externality calculus normally favours public transport. Now, travel on crowded public transport – particularly at peak times – comes with obvious negative externalities, given the risk of spreading illness. Travel by car is better for containing the spread of the virus, and also associated with lower-than-normal congestion externalities as road use has fallen, though the costs of the pollution it causes may be higher than normal due to the respiratory problems associated with COVID-19. Perhaps the clearest example of a mode of commuting that has become more desirable as a result of the virus is cycling. The broader point is that the social costs and benefits of different forms of commuting have changed, and this calls for temporary changes in policy.

Some simple empirical facts help to highlight the challenges that need addressing. First, there are large regional differences in commuting patterns. It is in London that commuting by public transport is by far the biggest issue. Figure 5 shows that 49% of workers resident in the capital commuted to work via public transport before the crisis, compared with around 9% of workers living in the rest of the UK. Journeys in London also frequently involve several forms of transport – for example, changing lines on the London Underground; this can heighten infection risks, particularly at crowded times (Goscé and Johansson, 2018).

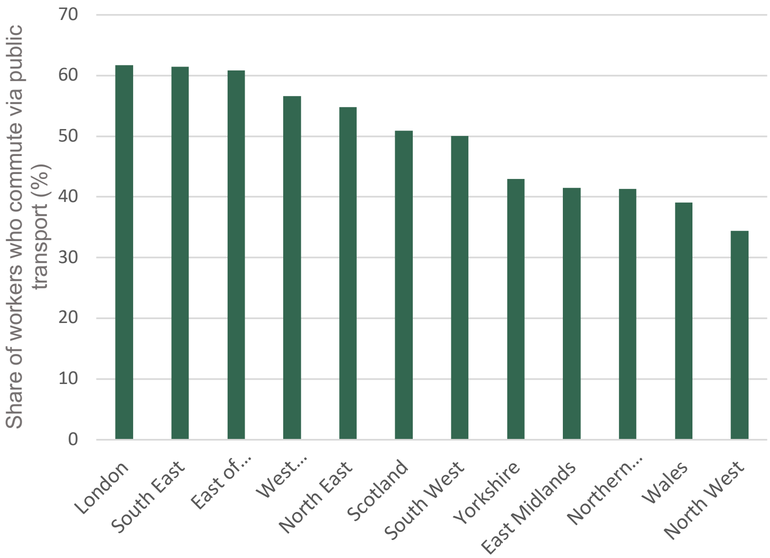
On the other hand, and fortunately given Figure 5, London residents are also disproportionately likely to work in occupations amenable to home working. Figure 6 shows the proportion of those taking public transport to work who could potentially work from home. Almost two-thirds of London residents who used to rely on public transport could work from home. Hence, one way of addressing the challenge caused by hazardous commuting is to pay particular attention to the policy levers encouraging working from home (discussed in the previous section) in London.

Figure 5. Means of getting to work in London and in the rest of the country



Source: Authors' calculations using UK Household Longitudinal Survey (wave 8). 'Public transport' includes those who travel by bus/coach, train or metro/underground/tram/light railway. 'Other' includes those who travel by motorbike or taxi, as well as those who usually work from home so do not commute. Calculations based on region of residence.

Figure 6. Share of those who normally commute to work via public transport who work in occupations that are amenable to home working



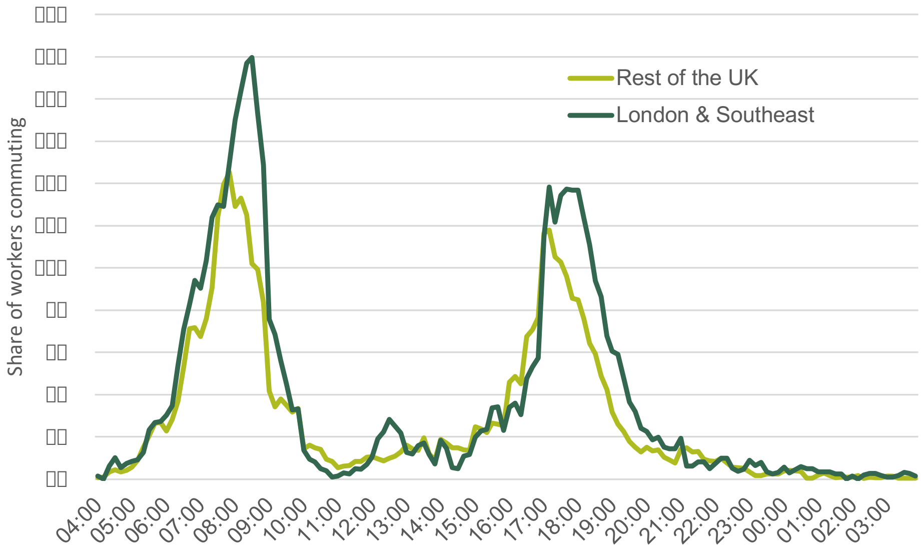
Source: Authors' calculations using Quarterly Labour Force Survey 2019, UK Household Longitudinal Survey (wave 8) and measures of whether occupations can be worked from home taken from Dingel and Neiman (2020), averaged at the three-digit-level occupation. Calculations based on region of residence.

Second, there is very substantial clustering of commuting at peak times. Achieving greater dispersion of commute times is one way to reduce the public health consequences of a given amount of commuting (and may well be complementary to other measures, such as trying to enforce minimum distances between people on public transport). Figure 7 shows that commuting, especially in London and the South East, clusters heavily around peak times. At 8:30am, 20% of workers in London and the South East are commuting. Flattening these peaks – both by reducing absolute demand for public transport and by shifting demand into less busy times of the day – would reduce the risk of infection.

One way of flattening these peaks would be to encourage firms to be innovative in how they structure working hours and shifts, to enable workers to spread their commutes more throughout the day. This could be achieved by shifting working hours on a firm-by-firm basis but, where possible, it will be preferable for firms to achieve this by enabling workers within the firm to start at different times. This not only reduces the need for coordination between firms (which the government would be well placed to help with, if necessary); it also reduces contact between workers within the workplace. It is therefore discussed further in the next section.

Finally, given the temporary change in the externality calculus of different modes of commuting, the government could alter the relative prices of different types of commutes to better reflect this new reality. Examples would be to reduce the relative price of commuting at off-peak times on the London Tube and bus network, or further measures to financially incentivise cycling. The government should, however, be mindful of the political economy of reversing temporary policies when they are no longer optimal. For example, if on balance it were judged that the relative social desirability of driving relative to public transport use had temporarily increased, we would still be hesitant to recommend temporary cuts in fuel duties, given that recent history suggests the government would find it very difficult to increase fuel duties again in the face of inevitable lobbying post-crisis.

Figure 7. Share of workers travelling to work in 10-minute intervals over the course of a weekday



Source: Authors' calculations using UK Time Use Survey 2014–15. Graph shows the share of workers who report their main activity in a 10-minute interval as commuting. Data are for a randomly selected weekday.

5 Making work safer

5.1 Ability to socially isolate at work

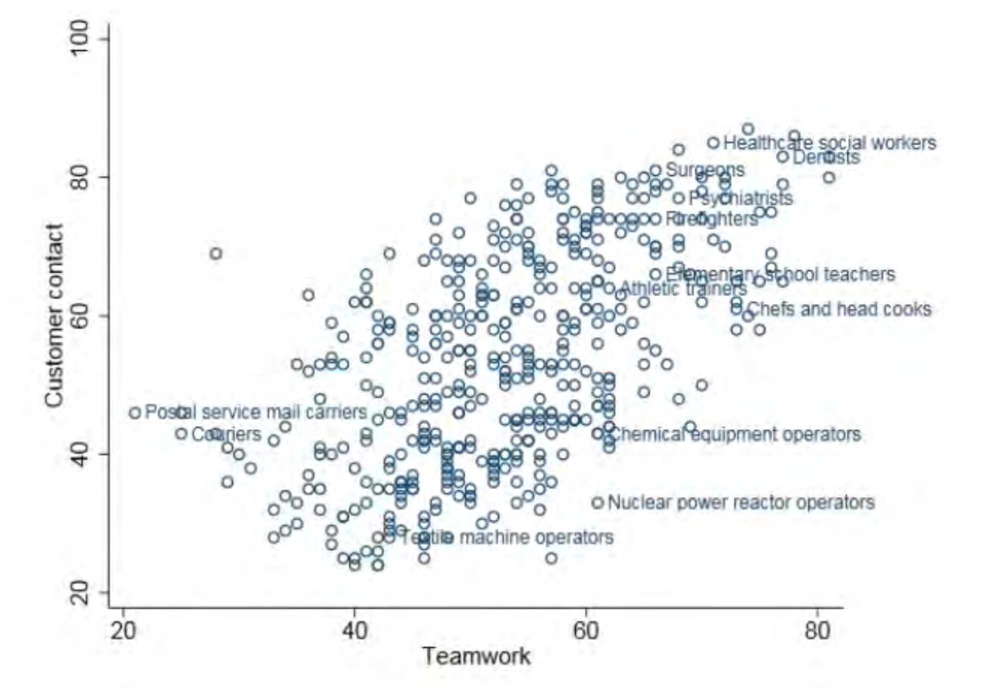
Social contact in the workplace – whether with customers or colleagues – will be another important dimension of risk when easing lockdown restrictions. The UK government has been consulting unions, large firms and business groups on the ease of social distancing in different types of workplaces – for example, outdoor work or work in another person's home. Assessing social distancing risk by workplace has the advantage that it is likely relatively easy for businesses and workers to self-assess which category they belong to. However, this is likely to be a crude tool. For example, a small number of workers sitting at well-spaced desks in an office might come into less contact with others than workers in a small garden centre who regularly come into contact with customers.

This points to two other dimensions for the ease of social distancing at work. Consumer-facing industries are likely to find social distancing measures more difficult to adopt than intermediate industries. And workplaces where physical teamwork is required will tend to have more social contact than those where workers are able to work individually on tasks most of the time.

Based on O*NET data for the US, Koren and Peto (2020) categorise occupations by the level of close contact that is required between workers, indicated by teamwork, and the need for face-to-face communication with customers. Figure 8 shows that these two indicators of the ease of social distancing are highly correlated. This suggests that there might be a fairly clear hierarchy of ability for social distancing in different roles.

However, these categorisations are necessarily based on pre-pandemic data. A crucial issue is the extent to which firms and workers can innovate, changing work practices to reduce the risk of infection in the workplace. Notably, some of the riskiest professions in Koren and Peto's taxonomy are considered key roles (such as healthcare, social work, psychiatry and teaching). We have already seen rapid innovation in each of these industries, as their workers have been asked to continue to work during the lockdown period.

Figure 8. Occupation-level correlation between intensity of contact with team members and with customers



Source: Figure 3 of Koren and Peto (2020).

5.2 Encouraging firms to adapt to make social distancing easier

After lockdown is eased, it seems inevitable that workplaces that are open will be asked to take measures to ensure social distancing. Doing this effectively will, in many cases, require considerable innovation, the nature of which will differ depending on the context.

One of the most obvious innovations is to rearrange work to reduce the number of employees in the workplace. This can come partly through encouraging employees to work from home where possible (see Section 3), which will improve safety for those who must work on site. Another option is to change shift patterns. Figure 7 shows that the majority of workers are in their workplace during the traditional work hours of 9–5. Adapting the timing of work and shift patterns such that this is spread more evenly throughout the day could ease congestion in some workplaces.

A second set of changes might be aimed at reducing contact between employees (and customers, where applicable) when they are on-site. Some types of face-to-face communication can be replaced by online meetings. Retail shops and restaurants that traditionally required close contact with customers have already shifted to click-and-collect or take-away. New software has allowed pharmacists to easily transfer information between them, minimising the cost of workers working non-overlapping hours and requiring less face-to-face contact. Construction sites are assigning workers to a small, consistent team which alternates shifts with other teams.

As even that short discussion helps illustrate, the appropriate innovations will be very idiosyncratic to the particular context in which they are applied. As such, it will be firms and industries that are best placed to work out *how* to innovate. But there may be market failures that prevent them from doing so, and the government has a key role in trying to mitigate them.

First, there is uncertainty over how long social distancing will need to remain in place, meaning that firms cannot easily judge how much benefit they will see from innovation. It seems clear that, where workers cannot reasonably work from home, workplaces will be required to implement social distancing measures for some time after lockdown is eased. Being absolutely clear about that now, even without being quantitatively precise about the timeline, would probably help to mitigate some of the effects of uncertainty and ensure that firms are not underinvesting in adaptations in the false hope that the end of lockdown means a return to normality.

Second, there are positive externalities from safer workplaces, as consumers and workers' wider networks of contacts will benefit from reduced infection transmission. Market forces may help: survey evidence suggests that consumer preferences are evolving to favour businesses with strong social distancing measures in place,[5] and firms with stronger social distancing practices might find employees more willing to return to work and less likely to become sick. There may be a significant role for government in helping this along by signalling social (un)acceptability with its own statements on social distancing. But the positive externalities to such measures, and hence the potential for underinvestment, will remain. There is a case for the government to use other tools, such as fiscal subsidies, to more closely align the private and social returns. Regulation and monitoring of social distancing in the workplace would not only help directly ensure that firms do the socially desirable thing by reorganising work; it would also help spur the innovation needed to make that social distancing as compatible as possible with productivity.

Finally, the government can assist by playing a central coordinating role in sharing examples of best practice of industry innovations, helping these to spread as quickly as possible. In fact, it may have something of a head start, since most of the public sector are 'key workers' (compared with 22% of the workforce as a whole (Farquharson et al., 2020)), meaning that different parts of government have already

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[5] For example, a YouGov survey on 20–21 April found that the majority of consumers would 'feel uncomfortable' visiting premises such as restaurants, pubs and gyms once restrictions are loosened. https://yougov.co.uk/topics/health/articles-reports/2020/04/22/dont-count-customers-returning-once-covid-19-lockd

gained experience in adopting innovations to bolster workplace safety during the pandemic.

6 Constraints making it difficult or undesirable for some workers to return to work

There is likely to be a substantial asymmetry between entering and exiting the lockdown. Compliance with lockdown restrictions was high and almost immediate, with Google mobility data showing retail and recreation locations receiving almost 80% less traffic than pre-social distancing (Google, 2020). It is not clear how people will respond to an easing of restrictions.

The likely consequences of infection differ widely across individuals, as do other costs of returning to work. Even if the risk of infection in the workplace can be reduced, some people may be unwilling to return to work if they or someone they are in contact with is at greater risk from the virus. Others will face other barriers such as caring responsibilities, especially while school and childcare closures remain in place.

In addition, from society's point of view, there can be greater risks from certain individuals commuting and spending time in the workplace, which may or may not coincide with the risks that are salient to individuals themselves. For example, if someone married to a key worker goes to work, gets infected and passes the virus to their spouse, there is an additional cost to society from the fact that a key worker may now be absent from work and that, as someone who tends to have greater-than-average social contact, they may spread the virus further. A similar argument may apply to parents in the scenario where schools and childcare settings reopen, since this could spread the virus indirectly through their children, though the importance of this infection channel is unknown.[6]

To give a sense of scale for how important these risks or constraints to commuting and/or working on-site could be, we focus on the group of workers who are the most plausible candidates for the next stage of loosening lockdown restrictions: those who are not key workers (since they are already working) and who cannot easily work from home. Figure 9 shows the prevalence of different risks or constraints among this group. Two-thirds of them have at least one flag associated with elevated risks or constraints (though note that, of course, these are only statistical proxies; actual risks will differ according to lots of unobservable factors, including genetics): being aged 60+, living with someone who is 60+, living with a key worker, or having pre-school or school-age children. About a sixth have one of the age-related flags, another sixth live with a key worker, and another third have a school-age or pre-school child.

One of the reasons why so many workers have elevated risks or constraints is that there is relatively little overlap between them, as Figure 9 shows. Older workers will tend to have greater health vulnerability, and the age groups below them tend to have children. There are, however, some groups who appear to have lower overall prevalence of risks or constraints than others. These include the youngest workers, as Figure 9 shows, and – to a lesser extent – those in London, as Figure 10 shows.

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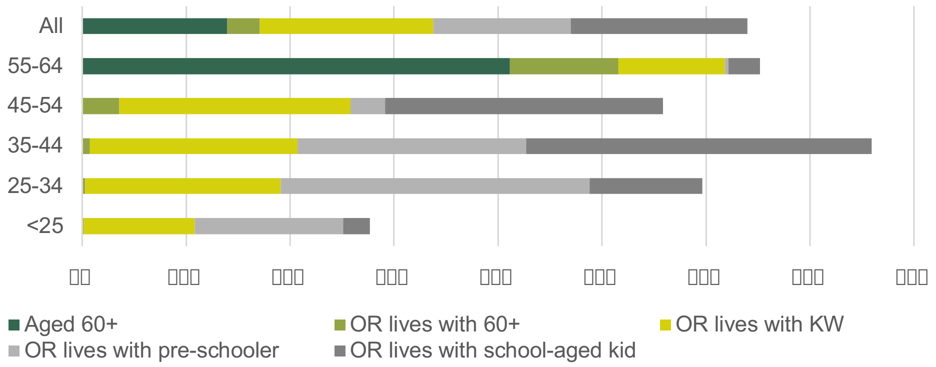
[6] Our understanding is that the extent to which children could transmit the virus is an active area of research for the scientific community: https://www.bbc.co.uk/news/health-52180783.

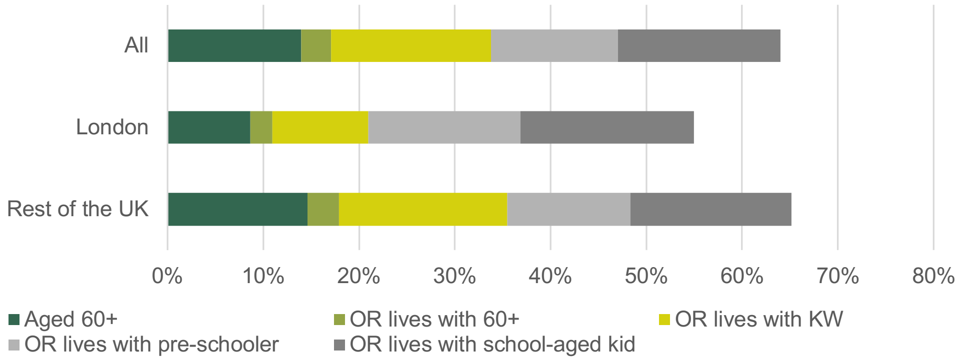
It is worth recalling the evidence shown and discussed in Section 2, which suggests that the youngest workers are disproportionately likely to be furloughed and to be in sectors that have been shut down – many of which, such as hospitality, are unlikely to be allowed back in full very soon. This suggests that policy to support the matching of workers to (perhaps temporary) new roles, and to remove barriers that stop this (such as exclusivity clauses imposed by furloughing firms), could be particularly important for this group, and particularly relevant to any exit strategy that involves letting young workers out to work first.

Figure 9. Constraints on working outside the home among non-key workers whose jobs do not typically allow home working: by age



Source: Authors' calculations using UK Labour Force Survey (2018Q4–2019Q3). Classification of ability to work from home based on Dingel and Neiman (2020). Key workers are identified based on the methodology used in Farquharson et al. (2020). This graph builds up who faces constraints to working. Workers will be counted in the left-most category that applies to them, i.e. there is no double-counting. The sample is all non-key workers who are in occupations where fewer than a third of workers are predicted to be able to work from home (pre-crisis).

Figure 10. Constraints on working outside the home among non-key workers whose jobs do not typically allow home working: by location of residence



Source: Authors' calculations using UK Labour Force Survey (2018Q4–2019Q3). Classification of ability to work from home based on Dingel and Neiman (2020). Key workers are identified based on the methodology used in Farquharson et al. (2020). This graph builds up who faces constraints to working. Workers will be counted in the left-most category that applies to them, i.e. there is no double-

counting. The sample is all non-key workers who are in occupations where fewer than a third of workers are predicted to be able to work from home (pre-crisis).

7 What jobs will be available?

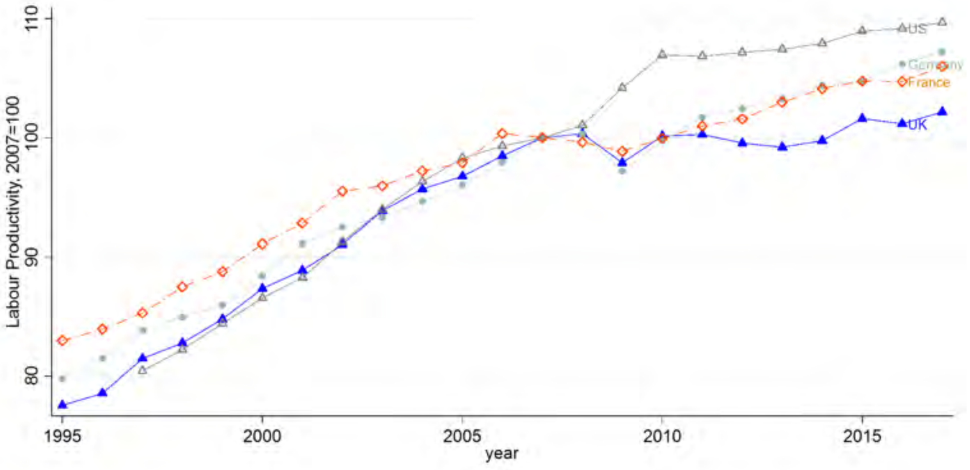
Many jobs will not be available again immediately, or perhaps ever. Demand for some goods and services, most notably hospitality, tourism and travel, will remain low for some time, and innovations to how work is organised may permanently reduce demand for certain occupations (while increasing demand for others). In the month starting on 25 March, job vacancies on the Department for Work and Pensions (DWP) Find a Job website fell by over 65% compared with the levels registered for the same period one year earlier.

Monitoring vacancies and how they match with the skill sets of the pool of furloughed or unemployed workers in each local labour market can help to inform policymakers on where skills are in short supply and on where it looks hard to find productive work for the unemployed without retraining or other measures. The effects of the crisis will be unequal across areas and difficult to precisely predict, making it likely that area-based policy will need to be responsive as information comes in (Overman, 2020) and that the quality of that information will be key. It is, of course, already obvious that some sectors are facing huge demands while others have been unable to operate. In order to provide essential services during the lockdown while keeping the economy ready for a smooth restart once restrictions are eased, policy will need to balance the need to reallocate employment to essential activities in the short term and maintaining workers' attachment to their previous employers in the longer term if that employer–employee match has a viable long-term future (Costa Dias et al., 2020): this is the balance between preserving the aggregate stock of firm-specific human capital, and avoiding long-lasting mismatch in the labour market which would take a long time to unwind (Fujita et al., 2020).That may be a difficult trick to pull off, but there are some obvious things that the government could do, such as prohibiting furloughing firms from inserting exclusivity clauses into their workers' contracts which prevent them from taking up other work while furloughed.

Given the amount of labour market disruption taking place, even with highly successful labour market policies it is likely that there will be areas where the unemployed find it difficult to find jobs appropriate to their skills, at least in the short term. In such cases, it could be a good time for the government to consider public investments that would employ these people in the interim to do productive work that will pay off later, such as improving national infrastructure. The opportunity cost of doing this will be unusually low, if it can indeed be well targeted at areas where private sector vacancies are not providing opportunities well matched to people's skill sets. Given the benefits from well-planned and coordinated public investments – rather than rushed ones – the government would be well advised to be on the front foot in thinking about any such measures now.

It is not just jobs that we want, but good jobs (see Acemoglu (2019)). Productivity concerns are important. As Figure 11 shows, the UK performed very poorly in terms of productivity growth coming out of the last recession, for a number of reasons. We were already in a challenging situation, and we want to avoid it getting even worse after this crisis.

Figure 11. Labour productivity before and after the financial crisis in the UK and other major economies



Source: Authors' calculations from EU KLEMS database.

The government will face a lot of lobbying by firms and industries. Ideally, it would like to promote work (and growth) in industries that will grow in future, and not use resources to protect declining industries. To some extent, the situation before the crisis tells us about the viability of certain industries. Some industries will not come back to where they were pre-crisis. High-street retail was already in decline (see, for example, the decline in retail employment depicted in figure 1 of Slaughter and Bell (2020)), while a shake-out of the airline industry had already looked likely – and demand for air travel may well be reduced for some time, perhaps even permanently.

Workers in different industries also differ in their potential contribution to the overall economy. Figure 12 shows the potential contribution of workers in different industries to UK gross value added (GVA) using a simple input–output model following Fadinger and Schymik (2020).[7] This measure reflects three factors: the value added of the industry, each industry's labour intensity, and the amount this industry supplies to other industries (and the amount these industries in turn supply to others, and so on).

We take input–output coefficients from ONS's input–output tables for 2015. It is very possible that input–output coefficients may have changed in response to the crisis. For example, restaurants that are still operating will likely make more use of delivery drivers. However, this gives us an illustrative indication of the relative importance of different sectors to gross value added – and an example of how to think about the issue.

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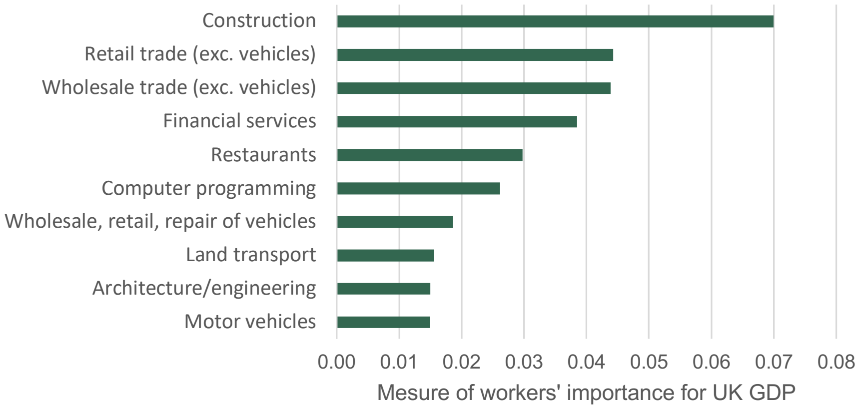
[7] Goods and services in each industry are produced by a representative firm using Cobb–Douglas technology, constant returns to scale and constant capital inputs. Given these assumptions, the effect on total UK GVA of increasing labour input in a given sector by 1% is $\beta(I-\Gamma')^{-1}\alpha_i$, where Γ is the input–output coefficient matrix with element γ_{ij} being the value of inputs from industry *i* used to produce a unit of output in industry *j*, β is a vector of value added shares in total UK GVA for different industries, and α_i is a vector with the labour share of industry *i* in row *i* and all other entries 0.

Figure 12 plots this measure for the top 10 private sector industries in terms of contribution to GVA. A given proportional increase in the number of workers in construction would have the largest impact on UK GVA, owing to the industry's large size, labour intensity and importance in supplying inputs to downstream industries. Other industries whose workforce is important are retail, wholesale, financial services, restaurants, computer programming and land transport.

Figure 12. Effect on UK GVA of increasing the labour force in that industry by 1% for the 10 private sector industries with the largest impacts



Source: Authors' calculations using 2015 ONS input–output analytical tables following Fadinger and Schymik (2020).

8 Conclusion

The government faces very difficult trade-offs in deciding when and how to ease lockdown restrictions to get people back into work. There is large uncertainty and limited knowledge about how things will evolve. We have discussed some key economic issues. Most notably, the government can help to reduce uncertainty by providing clear statements about policy in those areas where it can be confident of the broad direction of its impact and by providing insurance where possible. Enormous change and innovation is required by firms and workers, and certainty will help create the incentives to invest in that change. There are numerous market failures related to externalities, co-ordination and information. Policy can help to address these and we have discussed many specific kinds of policy instruments that could be well suited to doing so. Better data and the advice of the social science community on how these instruments can best be targeted, designed and implemented will help to make better policy.

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If the objective is herd immunity, on whom should it be built?[1]

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Assuming that there is no other solution than herd immunity in front of the current pandemic, on which categories of citizens should we build this herd immunity? Given the fact that young people face a mortality rate which is at least a thousand times smaller than people aged 70 years and more, there is a simple rational to build it on these younger generations. The transfer of some mortality risk to younger people raises difficult ethical issues. However, none of the familiar moral or operational guidelines (equality of rights, VSL, QALY, ...) that have been used in the Western world over the last century weights the value of young lives 1000 times or more than the lives of the elders. This suggests that Society could offer covid protection to the elders by confining them as long as this herd immunity has not been attained by the younger generations. This would be a potent demonstration of intergenerational solidarity towards the most vulnerable people in our community. The welfare gain of this age-specific deconfinement strategy is huge, as it can reduce the global death toll by more than 80%.

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1 Introduction

How should we win the war against the covid pandemic? In the absence of a treatment or a vaccine, there exists only two options. The first option is a long confinement of a large fraction of the population that would maintain the reproduction number R below unity for a very long period of time to obliterate the virus. The economic cost of this suppression strategy is now considered as unbearable in many countries. The other option is to progressively build the herd immunity by gradually exposing the population to the virus. Under this scenario, the containment is weakened to allow R to grow above 1, but not to far away from it to escape the risk of overwhelming hospitals. Whether this is obtained through fine tuning the intensity of the confinement in real time (Alvarez, Argente and Lippi, 2020) or through a stop-and-go policy remains to be decided.

In this paper, I suppose that herd immunity is the exit door from the pandemic. In the absence of a vaccine, attaining herd immunity requires to expose a fraction of the population to the virus, and to recognize that some people in this targeted population will die. Determining who should be exposed to the virus to attain the herd immunity is a crucial policy issue. Which criteria should be used to perform this task? Should we leave nature do its dismal work at random until the natural immunity be obtained, or should we protect some specific communities from this danger? Two issues, one on efficiency and the other on ethics, are at stake here. Consider first the now well-documented fact that some categories of people are more likely than others to die if exposed to the virus. Some individual characteristics such as the age or the existence of co-morbidity have been shown to have a huge influence on the lethality of the SARS-Cov-2. For example, Ferguson et al. (2020) report that the covid infection-fatality ratio is 0.002% for individuals less than 10 years old, and 9.3% for people aged 80 years and more. Given this 4650-fold difference in mortality risk, it may be desirable to expose less vulnerable people first in the hope of building the herd immunity before relaxing the protection of the more vulnerable people.

A few recent papers have supported a age-targeted deconfinement strategy. Acemoglu, Chernozhukov, Werning and Whinston (2020) characterize two intertemporally optimal exit strategies from lockdown, one in which the policy is constrained to be uniform across age classes, and the other in which different age classes can be treated in a discriminated way. They claim that 2.7 million lives could be saved in the United States by maintaining a stricter confinement for the seniors. Favero, Ichino and Rustichini (2020) compare different age-specific policies for Italy and come to the same conclusion of the

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overwhelming dominance of confining elderly people longer. Brotherhood, Kircher, Santos and Tertilt (2020) explore the impact of various confinement policies on the incentive of different age classes to behave efficiently.

Transferring some mortality risk across individuals raises complex moral issues. And discriminating the right to a safe life also raises constitutional concerns. The equality of rights, for example the equal right to the protection from a virus, is a dominant mode of Western ethical principles. The American Declaration of Independence holds the notion that ”all men are created equal” to be self-evident. The French Declaration of the Rights of Man and of the Citizen states that ”les hommes naissent et demeurent libres et égaux en droit”. And the WHO Constitution (1946) envisages ”the highest attainable standard of health as a fundamental right of every human being.” But in practice, the right to a safe life has always been vastly discriminated in the Free World. Some people are more exposed to deadly pollutants than others. The access to efficient health services is very heterogeneous across different localities within the same country. Rather than considering health protection as a basic human right, the practice of public decision-making has been to allow for tradeoffs between individual health and collective wealth. Standard guidelines for public benefit-cost analysis most often require to use a specific system of values to account for the impact of public policies on mortality risks. This value system has routinely discriminated against specific individual characteristics such as age and morbidity. Thus, transferring some mortality risk to less vulnerable people may not be socially desirable if Society values the lives of these less vulnerable people more. This may be the case for example if vulnerability is positively correlated with age, because preserving the life of a young person is commonly considered as more valuable than preserving the life of an older person. In this paper, I use the existing statistics of covid mortality rates for different age classes to determine the optimal targeted deconfinement for the most common ethical attitudes towards the preservation of different lives.

I don’t have a solution to break this moral dilemma in the general context. My aim in this paper is to quantify the consequences of different social norms used in the current context, as measured by the number of people who are expected to die, or by the number of life years lost. It is sad that democracies have rarely organized a public debate about how tradeoffs between health and wealth should be made at the collective level. The absence of democratic legitimacy attached to the competing value systems to perform this task creates a vacuum for decision-makers. The good news from my analysis is that all familiar value systems lead to the same conclusion in

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the context of the covid pandemic.

2 The model

The population is composed of I individuals. Individual $i \in \{1, ..., I\}$ has a probability p_i of dying conditional to being infected. Society associates a value v_i to changes in the survival probability of that individual.[1] Let x_i take value 1 if individual i is exposed to the virus and 0 if that individual is preserved from this exposure. Let π denote the proportion of the population that must be exposed to the virus. I characterize the strategy $X = \{x_1, ..., x_I\}$ that minimizes the aggregate value of lives lost under the constraint of attaining the proportion π of exposure to the virus:[2]

$$\min_{\{x_1,...,x_I\}\in\{0,1\}^I} \quad \sum_{i=1}^{I} x_i p_i v_i \quad \text{s.t.} \quad \sum_{i=1}^{I} x_i \geq \pi I. \tag{1}$$

Let me reinterpret this program in the context of the current covid pandemic. A first group of individuals is selected to be deconfined with the smallest restrictions in terms of social distancing in order to preserve the capacity of ICUs in the country. Let this subpopulation create their own herd immunity. The proportion of immunized individuals in this subpopulation is large because of the importance of social interactions in this first period. During this period, the second group of individuals is protected from physical contacts with the first group. Once the herd immunity is obtained in the first group, the second group is deconfined and some light social distancing rules are established to make sure that the proportion of immunized people in the whole population is larger than the new herd immunity proportion given these light restrictions.[3] An illustration of this dynamic policy is described by Favero, Ichino and Rustichini (2020) and Gollier (2020) for example. This dynamics may be complex, and this complexity may hide the crucial moral and economic issues behind the recommendations that can be extracted from its type of analysis. The bottom line of any individual characteristic-specific deconfinement strategy is that some classes of

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[1] In the different policies that I consider, the changes in mortality risk faced by different age classes remain moderate, so that v_i can be interpreted as the Value of Statistical Life (VSL), a concept that values marginal changes in the probability to die.

[2] In other words, I adopt a cost-efficiency approach. Contrary to the cost-benefit approach, I don't arbitrage here between health and wealth.

[3] Pindyck (2020) characterizes the relationship between the herd immunity proportion and the social distancing proportion.

Age class	Population size	Infection fatality proportion (p_i)
0-19	16,084,743	0.001%
20-29	7,470,908	0.007%
30-39	8,288,257	0.02%
40-49	8,584,449	0.05%
50-59	8,785,106	0.2%
60-69	7,999,606	0.8%
70-79	5,693,660	2.2%
80+	4,156,974	8.3%

Table 1: Estimation of the IFP by age class in France. Source: Saltje et al. (2020) and INSEE.

individuals will contribute more than others to build the herd immunity. Program (1) describes in its simplest form the key issues behind the political choice of deconfinement. Remember that refusing any discrimination in the deconfinement strategy is a decision in itself.

The solution of program (1) is trivial. The decision-maker must select a threshold λ such that all individuals i with a score $p_i v_i$ smaller than λ are exposed and all the other are protected. The threshold λ is selected so that this decision rule leads to having a proportion π of the population being exposed.

In this paper, I focus on age-specific deconfinement strategies.[4] This is because age is a key individual characteristic that affects at the same time the lethality of the virus and the societal value of lives saved. In the case of France, Salje et al. (2020) from Institut Pasteur have estimated the Infection Fatality Proportion (IFP) by age, using French data available in mid April. This estimation of the p_i is documented in Table 1. In France, 80% of the covid dead toll targeted individuals aged 66 years or older. Ferguson et al. (2020) documents age-differences of the IFP estimations exhibiting the same order of magnitude, using international data available in mid March.

I also assume that the post-pandemic herd immunity proportion is $\pi = 80\%$. In reality, this proportion remains uncertain, and is sensitive to the intensity of social interactions.

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[4] Other risk factors such as obesity, diabetes and gender also matter. I prefer to focus on age, as it is probably less controversial. See my discussion in Section 4.

3 Efficient age-specific deconfinement strategies

3.1 Equality

In most countries, the evolution of the pandemic is measured by the cumulated number of individuals who died from the virus. This is how politicians, the media and the citizens follows the evolution of the pandemic. This suggests a normative approach in which mortality risk is valued independent of the age of the victims: $v_i = 1$ for all $i \in \{1, ..., I\}$. It translates the ethical/constitutional concept of the equality into a value system.

Many life-saving regulations affect mortality risks across a wide population and result in a small change in risk at the individual level. Public administrations routinely evaluate the net social benefit of these policies. In France, the Quinet Report (Quinet, 2013) argues in favor of valuing changes in mortality risk independent of age to evaluate public policies and investments. In the United States, the Office of Management and Budget and the Environmental Protection Agency (EPA) have been recommending and using an age-independent life valuation approach over many decades (US-EPA, 2010): "The committee concluded that the existing economics literature does not provide clear theoretical or empirical support for using different values for mortality risk reductions for differently-aged adults". As explained by Robinson (2007) and Viscusi (2009), this decision has been very controversial. In 2008, the EPA produced a report evaluating the Clear Skies initiative, it used a constant value of statistical life, but it also examined an alternative measure of the policy containing a 37% discount VSL for people aged over 65. Elderly citizen groups launched a series of public protests against what has come to be known as the "senior discount" or the "senior death discount". Since then, the EPA has abandoned the age-adjustment of the VSL.

When comparing different exit strategies of the current pandemic, Favero, Ichino and Rustichini (2020) also value lives lost without differentiating victims by age. Notice that I do not monetize lives in this paper. Choosing a $v_i = v$ of 3 million or 10 million euros is irrelevant for the analysis.

Using Table 1, the equality score $p_i v_i = p_i v$ is increasing with age. Under this familiar ethical norm, the efficient strategy consists in determining a age threshold A such as all individuals aged less than A are deconfined, whereas all those aged more than A remain confined until herd immunity is obtained. Because 20% of the population is older than 65 years, this means that the deconfinement should be limited to people less than 65 years old.

3.2 Quality-adjusted life expectancy

A more recent tradition in health economics is to value each year of life lost adjusted for its health quality. It combines individual information on mortality and morbidity. As one grows older, life expectation goes down and morbidity goes up, implying a decreasing relationship between the Quality-Adjusted Life Expectation (QALE) and age in the population. It is an aggregate version of the quality-adjusted life year (QALY). This relation between QALE and age has been measured by Love-Koh et al. (2015) for the United Kingdom, and is documented in Table 2.

Suppose that the social planner considers that QALE is the morally acceptable way to value lives lost in the face of the covid crisis, i.e., $v_i = QALE_i$ for all age classes i. Under this assumption, the social planner will for example value the life of a 20-29 years old person 4.5 times more than the life of a 70-79 years old person. Compared to the equality-of-rights criterion, the QALE criterion puts more weight to the survival of young people. It has thus the potential to reverse the recommendation to expose young people first. This would be the case if the growth rate of the mortality rate with age is smaller than the reduction rate of QALE with age. As shown in the last column of Table 2, this is not the case since the QALE score is an increasing function of age. The QALE and equality criteria generate the same recommendation to limit the exposure people younger than 65 years old to the virus.

Because the quality-adjustment contained in the QALE measures favors younger people, there is no doubt that a non-quality-adjusted life expectancy criterion, such as the Value of statistical Life Year (VSLY), will generate the same recommendation to deconfine younger generations first.

3.3 Revealed preference

Economists have long pursued the goal of measuring how people value their own mortality risk. This has been made possible by the development of the concept of the Value of Statistical Life (VSL), by Drèze (1962), Schelling (1968) and Jones-Lee (1974). A large literature has been built over the last half century to measure how mortality differentials affects wages and real estate prices for example. Some RP studies estimate willingness to pay from market prices for products (such as airbags) that reduce the likelihood of a fatal injury. This yields estimates of the Revealed Preference (RP) valuation of statistical lives. A subset of these studies has documented the fact that these estimates are sensitive to the age of the person facing the mortality

Age class	QALE value (v_i)	QALE score ($p_i v_i$)
0-19	63.0	0.1
20-29	49.5	0.3
30-39	40.6	0.8
40-49	32.1	1.6
50-59	24.2	4.8
60-69	17.0	13.6
70-79	11.0	24.2
80+	5.8	47.8

Table 2: Quality-adjusted life expectation and QALE score by age class. Source: Love-Koh et al. (2015), and own computation.

risk. The law of one price suggests that the social planner should use the same system of values as the one used by the citizens to perform policy evaluations. Murphy and Topel (2006) have calibrated an age-dependent VSL function by using revealed preference studies to evaluate the social benefit of improved life expectancies over the last century. Greenstone and Nigam (2020) have used the age-specific life values of Murphy and Topel to estimate the net benefit of the confinement strategy in the face of the current pandemic. I report these RP values by age class in Table 3. The value weight of the RP approach has an inverted-U shape, where the value of life first slightly increases with age, peaks in the twenties, and then declines.[5]

As in the QALE approach, the reduction of the value $v_i = RP_i$ with age i is too small to compensate for the large growth rate of the mortality risk, so that the RP score $p_i RP_i$ is increasing with age. Here again, the efficient strategies is to expose people aged less than 65 years old.

3.4 Stated preference

In the context of mortality risk, the stated preference (SP) approach involves asking members of a representative sample of the population at risk about their WTP for a small hypothetical improvement in their survival probability. In some studies, they are asked to take the role of the social planner in

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[5] Shepard and Zeckhauser (1984) also estimates an inverted-U shaped age-sensitive VSL by using a life-cycle income and consumption model with a mortality risk. Their VSL starts at 500,000 at age 20 to peak at 1,250,000 at age 40, and declines to 630,000 at age 60, in USD of 1978. Under this valuation system, protecting the seniors is optimal too.

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Age class	RP value (v_i)	RP score ($p_i v_i$)
0-19	15.0	0.01
20-29	16.1	0.11
30-39	15.8	0.32
40-49	13.8	0.69
50-59	10.3	2.06
60-69	6.7	5.36
70-79	3.7	8.14
80+	1.5	12.45

Table 3: Revealed preference life valuation and RP score by age class. Source: Greenstone and Nigam (2020), and own computation.

determining the best choice in a set of options involving different number of individuals of different ages facing an increased mortality risk. In the covid context, Landier et al. (2020) confront respondents to two possible allocations of ventilators, one for retirement homes in which 50,000 lives for patients aged 70 years and older will be saved, and the other in hospitals in which 30,000 lives for patients aged 30 years and older will be saved. Twenty-eight percents of the respondents expressed a preference for saving the larger number of patients in retirement homes. Carlsson, Daruvala and Jaldell (2010) provide more information about the differential valuation of life of different ages. In the context of car or fire casualties, they found that avoiding the fatality of one 5-15-year-old person is equivalent to avoiding 1.4 fatalities of 35-45-year-old person, and to avoiding 3.3 fatalities of 65-75-year-old person. A linear interpolation of this SP valuation system is represented in Table 4.

Because the SP-score is increasing with age, the stated preference criterion is also compatible with prioritizing the protection to the elders in spite of their relatively lower stated value.

4 Discussion

The preliminary conclusion from the previous section is that whatever the familiar moral principles to be used to perform the policy analysis, it is optimal to protect the older generation from the exposure to the virus. This is because the growth of the morality risk with age is so large that there exists no reasonable valuation weights by age class that can reverse the

Age class	SP value (v_i)	SP score ($p_i v_i$)
0-19	1	0.001
20-29	0.857	0.006
30-39	0.762	0.015
40-49	0.646	0.032
50-59	0.509	0.102
60-69	0.372	0.298
70-79	0.234	0.515
80+	0.097	0.805

Table 4: Stated preference life valuation and SP score by age class. Source: Carlsson, Daruvala and Jaldell (2010), and own computation.

intuition that the most vulnerable people must be protected. Their lower life expectancy does not justify a choice reversal. In spite of this evidence, most countries are contemplating a deconfinement strategy which is not discriminated by age. It is thus useful to compare this observed policy with the optimal strategy. I illustrate this for the case of France.

Suppose that herd immunity can be obtained with an immunity rate of 80%. The observed policy of a non-discriminated deconfinement implies that all age classes will face a 80% rate of infection, implying in turn a death count corresponding to their age-specific mortality rate.[6] This is documented in the second column of Table 5 and by the dashed curve in Figure 4. On the contrary, given the demographic characteristics of France, the optimal strategy consists in deconfining all people aged 65 and younger (in fact 100% of the 0-59 age class, and 55.47% of the 60-69 age class). Remember that I assume that there is an acceptable confinement technology that fully preserves from the virus, so that I assume no death among the elders. In reality, the confinement will be imperfect, but I don't take account of this imperfection in my analysis. I also document fatalities by age class under the optimal policy inn Table 5 and in Figure 4.

Attaining the herd immunity under total deconfinement will impose 446,792 deaths, mostly for people older than 60 years. This must be compared to the death of 59,704 persons under the optimal age-specific deconfinement strategy. The optimal policy would thus save 387,088 lives. Almost

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[6] In reality, the social interaction matrix is not uniform, and old people have less interaction with others. This implies that their susceptibility ratio will asymptotically converge to a larger ratio than for younger generations. I don't take account of this dynamic effect in this analysis.

Age class	deaths in total deconfinement	deaths in optimal deconfinement	Δ deaths	QALE lost (in years)
0-19	129	161	32	2,026
20-29	418	523	105	5,147
30-39	1,326	1,658	332	13,445
40-49	3,434	4,292	858	27,542
50-59	14,056	17,570	3,514	85,115
60-69	51,197	35,500	-15,697	-266,511
70-79	100,208	0	-100,208	-1,103,033
80+	276,023	0	-276,023	-1,590,290
Total	446,792	59,704	-387,088	-2,826,533

Table 5: Estimated death toll and loss in quality-adjusted life expectation by age class for the total and optimal deconfinement.

3 million quality-adjusted life years would be saved under the optimal policy. In this study, I discriminate the deconfinement strategy only based on age. But we know now that comorbidities have a large impact on the mortality rate too. For example, in New York state, just over 86% of the 5,489 reported COVID-19 deaths before 6 April 2020 involved at least one comorbidity, according to the state's department of health.[7] Adding some of these comorbidities such as diabetes (37.3% of the New York deaths) and obesity in the individual characteristics of the discriminated deconfinement strategy could considerably reduce the death toll of this strategy, compared to what is described in Figure 5.

The ethical issue is that the benefit of the optimal policy implies a transfer of the mortality risk from the elders to the younger generations. For example, 32 more individuals below the age of 20 years will die in France under the optimal policy compared to the non-discriminated policy, but the optimal policy will save 276,023 people aged 80 or more. But because the utility loss from dying is larger for the young than for the old, the utilitarian norm (Adler, 2019) favors this transfer only if this valuation difference is not too large. A prioritarian norm gives even greater weight to individuals with lower lifetime utility, but for reasonable parameter values explored by Adler, Ferranna, Hammitt, and Treich (2019), it is unlikely to reverse the policy recommendation. One position that could oppose the policy recom-

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[7] https://www.the-hospitalist.org/hospitalist/article/220457/coronavirus-updates/comorbidities-rule-new-yorks-covid-19-deaths

mendation is the ”fair innings” argument introduced by Harris (1985, p. 91) : ”The fair innings argument requires that everyone be given an equal chance to have a fair innings, to reach the appropriate threshold but, having reached it, they have received their entitlement. The rest of their life is the sort of bonus which may be canceled when this is necessary to help others reach the threshold.” Taken literally, this argument, like the Rawlsian maxmin criterion, implies a lexicographic priority for the young by rejecting any transfer of mortality risk from old (who have reached their fair innings) to young.

Does the discriminated deconfinement strategy require a restriction of freedom? This pandemic entails an obvious externality issue, since the risky behavior of some people affects the risk borne by others. Implementing a pigouvian tax solution is not an operationally viable option. At the individual level, exiting the confinement has a cost and a benefit. The cost is the increased mortality risk. The benefit is psychological, social and financial. For the senior who should stay confined under the socially optimal strategy, I believe that it would be individually rational for them to remain confined. The deconfinement of the younger generations will generate a new wave of infection – this is indeed the objective – that will transform the country into a highly lethal environment for the seniors, for a period of 2 or 3 months. If a person aged 80 exits confinement, her probability of being infected would equal 80%, with a mortality rate of 8.3%. If her own VSL is 1 million euros, her own valuation of this increased mortality risk is 66,400 euros. I believe that her willingness to pay to eliminate the social and psychological stress of the 3-month confinement is much smaller than that, thereby supporting the rationality of the self-confinement of senior people. However, limited rationality may be a problem here, in particular if it implies a surge in demand for respirators. This could be countered by alleviating the burden of the confinement. On-line networking could be boosted in retirement home, together with ”happy hours” in shops. Free access could be offered to virus-free spaces in theaters and concert halls, and in nice (currently empty) hotels along our beaches for example. Some testing capacity could also be targeted to visitors in retirement homes that are most closely related to their senior guests.

What about the mortality risk borne by the younger generations? As I write this paper, the impatience of a vast majority of the younger generations is strong to exit from the containment. The risk that they will bear in the period of herd immunity building can be borne on a voluntary basis.[8] This

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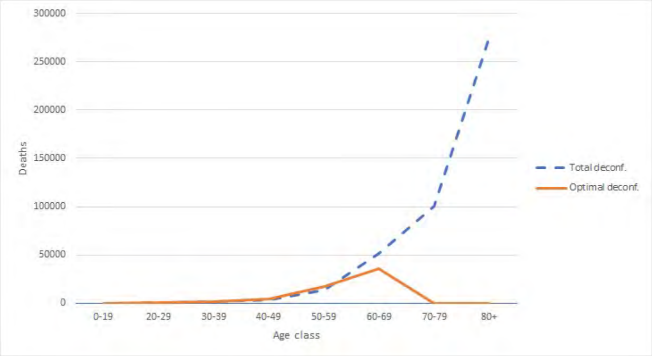
[8] Let’s for example consider a 30-year old person. Her covid mortality risk is 80% of



limits the ethical issue of the proposed transfer of mortality risk. Moreover, the additional mortality risk for the young is quite limited compared to other health risks faced by this age class. For example, the proposed age-specific deconfinement strategy examined in this paper generates 32 more covid victims aged 20 or less. This should be compared to 500+ (562 in 2017) young people who die in car accidents every year in France.

Then, why do most States refuse to consider a discriminated deconfinement strategy? People are often reluctant to play an active role in decisions involving important moral issues. Moral psychologists have long been studying when do people find it acceptable to sacrifice one life to save other lives. Awad et al. (2020) have revisited the well-known "trolley problem" in which one must rank two scenarios. In the "switch scenario", a trolley is about to kill five workers, but can be redirected to a different track, in which case it will kill one worker. In the "footbridge scenario", a man can be pushed in front of the trolley. This man will die, but his body will stop the trolley before it can kill the five workers on the track. In this second scenario, the decision-maker must take a more active and visible role in the death of the victim by pushing him on the trolley track. In all cultures, this footbridge scenario is considered as much less acceptable, probably for that reason. Landier, Sastry, Sraer and Thesmar (2020) make a similar observation in the context of the current pandemic. When confronting survey respondents to the question of whether to offer a single ICU to one of two

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0.02%. Using a VSL of 3 million euros, her covid mortality cost is estimated at 480 euros, which is likely to be much smaller than the social, psychological and financial benefit of her deconfinement.

sick persons, one with a larger chance of survival than the other, 37% of the respondents prefer the rule consisting in allocating the ICU by using the first-in-first-served rule. When exposing one age group of the population to build the herd immunity in order to protect another age group, this decision reallocates the mortality risk across individuals in a similar fashion than in the ICU story. The reluctance to take active decisions aiming at reallocating mortality risk across different classes of citizens is an important bias in collective decision making that one should address during this pandemic.[9] It goes against the standard public decision-making rules used in normal times in most western countries for at least 50 years. This bias may have catastrophic consequences in the final death toll, as shown in Table 5.

5 Conclusion

Most governments are implementing a Plan A of deconfinement aimed at obliterating the coronavirus. This requires maintaining the reproduction number R low enough for a relatively long period of time. The economic cost of this suppression strategy may be large, and its success probability may be far from unity. In the absence of treatment or vaccine, there exists only one possible Plan B, herd immunity. The problem of Plan B is the unbearable life cost of the non-discriminated deconfinement strategy typically considered to attain herd immunity. Under the assumptions of a 1% mortality rate and of a herd immunity with an asymptotic 80% rate of immunity, one should expect that 0.8% of the population will succumb.

However, this problem has a solution. It consists in building the herd immunity with the categories of the population which are the least likely to die if infected. Given the huge differences in mortality rates across age classes, this herd immunity should be built by deconfining the younger generations first. This strategy implies an increased mortality risk for these less vulnerable people, which is ethically questionable. However, because transferring the exposure from the old to the young reduces the death probability by a factor 1000, moral concerns could reverse this recommendation only if Society values one young life more than a thousand lives of people aged 65 years or more. This would go against several decades of policy evaluation practice in which all lives are equally valued, or in which years of life lost are counted. It also goes against observed individual preferences related to

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[9] In decision theory, there exists an argument for people having a preference for reducing the choice set based on regret aversion. Having no choice eliminates the risk of regret. See for example Sarver (2008) and Gollier (2018).

mortality risk, either revealed or stated.

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Covid Economics **Issue 16, 11 May 2020**

Nash SIR: An economic-epidemiological model of strategic behaviour during a viral epidemic[1]

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This paper develops a Nash-equilibrium extension of the classic SIR model of infectious-disease epidemiology (``Nash SIR"), endogenizing people's decisions whether to engage in economic activity during a viral epidemic and allowing for complementarity in social-economic activity. An equilibrium epidemic is one in which Nash equilibrium behavior during the epidemic generates the epidemic. There may be multiple equilibrium epidemics, in which case the epidemic trajectory can be shaped through the coordination of expectations, in addition to other sorts of interventions such as stay-at-home orders and accelerated vaccine development. An algorithm is provided to compute all equilibrium epidemics.

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[1] I thank Carl Bergstrom, Yonatan Grad, and Marc Lipsitch for encouragement and Sam Brown, Troy Day, Nick Papageorge, Elena Quercioli, Lones Smith, Yangbo Song, Marta Wosinska, and participants at the Johns Hopkins Pandemic Seminar in April 2020 for helpful comments.

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People's choices impact how a viral epidemic unfolds. As noted in a March 2020 *Lancet* commentary on measures to control the current coronavirus pandemic, "How individuals respond to advice on how best to prevent transmission will be as important as government actions, if not more important" (Anderson et al (2020)). Early on when pre-emptive measures could be especially effective (Dalton, Corbett, and Katelaris (2020)), people are at little personal risk of exposure and hence may be unwilling to follow orders to "distance" themselves from others. On the other hand, as infections mount and the health-care system is overwhelmed, people may then voluntarily take extreme measures to limit their exposure to the virus. Clearly, the way in which people's incentives change during the course of an epidemic is essential to how the epidemic itself progresses, and how widespread are its harms.

This paper develops a Nash equilibrium extension of the classic Susceptible-Infected-Recovered (SIR) model of viral epidemiology. "Nash SIR" augments the well-known system of differential equations that characterizes epidemiological dynamics in the SIR model with a system of Bellman equations characterizing the dynamics of agent welfare and a Nash-equilibrium condition characterizing the dynamics of agent behavior. What emerges is a model of *equilibrium epidemics* that, while highly stylized, sheds light on the interplay between epidemiological dynamics, economic behavior, and the health and economic harm done during the course of a viral epidemic.

The paper's most important modeling innovation is to account for the *economic complementarities* of personal interaction that can be lost when agents "distance" themselves to slow viral transmission. Such complementarities are missing from the existing literature (discussed below), but can impact the progression of an epidemic in meaningful ways. In particular, a *positive feedback* can arise in which people complying with public-health directives induces others to do so as well, and vice versa. As non-essential businesses close, there is less that people are able to do outside the home, reducing their incentive to go out. Similarly, as co-workers in an office (or professors in a university) stay home, there is less reason to go to the office yourself, especially when the work involved is collaborative and can be managed remotely.[1]

Developed independently, this paper's Nash-equilibrium SIR ("Nash SIR") model generalizes the Nash SIR model in Farboodi et al. (2020), by allowing for complementarities in social-economic activity.

In the traditional SIR model, the trajectory of the epidemic is completely determined by epidemiological fundamentals. Similarly, in Farboodi et al. (2020)'s Nash SIR model, the

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[1] The opposite is true of essential work. The more that essential workers are absent, the more valuable the work done by those who remain. More generally, there may be congestion effects associated with social-economic activity, increasing the benefit one gets as others reduce their activity. This paper abstracts from congestion for ease of exposition.

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epidemic has a unique equilibrium trajectory. By contrast, in this paper's Nash SIR model, there may be multiple potential trajectories for the epidemic, each of which induces agents to behave in a way that generates that epidemic trajectory. Because of this indeterminancy, the ultimate harm done during an epidemic, in terms of lost lives and lost livelihoods, can hinge on what agents believe about what others believe. This paper's model therefore highlights the importance of coordinating mechanisms, such as effective political leadership, in shaping expectations during an epidemic.

In addition to *coordinating interventions* such as a political leader's public statements, *fundamental interventions* such as public policies, public-health programs, scientific effort, and new cultural practices impact the set of equilibrium-epidemic possibilities. Such impacts can be explored using the Nash SIR model, by computing the set of equilibrium epidemics with and without the intervention in question. To enable such exploration, I provide an algorithm to compute all equilibrium epidemics in any instance of the model. This algorithm requires solving a set of problems, each of which corresponds to a different potential "final condition" and involves solving a system of first-order differential equations that augments the traditional SIR equations.

Relation to the literature. This paper follows the dominant tradition within economics of modeling disease hosts as dynamically-optimizing agents with correct forward-looking beliefs. A few notable examples include Geoffard and Philipson (1996), Kremer (1996), Adda (2007), Chan et al. (2016), and Greenwood et al. (2019). More recently, there has been an outpouring of important work motivated by the SARS-CoV2 outbreak, much of it embedding economic models into an SIR (or closely related) framework. Some notable examples include Alvarez et al. (2020), Bethune and Korinek (2020), Eichenbaum et al. (2020), Garibaldi et al. (2020), Glover et al. (2020), Jones et al. (2020), Keppo et al. (2020), Krueger et al. (2020), and Toxvaerd (2020).

There is also of course an enormous literature within epidemiology that models behavioral response to infectious disease. However, epidemiologists have been slow to adopt economics-style modeling, usually instead making ad hoc assumptions about behavior. For instance, Bootsma and Ferguson (2007) assume that people's intensity of social-contact avoidance during the 1918 flu pandemic varied depending on how many others in their community had recently died. An example that grapples with the dynamics of social distancing in the current pandemic is Kissler et al. (2020).

Thanks to the recent explosion of interest in economic epidemiology among economists, the gap between economics and infectious-disease epidemiology is closing. Farboodi et al. (2020) provide an elegant Nash-equilibrium extension of the SIR model that augments the

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usual system of differential equations that governs epidemiological dynamics with just two additional differential equations. Toxvaerd (2020) beautifully analyzes a similar equilibrium SIR model, establishing compelling features of the equilibrium trajectory. Because of their analytical simplicity and tight connection to existing models and methods within epidemiology, Farboodi et al. (2020), Toxvaerd (2020), and others in this fast-growing literature could potentially have enormous influence on infectious-disease epidemiology, marrying the fields and promoting further cross-fertilization of ideas.

Yet there is also a danger here. This new crop of equilibrium SIR models make an implicit assumption that the benefit people get from social-economic activity does not depend on others' activity. Consequently, the "activity game" that people play necessarily exhibits negative externalities (activity increases others' risk of infection) and strategic substitutes (increased risk of infection prompts others to be less active, Bulow et al. (1985)). As a profession, we have strong insights about such games, insights that can be easily and powerfully communicated. These models could therefore be highly influential in terms of shaping public policy. However, the insights that we get from these models could be misguided if, in fact, the activity game exhibits positive externalities and/or strategic complements. This is especially important because, as I discuss in the concluding remarks, the qualitative nature of the game does indeed change during the course of the epidemic.

The rest of the paper is organized as follows. Section 1 presents the economic-epidemiological model, along with preliminary analysis. Section 2 analyzes equilibrium epidemics in more detail. Section 3 discusses some limitations of the model and directions for future research.

1 Model and Preliminary Analysis

This section presents the economic-epidemiological model, divided for clarity into three parts: *the epidemic*, on how the epidemic process depends on agents' behavior (Section 1.1); *the economy,* on how the epidemic impacts economic activity, both directly by making people sick and indirectly by changing behavior (Section 1.2); and *individual and collective behavior,* on how the state of the epidemic and expectations about economic activity impact Nash-equilibrium behavior at each point along the epidemic trajectory (Section 1.3).

1.1 The epidemic

There is a unit-mass population of hosts, referred to as "agents." Building on the classic Susceptible-Infected-Recovered (SIR) model of viral epidemiology, each host is at each time $t \geq 0$ in one of five epidemiological states: "susceptible" (S) if as-yet-unexposed to the virus;

"carriage/contagious" (C) if asymptomatically infected; "infected/sick" (I) if symptomatically infected; "recovered from carriage" (R_C) if immune but never sick; and "recovered from sickness" (R_I) if immune and previously sick.[2]

Epidemiological distance. At each point in time t, each agent who is not sick decides how intensively to distance themselves from others. Distancing with intensity $d_i \in [0, 1]$ causes an agent to avoid fraction αd_i of "meetings" with other agents, where $\alpha \in (0, 1]$ is a parameter capturing the maximal effectiveness of distancing. Agents who are sick are assumed to be automatically isolated, as if distancing with $\alpha = 1$. (The analysis extends easily to a more general context in which sick agents also transmit the virus.)

Let $\Omega \equiv \{S, C, R_C, R_I\}$ denote the set of not-sick epidemiological states. For each $\omega \in \Omega$, let $d_\omega(t)$ denote the average distancing intensity of those currently in state ω at time t who choose to distance themselves. Let $\mathbf{d}_t \equiv (d_\omega(t') : \omega \in \Omega, 0 \leq t' < t)$ denote the *collective distancing behavior* of the agent population up to time t, and let $\mathbf{d} \equiv (d_\omega(t) : \omega \in \Omega, t \geq 0)$ be their collective distancing behavior over the entire epidemic.

Epidemiological dynamics. The following notation is used to describe the state of the epidemic at each time $t \geq 0$, depending on agents' distancing behavior:

$S(t; \mathbf{d}_t)$ = mass of agents who are susceptible;

$C(t; \mathbf{d}_t)$ = mass of agents who are in carriage, i.e., asymptotically infected but not sick;

$I(t; \mathbf{d}_t)$ = mass of agents who are sick;

$R_C(; \mathbf{d}_t)$ = mass of agents who are immune and were not previously sick; and

$R_I(t; \mathbf{d}_t)$ = mass of agents who are immune and were previously sick.

Because the population has unit mass, $\sum_{\omega \in \Omega} \omega(t) = 1$ for all t.

Agents transition between epidemiological states as follows:

$S \to C$: Susceptible agents become asymptomatically infected once "exposed" to someone currently infected, at a rate that depends on agents' behavior (details below);

$C \to I$: Each agent with asymptomatic infection becomes sick at rate $\sigma > 0$; and

$C \to R_C$ and $I \to R_I$: Each agent with infection clears their infection at rate $\gamma > 0$.

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[2] It remains unknown whether those who recover from SARS-CoV2 infection are immune to re-infection and, if so, for how long (Lipsitch (2020)).

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Initially at time $t = 0$, mass $\Delta > 0$ have asymptomatic infection but no one is yet sick and no one is yet immune;[3] that is, $S(0) = 1 - \Delta$, $C(0) = \Delta$, and $I(0) = R_C(0) = R_I(0) = 0$. Epidemiological dynamics at times $t > 0$ are then uniquely determined by the following system of differential equations:

$$S'(t; \mathbf{d}_t) = -\beta(1 - \alpha d_S(t))(1 - \alpha d_C(t))S(t; \mathbf{d}_t)C(t; \mathbf{d}_t) \tag{1}$$

$$C'(t; \mathbf{d}_t) = -S'(t; \mathbf{d}_t) - (\sigma + \gamma)C(t; \mathbf{d}_t) \tag{2}$$

$$I'(t; \mathbf{d}_t) = \sigma C(t; \mathbf{d}_t) - \gamma I(t; \mathbf{d}_t) \tag{3}$$

$$R'_C(t; \mathbf{d}_t) = \gamma C(t; \mathbf{d}_t) \tag{4}$$

$$R'_I(t; \mathbf{d}_t) = \gamma I(t; \mathbf{d}_t) \tag{5}$$

Let $\mathcal{E}(t; \mathbf{d}_t) \equiv (S(t; \mathbf{d}_t), C(t; \mathbf{d}_t), I(t; \mathbf{d}_t), R_C(t; \mathbf{d}_t), R_I(t; \mathbf{d}_t))$ denote the "epidemic state" at time t and $\mathcal{E}(\mathbf{d}) \equiv (\mathcal{E}(t; \mathbf{d}_t) : t \geq 0)$ the "epidemic process."

Note on notation: I use "$\mathbf{d}_t$ notation" in equations (1-5) to emphasize how the epidemic state at time t depends on agents' previous distancing behavior. However, to ease exposition, I henceforth suppress this notation, except where needed for clarity.

Equations (2-5) are standard—reflecting agents' progression over time into carriage and then *either* to infection at rate σ *or* to viral clearance at rate γ, and from infection to clearance at rate γ—but equation (1) is different than in a standard SIR model.

Each susceptible agent i has a *potential* meeting (i.e., opportunity for transmission) with another randomly-selected agent j at "transmission rate" $\beta > 0$. Since fraction $S(t)$ of the population is susceptible and fraction $C(t)$ have unisolated infection, the flow of potential meetings between susceptible and infected agents across the entire population is $\beta S(t)C(t)$. However, because susceptible and contagious agents distance themselves with intensity $d_S(t)$ and $d_C(t)$, respectively, each such potential meeting is avoided with probability $(1 - \alpha d_S(t))(1 - \alpha d_C(t))$. The overall flow of newly-exposed hosts is therefore $\beta(1 - \alpha d_S(t))(1 - \alpha d_C(t))S(t)C(t)$, a functional form that appeared first in Quercioli and Smith (2006).

End of the epidemic. For analytical convenience, I assume that the epidemic ends at time $T > 0$ when a vaccine is introduced, giving all still-susceptible agents subsequent immunity. (Infected agents remain infected, but there are no new infections after time T.) I focus on

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[3] The model can be easily extended to allow for innate immunity, by allowing some mass of hosts to be in states R_I and R_C at time $t = 0$. For instance, during the "second wave" of SARS-CoV2 infections expected to arrive in Fall 2020, some hosts may retain immunity due to exposure during the first wave in Spring 2020.

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the case when $T < \infty$ and T is known to all agents, but the analysis can be easily extended to a setting in which T is a random variable drawn from interval support.

Information states and distancing strategies. Agents' distancing decisions depend on what they know about their own epidemiological state and the overall epidemic. This paper focuses on the simplest non-trivial case, assuming that (i) agents know when they are sick but otherwise observe nothing about their own epidemiological state and (ii) agents have correct beliefs about the epidemic process. The model can be extended in several natural directions, to include diagnostic testing (allowing agents to learn more about their own epidemiological state) and incorrect beliefs, but such extensions are left for future work.

Agent i's *information state* captures what she knows and believes, which depends only on (i) the time $t \geq 0$ and (ii) whether she is sick (state I), was previously sick (state R_I), or has not yet been sick (combined state $N \equiv S \cup C \cup R_C$).

An agent currently in information state $\iota \in \{N, I, R_I\}$ is referred to as a "ι-agent." Let $N(t) = S(t) + C(t) + R_C(t)$ denote the mass of N-agents; thus, $N(t) + I(t) + R_I(t) = 1$.

Agent i's *distancing strategy* specifies her likelihood of distancing herself at each time t in each information state. I-agents are automatically isolated, as mentioned earlier. R_I-agents know that they are immune and therefore have a dominant strategy not to distance themselves. It remains to determine the behavior of N-agents.

Let $d_N(t)$ denote the share of N-agents who distance themselves. Because susceptible and contagious agents are in the same not-yet-sick information state, $d_N(t) = d_S(t) = d_C(t)$ and equation (1) simplifies to:

$$S'(t) = -\beta(1 - \alpha d_N(t))^2 S(t)C(t) \tag{6}$$

Attack rate. Each agent's ex ante likelihood of becoming infected, referred to as the "attack rate" of the virus, is equal to $\lim_{t\to\infty}(R_C(t) + R_I(t))$. The attack rate is always strictly less than one, even if a vaccine is never discovered ($T = \infty$) and the epidemic is left completely uncontrolled; see Brauer et al. (2012) and Katriel and Stone (2012) for details.

1.2 The economy

Each agent's activities fall into three broad categories: *isolated activities* that can be performed while distancing (e.g., lifting weights, collaborating online), *public activities* that require entering public spaces but do not require interacting with others (e.g., going for a walk, getting gas), and *social activities* that require interacting physically with others (e.g., meeting friends, working in an office building). An agent who distances herself with intensity

d_i can continue engaging in isolated activity, but forgoes fraction αd_i of public and social activity and reduces others' opportunities to join her in social activity.

Availability for social interaction. A not-sick agent who does not distance enjoys all the benefits of public activity, but engages in social activity only with those who are "socially available." Let $A(t)$ denote agents' *availability* for social interaction at time t, averaged across the entire population:

$$A(t) = (1 - \alpha d_N(t))N(t) + R_I(t) = 1 - I(t) - \alpha d_N(t)N(t). \tag{7}$$

(Recall that I-agents are completely unavailable due to sickness, while R_I-agents find it optimal not to distance themselves at all.)

Economic output. Economic activity generates *benefits*, a broad concept that should be understood to include everything from income (work activity) and access to goods and services (shopping) to psycho-social well-being (from interactions with friends). Sick agents are assumed for simplicity to be incapacitated and hence unable to engage in any economic activity; their economic benefit is normalized to zero. The benefit that well agents get depends on their own and others' distancing decisions, as well as how many people are currently sick.

Let $b(d_i; A)$ denote the flow benefit that agent i gets when well and choosing distance $d_i \in \{0, 1\}$, given population-wide average availability $0 \leq A \leq 1$. For concreteness, I assume that

$$b(d_i; A) = a_0 + a_1(1 - \alpha d_i) + a_2(1 - \alpha d_i)A. \tag{8}$$

Discussion: meaning of the economic parameters. The parameters $a_0, a_1, a_2 > 0$ capture the importance, respectively, of isolated activities, public activities, and social activities for agent welfare. More precisely: a_0 captures the baseline level of benefits that a well agent gets while quarantined in the home; a_1 captures the extra benefits associated with being able to leave the home, e.g., the extra pleasure and health benefit of walking outside, the extra convenience of shopping in person rather than online; and a_2 captures the extra benefits associated with sharing the same physical space with others, e.g., eating out at a restaurant rather than at home, hugging a friend rather than just talking on the phone. (Put differently: a_2 is the cost associated with everyone else being quarantined; a_1 is the cost of quarantining yourself, in a world where everyone else is quarantined; and a_0 is the cost of being sick, in a world where everyone is quarantined.) These parameters can be changed in many ways. For instance, a restaurant service that delivers safely-prepared fresh-cooked meals would increase a_0 and reduce a_2, as would improved virtual-meeting technology that enhances remote collaboration.

Discussion: functional form of economic benefits. The assumption that the benefits of public and social activity are linear in own and others' availability simplifies the presentation but is not essential for the analysis or qualitative findings. For instance, suppose that agents were to prioritize their activities, e.g., by leaving the home only to get urgently-needed supplies, or to visit only with their dearest friends. In that case, each agent's benefit from public and social activity would naturally be a concave function of her own personal distance and of others' availability. The analysis can be easily adapted to allow for such concavity, but at the cost of complicating the presentation.

Economic losses due to the virus. If the virus did not exist, then no one would become sick and everyone would choose not to distance. All agents would then get constant flow economic benefit $b(0;1) = a_0 + a_1 + a_2$ and, since the population has unit mass, overall economic activity would also be $b(0;1)$. The virus reduces economic activity directly, by making people sick, and indirectly, by inducing not-yet-sick agents to distance themselves. Distancing in turn creates two sorts of economic harm: "private harm" that distancing oneself reduces one's own public and social activity, and "social harm" that distancing oneself reduces others' social activity.

Let $b_t(d_i)$ be shorthand for each well agent's flow economic benefit at time t. $b_t(d_i)$ depends on (i) how many people are recovered from sickness, $R_I(t)$, and how many are currently sick, $I(t) = 1 - N(t) - R_I(t)$, (ii) what fraction $d_N(t)$ of not-yet-sick agents are distancing, and (iii) her own distancing choice $d_i \in \{0,1\}$:

$$\begin{aligned} b_t(d_i) &= a_0 + a_1(1-\alpha d_i) + a_2(1-\alpha d_i)A(t) \\ &= a_0 + a_1(1-\alpha d_i) + a_2(1-\alpha d_i)((1-\alpha d_N(t))N(t) + R_I(t)) \end{aligned}$$

All agents suffer economically throughout the epidemic, relative to the no-virus benchmark case in which everyone gets flow benefit $a_0 + a_1 + a_2$:

> *Sick:* I-agents are incapacitated and get zero economic benefit. These agents lose $a_0 + a_1 + a_2$.
>
> *Previously sick:* R_I-agents do not distance, but have less opportunity for social interaction due to others' distancing behavior. These agents lose social-activity benefit $a_2(1 - A(t))$.

Not-yet-sick: N-agents choose distancing intensity $d_N(t)$, reducing their public and social activities by a factor of $(1-\alpha d_N)$. These agents lose public-activity benefit $a_1\alpha d_N$ and lose social-activity benefit $a_2(1-(1-\alpha d_N)A(t)) = a_2(1-A(t)+\alpha d_N A(t))$.

Let $\Gamma_E(t)$ denote the lost economic activity at time t, across the entire population. Overall economic loss across the entire epidemic is $\Gamma_E = \int_0^\infty \Gamma_E(t)dt$. (If future losses are discounted by discount factor $0 < \delta \leq 1$, then the overall economic loss has present value $\Gamma_E = \int_0^\infty \delta^t \Gamma_E(t)dt$ at time 0. I focus on the case without discounting for ease of exposition.)

Lemma 1. $\Gamma_E(t) = a_0 I(t) + a_1(1-A(t)) + a_2(1-A(t)^2)$.

Proof. See the Appendix. □

1.3 Individual welfare and equilibrium behavior

Each agent seeks to minimize her own total[4] losses during the course of the entire epidemic.

Let $l_i(t)$ denote agent i's *flow loss* at time t. As discussed earlier: $l_i(t) = a_0 + a_1 + a_2$ if i is sick; $l_i(t) = a_2(1-A(t))$ if i is well and not distancing, where $A(t)$ is others' availability for social interaction; and $l_i(t) = a_1\alpha + a_2(1-A(t)+\alpha A(t))$ if i is well and distancing.

Let $L_\omega(t)$ denote agent i's expected future total losses starting from time t if in epidemiological state $\omega \in \{S, C, I, R_C, R_I\}$, referred to as "continuation losses from state ω." (Continuation losses depend on future agent behavior and the future trajectory of the epidemic, but I suppress such notation as much as possible for ease of exposition.) A susceptible agent who becomes infected at time t will not notice this transition but, at that moment, her continuation losses change from $L_S(t)$ to $L_C(t)$. Let $H(t) \equiv L_C(t) - L_S(t)$ denote the "harm of susceptible exposure" at time t.

Let $p_i(t)$ denote agent i's subjective belief about her own likelihood of being susceptible at time t, conditional on being not-yet-sick. At time t, mass $N(t)$ of agents are not-yet-sick, of whom mass $S(t)$ remain susceptible. Thus, N-agents' average likelihood of being susceptible is $\frac{S(t)}{N(t)}$. For simplicity, I will focus on epidemics with *symmetric behavior* by all those in the same information state at each point in time, in which case $p_i(t) = \frac{S(t)}{N(t)}$.

Gain from distancing: reduced exposure. Suppose that, at time t, agent i distances with intensity $d_i \in [0,1]$ and other N-agents distance themselves with intensity $d_N \in [0,1]$. Agent i is then exposed to the virus at rate $\beta(1-\alpha d_i)(1-\alpha d_N)C(t)$, compared to being exposed at rate $\beta(1-\alpha d_N)C(t)$ if not distancing at all. The "gain from distancing" at time

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[4] The analysis can be trivially extended to allow for discounting of future losses.

t, denoted $GAIN_t(d_N)$, is therefore

$$GAIN_t(d_i, d_N) = \alpha d_i \beta(1 - \alpha d_N)C(t) \times H(t) \times \frac{S(t)}{N(t)}. \tag{9}$$

The marginal gain from distancing $_t(d_N) = \frac{\mathrm{d}GAIN_t(d_i,d_N)}{\mathrm{d}d_i}$ is then

$$MG_t(d_N) = \alpha(1 - \alpha d_N)\frac{\beta S(t)C(t)H(t)}{N(t)}. \tag{10}$$

Note that the marginal gain from distancing is decreasing in d_N. This is because, as others distance themselves more, agents face less risk of exposure.

Economic cost of distancing: reduced activity. If other N-agents choose distancing intensity d_N, agent i gets flow economic benefit $a_0 + a_1(1-\alpha d_i) + a_2(1-\alpha d_i)((1-\alpha d_N)N(t) + R_I(t))$ when choosing distancing intensity d_i, compared to $a_0 + a_1 + a_2((1-\alpha d_N)N(t) + R_I(t))$ when not distancing at all. The "cost of distancing" at time t, denoted $COST_t(d_i, d_N)$, is therefore

$$COST_t(d_i, d_N) = a_1 \alpha d_i + a_2 \alpha d_i((1 - \alpha d_N)N(t) + R_I(t)). \tag{11}$$

The marginal cost of distancing $MC_t(d_N) = \frac{\mathrm{d}COST_t(d_i,d_N)}{\mathrm{d}d_i}$ is then

$$MC_t(d_N) = a_1 \alpha + a_2 \alpha((1 - \alpha d_N)N(t) + R_I(t)). \tag{12}$$

Note that the marginal cost of distancing is decreasing in d_N. This is because, as others distance themselves more, there are fewer opportunities for social activity.

Because the marginal gain and the marginal cost of distancing are each decreasing in d_N, the game that N-agents play may exhibit "strategic substitutes" or "strategic complements" (Bulow et al. (1985)), depending on the epidemic state. By contrast, in Quercioli and Smith (2006), there are no sources of strategic complementarity.

"Distancing game" among agents. At each time t, the not-yet-sick N-agents play a *game* when deciding whether or not to distance. (Sick I-agents are incapacitated, while previously sick R_I-agents obviously prefer not to distance. Thus, only N-agents have a non-trivial decision.) I assume that N-agents play a Nash equilibrium (NE) of this game, and focus on symmetric NE in which all N-agents choose the same distancing intensity.

Proposition 1. *Given epidemic state $\mathcal{E}(t) = (S(t), C(t), I(t), R_C(t), R_I(t))$ and harm from susceptible exposure $H(t) = L_C(t) - L_S(t)$, the "time-t distancing game" played by not-yet-sick agents has a unique symmetric NE, in which agents choose distancing intensity $d_N^*(t)$.*

In particular: (i) if $MG_t(0) \leq MC_t(0)$*, then* $d_N^*(t) = 0$*; (ii) if* $MG_t(1) \geq MC_t(1)$*, then* $d_N^*(t) = 1$*; and (iii) otherwise, if* $MG_t(0) > MC_t(0)$ *and* $MG_t(1) < MC_t(1)$ *then*

$$d_N^*(t) = \frac{\frac{\beta S(t)C(t)H(t)}{N(t)} - a_1 - a_2(N(t) + R_I(t))}{\alpha\left(\frac{\beta S(t)C(t)H(t)}{N(t)} - a_2 N(t)\right)} \in (0,1). \tag{13}$$

Proof. The proof is in the Appendix. □

Uniqueness of symmetric NE is not obvious, since the time-t distancing game may have either strategic substitutes or strategic complements, depending on the epidemic state and the harm of susceptible exposure. However, uniqueness arises because N-agents have a dominant strategy whenever the game has strategic complements.

Equilibrium epidemics. Let $\mathcal{E}(\mathbf{d}_N)$ denote the epidemic process that results when N-agents choose distancing intensity $d_N(t)$ at each time t, as determined by the system (2-6). $\mathcal{E}^*$ is referred to as an *equilibrium epidemic process* (or "behaviorally-constrained epidemic") if (i) $\mathcal{E}^* = \mathcal{E}(\mathbf{d}_N^*)$ and (ii) given the epidemic process $\mathcal{E}^*$, the time-t distancing game has a symmetric NE in which N-agents choose distancing intensity $d_N^*(t)$, for all $t \geq 0$.

2 Equilibrium Epidemic Analysis

This section characterizes all equilibrium epidemics with symmetric[5] agent behavior (or, more simply, "equilibrium epidemics") and provides an algorithm for computing them. The analysis is organized as follows. First, the augmented system of differential equations that governs economic-epidemiological dynamics in the Nash SIR model is presented. This system builds on the well-known system that governs epidemiological dynamics in the SIR model. Second, for any given "final prevalences" $(S(T), C(T), I(T), R_I(T))$ at time T when distancing ends (due to a perfect vaccine being introduced), there is at most one equilibrium epidemic having these final prevalences.

2.1 Economic-epidemiological dynamics

At any given time t, the epidemic is characterized by: (i) the mass of agents in each epidemiological state ($S(t)$, $C(t)$, $I(t)$, $R_C(t)$, $R_I(t)$); (ii) the welfare of agents in each epidemiological state (as captured by state-contingent "continuation losses" $L_S(t)$, $L_C(t)$, $L_I(t)$, $L_{R_C}(t)$, $L_{R_I}(t)$); and (iii) the distancing behavior of agents who are not yet sick ($d_N^*(t)$).

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[5] I do not know if an equilibrium epidemic can exist with asymmetric behavior by symmetric agents.

Epidemiological dynamics. The dynamics of the epidemic state $\mathcal{E}(t) = (S(t), C(t), I(t), R_C(t), R_I(t))$ up until time T are determined by equations (2-6) and depend on N-agents' distancing behavior. After the vaccine is introduced at time T, equations (2-5) remain unchanged but, because there is no further transmission of the virus, $S'(t) = 0$.

Distancing behavior. Lemma 1 characterizes N-agents distancing behavior $d_N(t)$ at each time t, depending on the epidemic state $\mathcal{E}(t)$ and the harm of susceptible exposure $H(t) = L_C(t) - L_S(t)$.

Welfare dynamics. It remains to characterize how the continuation losses associated with each epidemiological state change over time.

State R_I. Agents who have recovered from sickness remain well[6] and choose not to distance. Such an agent still suffers from the fact that others are distancing, losing social-activity benefit $a_2(\alpha d_N^*(t)N(t) + I(t))$ relative to the no-virus benchmark in which everyone earns flow benefit $a_0 + a_1 + a_2$. Because these losses are "sunk" once experienced, and because R_I-agents do not transition to any other state,

$$L'_{R_I}(t) = -a_2(\alpha d_N^*(t)N(t) + I(t)). \tag{14}$$

After time T when new transmission stops, all social distancing stops, i.e., $d_N^*(t) = 0$ for all $t > T$. However, well agents still suffer from not being able to engage socially with those who are sick. In particular, $L_{R_I}(t) = \int_{t' \geq t} a_2 I(t')\mathrm{d}t'$ for all $t \geq T$.

State I. Sick agents incur flow loss $a_0 + a_1 + a_2$ and transition to the recovered state R_I at rate γ. Thus,

$$L'_I(t) = -(a_0 + a_1 + a_2) + \gamma(L_I(t) - L_{R_I}(t)). \tag{15}$$

State R_C. Agents who have recovered from carriage never learn that they are immune, and so continue to distance themselves throughout the entire epidemic. In particular, these agents lose public-activity benefit $a_1 \alpha d_N^*(t)$, lose social-activity benefit $a_2(1 - (1 - \alpha d_N^*(t))((1 - \alpha d_N^*(t))N(t) + R_I(t))$, and never transition to another state. Thus,

$$L'_{R_C}(t) = -a_1\alpha - a_2(1 - (1 - \alpha d_N^*(t))((1 - \alpha d_N^*(t))N(t) + R_I(t)). \tag{16}$$

After time T, because all social distancing stops and R_C-agents do not become sick, their

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[6] The analysis can be extended in a straightforward way to allow for the possibility of re-infection, for instance, by having recovered agents transition back at some rate to the susceptible state.

only subsequent losses come from not being able to interact with other people who are sick, the same as R_I-agents. So, $L_{R_C}(t) = L_{R_I}(t)$ for all $t \geq T$.

State C. Agents with asymptomatic infection incur the same flow losses due to social distancing as all not-yet-sick agents (including those in state R_C), but transition to sickness at rate σ and to asymptomatic recovery at rate σ. Thus,

$$L'_C(t) = L'_{R_C}(t) + \gamma(L_I(t) - L_C(t)) + \sigma(L_{R_C}(t) - L_C(t)). \tag{17}$$

State S. Susceptible agents incur the same flow losses as all other not-yet-sick agents, but become asymptomatically infected at rate $\beta(1-\alpha d^*_N(t))^2 S(t)C(t)$. Thus,

$$L'_S(t) = L'_{R_C}(t) + \beta(1-\alpha d^*_N(t))^2 S(t)C(t)(L_C(t) - L_S(t)). \tag{18}$$

After time T, S-agents remain susceptible and only suffer from not being able to interact with others who are sick, the same as R_I-agents. So, $L_S(t) = L_{R_I}(t)$ for all $t \geq T$.

2.2 Algorithm

Suppose for a moment that an equilibrium exists with final epidemic state $\mathcal{E}(T)$. Here I discuss how to determine numerically whether an equilibrium epidemic exists with this "final condition" and, if so, to compute the entire epidemic trajectory.

Observe first that the final epidemic state uniquely pins down the trajectory of the epidemic *after* time T. Because there is no new transmission, no one distances and subsequent epidemiological dynamics are trivial: contagious agents leave state C at rate $\gamma+\sigma$, fraction $\frac{\sigma}{\gamma+\sigma}$ becoming sick; sick agents recover at rate γ; and others remain in their current state. Moreover, because $C(T)$ and $I(T)$ together determine $(I(t) : t \geq T)$, they also determine $L_{R_I}(t) = L_{R_C}(t) = L_S(t) = \int_{t' \geq t} a_2 I(t') \mathrm{d}t'$ for all $t \geq T$, which in turn determine $L_C(t)$ and $L_I(t)$ after T.

Having determined $L_S(T)$ and $L_C(T)$, we now know $H(T) = L_C(T) - L_S(T)$, the harm of susceptible exposure just before the vaccine is introduced. Together with the final epidemic state, this uniquely determines N-agents' equilibrium distancing intensity just *before* the vaccine is introduced, as characterized in Proposition 1.

Having determined N-agent behavior $d^*_N(t)$, we now can determine: $S'(T)$ (equation (6)) and all other epidemiological dynamics, which remain unchanged (equations (2-5)); $L'_{R_I}(T)$, which in turn determines $L'_I(T)$ (equations (14,15)); and $L'_{R_C}(T)$, which together with $L'_I(T)$ determines $L'_C(T)$, which in turn determines $L'_S(t)$ (equations (16,17,18)). In this way, any *candidate epidemic* can be uniquely traced backward over time, from the given final epidemic state ("final condition"), until one of three things happens: (i) the trajectory hits an invalid boundary[7], in which case no equilibrium epidemic exists with the given final condition; (ii) the backwards trajectory "ends" at the desired initial epidemic state $\mathcal{E}(0) = (1-\Delta, \Delta, 0, 0, 0)$, in which case a unique equilibrium epidemic exists with the given final condition; or (iii) the backwards trajectory ends at some other initial epidemic state $\mathcal{E}(0) \neq (1 - \Delta, \Delta, 0, 0, 0)$, in which case no equilibrium epidemic exists with the given final condition.

3 Concluding Remarks

This paper introduces Nash SIR, an economic-epidemiological model of a viral epidemic that builds on the classic Susceptible-Infected-Recovered (SIR) model of infectious-disease epidemiology. The model departs from the previous literature by focusing on the complementarities associated with the social-economic activity that can be lost when agents distance themselves to prevent the spread of infection.

A changing game. An important complicating feature of this paper's model is that, as the epidemic progresses through its course, the basic strategic structure of the "distancing game" that agents play changes over time. For instance, very early in the epidemic when infection remains rare, the distancing game exhibits negative externalities, since agents get little health benefit but suffer substantial economic harm when others distance themselves. However, that changes once infection grows more common, as others' distancing generates greater health benefit. Moreover, the game can shift between having strategic substitutes and strategic complements.

Complementarity and multi-dimensionality of agent actions. This paper focuses on a simple context in which the only way to protect oneself from infection is to avoid public and in-person social activity. However, people can also prevent transmission in other ways, such as wearing a mask. Bearing that in mind, it would be interesting to generalize the analysis to allow agents to decide both (i) how much to curtail their public and social activities ("avoidance," as in this paper), and (ii) how much to change their behavior during such activities ("vigilance," as in Quercioli and Smith (2006)). The game that agents play in this richer context has an interesting strategic structure, with agents' vigilance decisions always being strategic substitutes, agents' avoidance decisions potentially being either strategic

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[7] An "invalid boundary" is reached if $S(t)$, $C(t)$, $I(t)$, $R_C(t)$, or $R_I(t)$ equals zero at any time $t > 0$.

complements or strategic substitutes, more vigilance promoting less avoidance, and more avoidance promoting less vigilance.

Asymmetry and social inequality. This paper assumes that agents are symmetric for ease of exposition, but this assumption appears to entail meaningful loss of generality. In particular, assuming that all agents are the same at the start of the epidemic obscures important issues related to inequality and social justice. To see why, suppose that agents belong to one of two social classes: "elites" who are able to earn income and care for themselves from home (higher a_0) and "non-elites" whose income and well-being hinge more on being in public social spaces (higher a_2). With less to lose by staying at home, elites will distance themselves relatively early during the epidemic. Having distanced less in the past, non-elites will then be more likely than elites to already have been exposed to the virus—further reducing their relative incentive to distance. In the end, the equilibrium trajectory of the epidemic could exacerbate pre-existing inequality, with non-elites bearing the brunt of the burden of the epidemic, being more likely to become sick and suffering more from the economic contraction associated with elite-driven distancing.

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A Mathematical proofs

Proof of Lemma 1.

Proof. Recall that $A(t) = (1 - \alpha d_N(t))N(t) + R_I(t)$ and hence $1 - A(t) = I(t) + \alpha d_N(t)N(t)$.

Isolated activity: Sick agents get no benefit, while well agents get full benefit a_0. The overall economic loss due to reduced isolated activity at time t is therefore $a_0 I(t)$.

Public activity: Sick agents get no benefit, well agents who do not distance get full benefit a_1, and well agents who distance get benefit $a_1(1-\alpha)$. Since fraction $d_N(t)$ of N-agents distance and no R_I-agents distance, the overall economic loss due to reduced public activity at time t is therefore $a_1(I(t) + \alpha d_N(t)N(t)) = a_1(1 - A(t))$.

Social activity: Sick agents get no benefit, well agents who do not distance get benefit $a_2 A(t)$, and well agents who distance get benefit $a_2(1-\alpha)A(t)$ (and hence lose $a_2(1 - A(t) + \alpha A(t))$). The overall economic loss due to reduced social activity at time t is therefore a_2 times

$$\begin{aligned}
& I(t) + (1 - A(t))(R_I(t) + (1 - d_N(t))N(t)) + (1 - A(t) + \alpha A(t))d_N(t)N(t) \\
&= I(t) + (1 - A(t))(R_I(t) + (1 - d_N(t))N(t)) + ((1 - A(t))(1 - \alpha) + \alpha)d_N(t)N(t) \\
&= 1 - A(t) + (1 - A(t))\left(R_I(t) + (1 - d_N(t))N(t) + (1 - \alpha)d_N(t)N(t)\right) \\
&= (1 - A(t)) \times (1 + R_I(t) + (1 - \alpha d_N(t))N(t)) \\
&= (1 - A(t)) \times (1 + A(t)) = 1 - A(t)^2
\end{aligned}$$

as desired. ☐

Proof of Proposition 1.

Proof. (i) *No distancing:* If $MG_t(0) \leq MC_t(0)$, then the time-t distancing game has a symmetric NE in which all agents choose not to distance, i.e., $d_N^*(t) = 0$. To establish uniqueness, note by equations (10-12) that $MG_t(0) \leq MC_t(0)$ implies $\frac{\beta S(t)C(t)H(t)}{N(t)} \leq a_1 + a_2(N(t) + R_I(t))$. But then

$$\begin{aligned}
MG_t(1) &= \alpha(1-\alpha)\frac{\beta S(t)C(t)H(t)}{N(t)} \\
&\leq \alpha(1-\alpha)(a_1 + a_2(N(t) + R_I(t))) \\
&< \alpha(a_1 + a_2((1-\alpha)N(t) + R_I(t))) \\
&= MC_t(1)
\end{aligned}$$

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Since $MG_t(d_N)$ and $MC_t(d_N)$ are each linear in d_N, the fact that $MG_t(0) \leq MC_t(0)$ and $MG_t(1) < MC_t(1)$ implies that $MG_t(d_N) < MC_t(d_N)$ for all $d_N \in (0, 1]$. In particular, N-agents have a dominant strategy not to distance.

(ii) *Maximal distancing:* If $MG_t(1) \geq MC_t(1)$, then a symmetric NE exists in which all agents choose to distance as much as possible, i.e., $d^*_N(t) = 1$. To establish uniqueness, note by equations (10-12) that $MG_t(1) \geq MC_t(1)$ implies $(1-\alpha)\frac{\beta S(t)C(t)H(t)}{N(t)} \geq a_1 + a_2((1-\alpha)N(t) + R_I(t))$. But then

$$\begin{aligned} MG_t(0) &= \alpha \frac{\beta S(t)C(t)H(t)}{N(t)} \\ &\geq \frac{\alpha}{1-\alpha}(a_1 + a_2((1-\alpha)N(t) + R_I(t))) \\ &> \alpha(a_1 + a_2(N(t) + R_I(t))) \\ &= MC_t(0) \end{aligned}$$

Since $MG_t(d_N)$ and $MC_t(d_N)$ are each linear in d_N, the fact that $MG_t(1) \geq MC_t(1)$ and $MG_t(0) > MC_t(0)$ implies that $MG_t(d_N) > MC_t(d_N)$ for all $d_N \in [0, 1)$. In particular, N-agents have a dominant strategy to distance.

(iii) *Intermediate distancing:* If $MG_t(0) > MC_t(0)$ and $MG_t(1) < MC_t(1)$, then it must be that $MG'_t(d_N) = -\frac{\alpha^2 \beta S(t)C(t)H(t)}{N(t)} < -\alpha^2 a_2 N(t) = MC'_t(d_N)$ and hence that there exists a unique $d^*_N(t) \in (0, 1)$ such that $MG_t(d^*_N(t)) = MC_t(d^*_N(t))$, $MG_t(d_N) > MC_t(d_N)$ for all $d_N < d^*_N(t)$, and $MG_t(d_N) < MC_t(d_N)$ for all $d_N > d^*_N(t)$. In particular, solving $MG_t(d^*_N(t)) = MC_t(d^*_N(t))$ yields

$$d^*_N(t) = \frac{\frac{\beta S(t)C(t)H(t)}{N(t)} - a_1 - a_2(N(t) + R_I(t))}{\alpha\left(\frac{\beta S(t)C(t)H(t)}{N(t)} - a_2 N(t)\right)}. \tag{19}$$

□

Covid Economics **Issue 16, 11 May 2020**

Should I stay or should I go (out): The role of trust and norms in disease prevention during pandemics[1]

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In this paper we construct country specific indices of mobility and trust. We use Google Covid-19 Community Mobility Reports for the former, and World Values Survey and the European Values Study for the latter. We find that the trust index has some power in explaining mobility attitudes of nations, and trust increases mobility around workplaces, groceries/pharmacies, parks, and transit stations. We then present a model where people decide whether to stay at home or go out and if they go out how much effort to spend to protect themselves from the disease which has positive externalities on others. We assume that the effort cost of protection depends on the norm in the community and show that more people can go out when either the norm increases or people put more weight on it. Interpreting the weight on the norm as a measure of trust, our theory sheds light on the empirical findings.

Covid Economics 16, 11 May 2020: 135-160

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[1] We thank Kathy Yuan for helpful conversations and feedback.

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Covid Economics 16, 11 May 2020: 135-160

1 Introduction

Many countries use social distancing to stop the spread of Covid-19. In order for social distancing to be effective, a large proportion of the population must comply with it. In most countries social distancing has been in the form of measures that encourage staying at home. For example, in the UK people are advised to stay at home and save lives, and this message is propagated through both traditional and social media channels. In this paper, we aim to understand the effectiveness and the drivers behind compliance to these measures in different countries. *Trust in others* emerged as one driver of compliance to social distancing. For example the Economist in a recent article says "Trusting countries have generally implemented less stringent lockdowns. Rather than harshly enforcing social-distancing rules, their governments rely on citizens to observe guidelines voluntarily." The article also states that high trust among their citizens may have lulled these countries into a "false sense of security." Durante, Guiso, and Gulino (2020) using data on individual mobility across Italian provinces find that after the start of the pandemic, mobility declined disproportionately more in areas with higher civic capital.

In this paper we document that, after controlling for factors that can potentially influence mobility such as stringency of lockdowns, case counts, and weather, mobility has been higher in more trusting countries than the less trusting ones. To measure trust we construct an index based on World Values Survey (WVS) and the European Values Study(EVS). We find that this index has quite a bit of power in explaining mobility attitudes of nations, and the effect of trust is significantly positive for measures of mobility such as workplace, retail, parks, transit stations and workplaces. Interestingly, the mobility around residential areas are negatively related to trust which is exactly what one would expect since people remain around their homes when they have lower mobility everywhere else. We discuss the data and the empirical results in Sections 2 and 3.

In section 4, we present a model that can potentially explain this finding and shed light on the seemingly different conclusions of the empirical studies mentioned above. In our model, people prefer to go out relative to staying in their homes. The value people attach to going out is heterogenous. Some people are able to work effectively from home whereas others lose their productivity if they are away from their workplace. This variation in productivity from home causes part of the heterogeneity. In addition, people have different preferences for socializing, going to restaurants, cultural activities, etc.

A key point that we make in our model is that individuals face multiple decision margins when they try to protect themselves from contracting the disease. To highlight the various tradeoffs, we introduce two groups, susceptible and contagious, who do not know their own status and decide whether to stay at home or go out. We assume that by staying at home a susceptible person can avoid contracting the disease. However, people can go outside their homes and still protect themselves from contracting the disease albeit imperfectly. These protective measures may include keeping a safe distance from other people when possible, avoid shaking hands or kissing, wear masks and gloves, keep their hands away from their faces, wash their hands frequently, etc.

The protective measures are costly to implement since they require both attention and effort. In addition to its direct costs, we allow for the cost of protection to also depend on the prevailing norms in the society. For example, when wearing masks becomes the norm, individuals find it less costly to wear masks. Similarly, when others do not expect shaking hands as a form of greeting, it becomes easier to avoid shaking hands.[1]

For a person who decides to go out, the probability of contracting the disease depends on several factors some of which are standard such as contagiousness of the disease and the proportion of contagious people in the population. Importantly, it also depends on the level of protection chosen by the individual and the level of protection in the community. When others are protecting themselves, they are also less likely to spread the disease. Hence, protection has a positive externality. Lastly, the probability of contracting the disease depends on the proportion who choose to go out which is endogenously determined. In Garibaldi, Moen, and Pissarides (2020) and Farboodi, Jarosch, and Shimer (2020) probability of contracting the disease depends on how much activity an agent chooses to engage in outside their home. Our specification is related to theirs in the sense that going out imposes a negative externality on others. However, agents in our model are able to protect themselves by costly effort which has a positive externality on others which is an aspect that is not present in the other models.

Each person in our model takes the protection level in the community and the proportion of people who go out as given and choose the optimal level of protection. They compare the resulting overall benefit from going out with the benefit from staying at home and decide whether to go out or not. In equilibrium, the protection effort of those who choose to go out must equal the protection level in the community, and the proportion who choose to go out equals the proportion who go out that is conjectured by each individual.

We then look at comparative statics in our model. First, we consider an increase in the norm while keeping its importance constant. We show that an increase in the norm leads to an increase in the

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[1] The importance of trust and norms have been recognized in economics for a long time. For example, Arrow (1974) points out that "trust is an important lubricant of a social system." In political science Putnam (1993), and Fukuyama (1995) argue that trust is crucial for the performance of a society's institutions. The role of trust and norms in team incentives have been studied in organizational economics. (e.g. Kandel and Lazear (1992), Casadesus-Masanell (2004).) An excellent survey of the role of trust in economic outcomes can be found in Guiso, Sapienza, and Zingales 2006.

protection effort of the community if there is enough heterogeneity in agents' preferences for going out. As a result an individual who goes out is less likely to contract the disease when the norm increases. We show that this effect can lead to an increase in the number of agents who go out. That is, we find that when the norm for taking protective actions in the community is larger, more people may choose to go out.

We then consider an increase in the importance of the norm in the community while keeping the norm itself constant. We find that this increase can lead to an increase in each agent's protection effort and, consequently, in the community protection. As a result effort cost of going out increases and the probability of contracting the disease decreases. If the second effect dominates, then more people go out when they put a higher weight on the norm. If we interpret that a society where people put a larger weight on deviating from the norm as a community with more trust, this result implies that a larger proportion of people may choose to go out in communities with higher trust.

2 Changes in mobility

In order understand the factors that have resulted in changes in mobility in a world facing a pandemic, we collected data from a variety of sources. We use the Google Covid 19 Community Mobility Reports[2] to track the changes that has transpired in the movements of people across 131 countries. This data measures the change in mobility relative to a baseline in six categories: Retail & Recreation, Grocery & Pharmacy, Parks, Transit Stations, Workplaces, Residential. The baseline is calculated for each weekday as the median level of activity in the five week period between January 3rd and February 6th, 2020. Then the activity for each calendar date is compared to the baseline and the percentage change in activity is calculated.

To demonstrate that the arrival of the pandemic has resulted in a dramatic change in mobility in almost all of the six areas reported by Google, we present a few visualizations. To do this we pick two dates: February 19th, 2020 and April 22nd, 2020, which are both Wednesdays, and present heat-maps to track the changes relative to the baseline. Note that for both of the dates, the baseline level used by Google to construct these mobility figures is the same. Below we show the heat-maps only for the two of the six areas, and we relegate the rest to the appendix.

Figure 1 presents the observed changes in mobility for retail and recreation areas. According to Google these include restaurants, cafes, shopping centers, theme parks, museums, libraries, and movie

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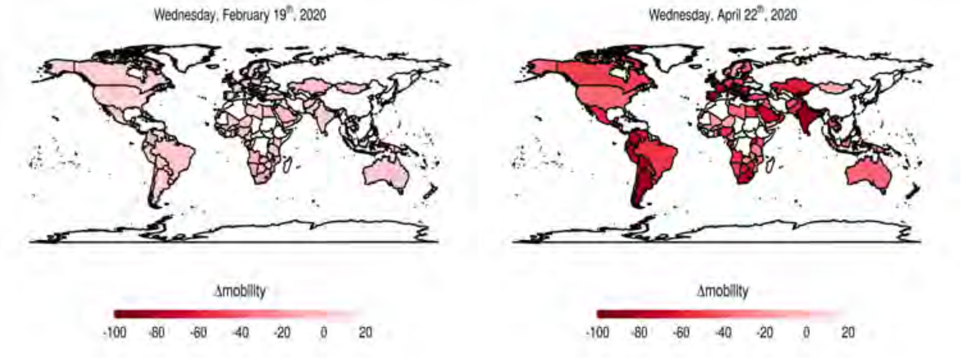
[2] https://www.google.com/covid19/mobility/

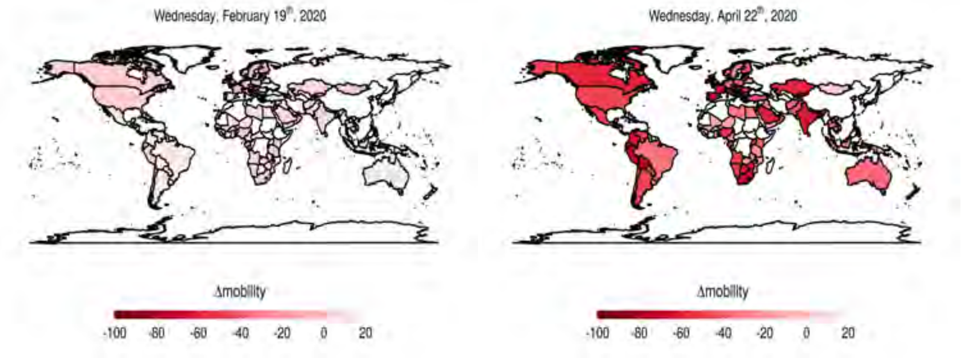
theaters. It is clear from the panel (a) of figure 1 that on February 19th people around the globe were moving around like business as usual, while panel (b) implies that merely two months later their visits to such areas has declined considerably. In the heat-maps, the countries which are left white are those for which Google does not provide data. Unfortunately, one of these countries is China which was in the midst of the full-on outbreak at the first date we consider.



(a)

(b)

Figure 1: Changes in mobility around retail and recreation establishments



(a)

(b)

Figure 2: Changes in mobility around workplaces

Next consider the changes in mobility around places of work, once again for the same two dates. We present the resulting heat-map in figure 2. A similar story emerges in that, within two months, the workplaces of the world seemed to have emptied out.

We present the remaining four heat-maps in the appendix. The story is qualitatively similar for three of remaining areas: Groceries and Pharmacies, Transit Stations and Parks. One sees that in February the activity seemed to have been around baseline levels, while in April, as no corner of the world could stay out of the way of the outbreak, people have substantially reduced their mobility. Interestingly, the reduction in mobility around groceries and pharmacies is somewhat less compared to other measures. It seems that in many countries around the world, the only reason people move in April is to acquire supplies, even though they do this less compared to the baseline. The mobility around residential areas presents qualitatively a mirror image of the other areas. In the past two months, people moved mainly around their homes throughout the world.

Overall, the mobility measures published by Google presents a stark picture. We posit a number of factors which can affect the mobility patterns that are naturally related to the current Covid 19 pandemic. The most important of these factors are the restrictions imposed by governments all over the world to slow down the diffusion of the infections in their populations. In order to track the government response to the pandemic, we use Oxford COVID-19 Government Response Tracker (OxCGRT) dataset compiled by Hale et al. (2020) and the corresponding stringency index they develop for 150 jurisdictions around the world. After merging this dataset with the Google mobility data set we are left with 111 countries.[3]

We next present a heatmap of the stringency index developed by Hale et al. (2020) in figure 3 for the same dates as above.

As can be seen in figure 3, it is striking to see once again that Covid 19 was seen mostly as a Chinese problem in the middle of February. In a matter of two months, however, it turned in to a global pandemic, and as a result, many of the world's governments have introduced rather severe restrictions on their populations. Moreover, comparing the figures 1, 2 and 3, one may be tempted to conclude that the biggest culprit behind the reduction of mobility across the globe must have been the introduction of government restrictions. We, however, demonstrate in our econometric analysis below that this is only partially true.

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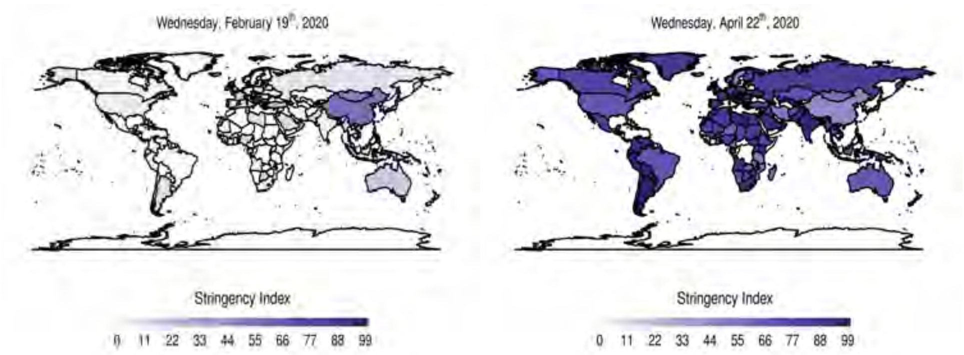
[3] In the model we present in section 4 stricter government measures can be interpreted as reducing the benefits of going out. This would especially be the case when restrictions are in the form of fines and curfews. Government measures can also effect the cost of effort of taking protective measures which have a more delicate effect in the model.



(a)

(b)

Figure 3: Changes in measures implemented around the world

This OxCGRT dataset also contains information on the confirmed number of cases and the deaths due to Covid 19. Information regarding the confirmed number of cases can influence the choices of individuals by effecting their perception of the probability of getting infected as well as the costs of becoming infected. Thus, we include these variables in our econometric analysis as well.

We believe the value of going out can change day to day due to weather conditions among other factors. In order to control for the weather conditions, we use the Global Historical Climatology Network's (GHCN) daily dataset.[4] This dataset consists of various climatic measurements taken by land stations all over the world. We identify the country in which each station resides, and construct a daily average temperature measure for each country. Merging this dataset with the mobility and stringency measures datasets provides us with daily observations of temperature, confirmed cases and deaths, stringency index and changes in mobility for 102 countries.

We present in figure 4 the changes in the temperatures around the world also on the same dates in February and April. The changes are as expected. The southern hemisphere is going through a rather warm period, while in the northern hemisphere winter turned into spring. As we demonstrate on our econometric analysis, this increase in temperatures has tempted the citizens of the world to go out more.

In the next section, we estimate several econometric models to understand the drivers of changes in mobility around the globe using the datasets that we have described. Given that Google provides

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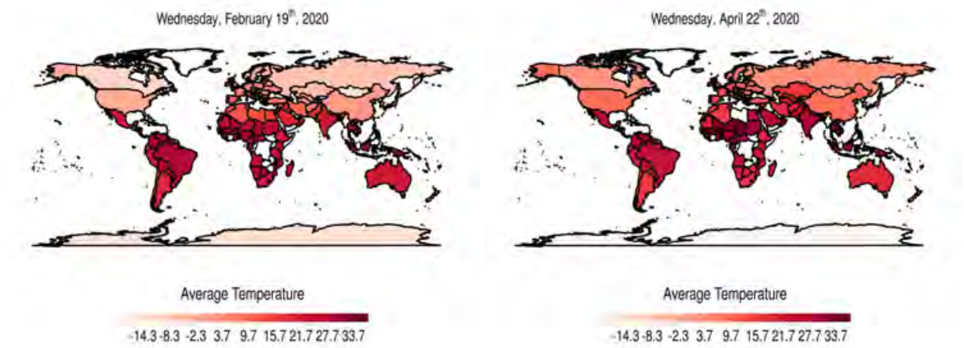
[4] https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn.



(a) (b)

Figure 4: Changes in temperatures

a dataset with daily observations, we are in a position to use fixed effects techniques to control for unobserved heterogeneity in the responses of each country to the emergence of the pandemic. Since we have 99 daily observations for the 102 countries in the dataset, these fixed effects are rather precisely estimated. The fixed effect of a country can be considered to be a stringency measure, weather, and disease contagiousness/severity adjusted change in mobility—a country specific characteristic. We observe that these fixed effects present a large geographic variation. Indeed, our main goal in this paper is to explore possible mechanisms which might induce different innate responses in terms of mobility to the news of an impending pandemic.

In order to further investigate the variance across countries in our adjusted mobility measure, we appeal to cultural factors. In particular, we check if the perceptions of individuals about the reliability of their peers in disease prevention plays a role. Clearly, each individual, faced with a possible infection, considers taking precautions herself. However, once one goes out, it matters whether others also invest effort in taking precautions. In order to proxy the beliefs of an individual on whether others in the community also engage in preventive effort, we employ the most recent trust perception survey data as provided in the WVS and the EVS. For all available countries in these surveys, we record the answer to the question: “Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?” to which the respondents can choose to answer with: i) “Most people can be trusted”, ii) “Need to be very careful ”, iii) “Don’t know”, and finally, iv) “No Answer”. We construct a trust index for each country by

$$Trust_i = \frac{\#\text{Most people can be trusted}}{\#\text{Most people can be trusted} + \#\text{Need to be very careful}}. \tag{1}$$

Figure 5 illustrates that this measure also presents us with a large geographic variation. We explore in the next section whether this index has any explanatory power regarding adjusted mobility measures that we obtain from the country fixed effects. After merging the trust index data with the adjusted mobility measures for each country we are left with a dataset that includes only 73 countries to use in our econometric analysis.

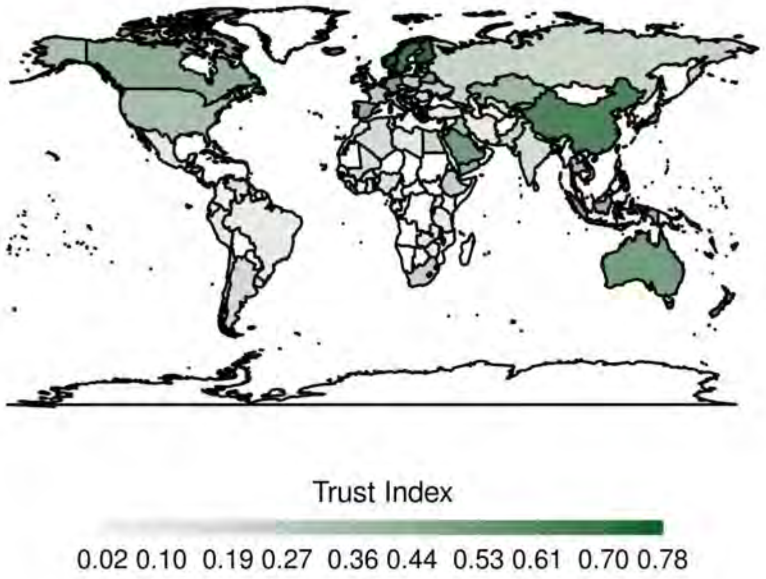


Figure 5: Trust index around the world

3 Estimation Results

3.1 Understanding changes in mobility

In this subsection, we present an empirical model to explain the observed variations across countries in mobility. There is clearly one very prominent piece of information that induces the observed responses: *the pandemic*. We are going to assume that a pandemic is underway was already known mid February, and clearly since March it is known everywhere. In order to control for other factors that may impact the mobility decisions of individuals, we include in our model a variable which proxies the level of government restrictions to movements. We control for the severity of the outbreak by using the confirmed number of cases. Since the value of going out can be significantly affected by weather conditions, we incorporate daily average temperatures in the model.

In particular, let y_{kit} correspond to the mobility measure k, where k is one of {Retail and Recreation, Grocery and Pharmacy, Parks, Transit Stations, Workplaces, Residential} for country i on date t. We have daily observations of Stringency Index, SI_{it}, confirmed cases, CC_{it} and finally the daily average temperature, $temp_{it}$. In the regression, we include the logarithm of $1 + CC_{it}$.[5] We, therefore, first estimate the following model:

$$y_{kit} = \alpha_{ki} + \beta_{SI} SI_{it} + \beta_{CC} \log(1 + CC_{it}) + \beta_{temp} temp_{it} + \tau_{kt} + \varepsilon_{kit}. \tag{2}$$

Here, SI represents the stringency index developed by Hale et al. (2020) taken from the OxCGRT dataset. We take the confirmed number of cases, CC_{it}, from the same dataset. The average temperature in country i on date t is given by $temp_{it}$, and is constructed using the GHCN data.

In this specification we include two types of fixed effects. The country specific effects, α_{ki}, intend to capture the innate response of country i to the pandemic in terms of mobility measure k. The daily events which impact the behavior of everyone on earth are controlled by means of the date fixed effects τ_{kt}.

Let us first present the regression results we obtain from estimating the equation given in (2). In table 1, we present the regression results with and without date fixed effects. In both cases, robust standard errors are computed by clustering at country level. Qualitatively, the effects of variables we consider turn out to be similar with or without date fixed effects. An important distinction arises with respect to mobility in the residential areas compared to other locations. With the exception of residential areas,

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[5] Here we add one to the number of confirmed cases in order to avoid problems due to the scale observations that are zero.

the stringency of the measures, number of confirmed cases and deaths seem to be negatively related to mobility while temperature is positively related. As one should expect the mirror image of these effects apply for residential areas. All these results seem to be quite reasonable. We ran a series of Wald tests to decide whether or not to include the date fixed effects. The tests suggested in all 6 cases that the date fixed effects contribute significantly to the explanatory power of our empirical. Hence, we proceed with the model using date fixed effects.[6]

Note that the marginal effects of the stringency index and temperature are considerably larger than the marginal effects of the confirmed number of cases. Given our logarithmic specification of the effect of the confirmed cases, the marginal effect of an additional infection is given by the ratio of the coefficient and the total number of confirmed cases. Therefore, for large levels of the number of confirmed cases, the additional effect on mobility is very small. [7]

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[6] We also considered an extended version of the model which we do not report here. Namely, in the estimating equation we included the number of confirmed deaths as an additional explanatory variable. The correlation between this variable and the number of confirmed cases is very high. A series of Wald tests indicate that we cannot reject the hypothesis that the number of confirmed cases do not effect mobility for all of the six measures.

[7] We alternatively tried specifications where the number of confirmed cases enter the model linearly. The results indicated, as expected, also an extremely small marginal effect.

Table 1: Results for all mobility measures

	Dependent variable:											
	Retail & Recreation		Grocery & Pharmacy		Parks		Transit Stations		Workplaces		Residential	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
SI	-0.486^{***}	-0.379^{***}	-0.359^{***}	-0.316^{***}	-0.358^{***}	-0.280^{***}	-0.517^{***}	-0.381^{***}	-0.460^{***}	-0.343^{***}	0.206^{***}	0.149^{***}
	(0.033)	(0.046)	(0.030)	(0.043)	(0.048)	(0.059)	(0.035)	(0.042)	(0.032)	(0.043)	(0.016)	(0.019)
$\log(1+CC)$	-4.463^{***}	-3.642^{***}	-2.004^{***}	-1.182^{***}	-2.801^{***}	-2.403^{***}	-4.317^{***}	-2.993^{***}	-3.103^{***}	-2.461^{***}	1.328^{***}	0.807^{***}
	(0.368)	(0.489)	(0.358)	(0.447)	(0.728)	(0.903)	(0.368)	(0.496)	(0.337)	(0.420)	(0.169)	(0.222)
temp	0.530^{***}	0.544^{***}	0.386^{**}	0.459^{***}	1.717^{***}	1.644^{***}	0.725^{***}	0.790^{***}	0.522^{***}	0.469^{***}	-0.397^{***}	-0.416^{***}
	(0.139)	(0.167)	(0.157)	(0.175)	(0.230)	(0.222)	(0.124)	(0.160)	(0.136)	(0.169)	(0.049)	(0.063)
Country FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Observations	7,121	7,121	7,119	7,119	7,121	7,121	7,121	7,121	7,121	7,121	7,090	7,090
R^2	0.929	0.941	0.746	0.792	0.720	0.733	0.941	0.951	0.877	0.907	0.904	0.927
Adjusted R^2	0.928	0.940	0.742	0.787	0.716	0.726	0.940	0.950	0.875	0.905	0.903	0.925
F Statistic	870.464^{***}	632.956^{***}	195.964^{***}	151.268^{***}	171.783^{***}	108.707^{***}	$1,062.319^{***}$	776.315^{***}	474.604^{***}	386.679^{***}	627.260^{***}	502.245^{***}

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

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3.2 Understanding the innate attitudes towards mobility

We next take the country fixed effects from the regressions with date fixed effects as reported in table 1. For each mobility measure, this gives us a country specific index of mobility for the six areas considered which are corrected for stringency of measures, severity of the outbreak as well as the weather conditions. These country specific effects can be interpreted to be an indication of the mobility that would take place at the beginning of an outbreak when the population only knows that there is a coming outbreak. Any changes in mobility in such a situation would possibly depend on the institutions of the country and the cultural traits that define the populace in each country. The cultural variable that we focus on intends to capture the trust between the individuals in each country. Thus, we run a regression with the following specification:

$$\alpha_{ki} = \mu_k + \eta Trust_i + \varepsilon_{ki}, \tag{3}$$

where $Trust_i$ is the trust index we calculated using the formula given in equation 1 and using data from the WVS and EVS. The dependent variable α_{ki} is the adjusted mobility measure in country i for area k. The results are presented in table 2.

The result is rather striking. First, this index has quite a bit of explanatory power with regard to innate mobility attitudes of nations. Second, the effect of trust is significantly positive for all measures except for mobility around residential areas. This implies that there is a correlation between mobility around public places and trust of others in the populace. Interestingly, the mobility around residential areas are negatively related to trust.

It is tempting to interpret this finding causally, although it is clear that there may be a number reasons for finding such a correlation. The most obvious objection to this finding would be perhaps that trust acts as a proxy for something else. A number of studies have found important effects of trust on economic outcomes. For example, Tabellini (2010) argues that there is a causal relationship between economic development and trust. Guiso, Sapienza, and Zingales (2006) present a survey of the impact of trust on economic activity. Therefore, one can imagine that perhaps trust in the regressions presented in table 2 is proxying for some other socioeconomic factor which is causing the positive change in innate mobility.

In order to investigate whether trust has an effect after controlling for other economic determinants, we use another data set providing an index of public integrity for a large number of countries around the world. This data set is the international public integrity (IPI) dataset as compiled by Mungiu-Pippidi et al. (2017). The IPI index they develop combines a number of measures regarding the perceptions of the public on judiciary, press, administration, etc. The data set contains also measures on average

Table 2: Country Fixed Effects vs Trust

	Dependent variable:					
	Country Fixed Effect For The Category					
	Retail & Recreation	Grocery & Pharmacy	Parks	Transit Stations	Workplaces	Residential
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	-11.881^{***}	-11.367^{***}	-49.438^{***}	-14.585^{***}	-8.149^{***}	10.063^{***}
	(2.021)	(1.829)	(5.608)	(2.330)	(1.746)	(1.174)
trust	41.507^{***}	37.808^{***}	125.092^{***}	36.628^{***}	24.690^{***}	-20.775^{***}
	(6.121)	(5.540)	(16.986)	(7.059)	(5.289)	(3.556)
Observations	73	73	73	73	73	73
R^2	0.393	0.396	0.433	0.275	0.235	0.325
Adjusted R^2	0.385	0.388	0.425	0.265	0.224	0.315
F Statistic	45.987^{***}	46.575^{***}	54.235^{***}	26.927^{***}	21.796^{***}	34.132^{***}

Note: *p<0.1; **p<0.05; ***p<0.01

number of schooling years in each country (*schooling*), the gross national income per capita (*gnipc*), and the fraction of the urban population (*urban*). We merge our adjusted mobility measure (country fixed effects), trust index we constructed from the WVS and EVS, and IPI-dataset, resulting in a match of 69 countries. The results of the regression of innate mobility measures for each country is presented in table 3.

It is interesting to see that after controlling for a number of socioeconomic factors, trust remains to be an important explanatory variable in understanding the innate mobility attitudes of people around the world. The other control variables have mostly expected signs, and the regressions explain quite a large chunk of the variance in the underlying data. Therefore, we interpret this finding as a clear indication of a positive link between trust and mobility in a world facing a pandemic.

In the rest of the paper, we develop a theoretical model which provides a possible mechanism of how this observation may arise.

Table 3: Country Fixed Effects vs Trust

	Dependent variable:					
	Country Fixed Effect For The Category					
	Retail & Recreation	Grocery & Pharmacy	Parks	Transit Stations	Workplaces	Residential
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	−31.646*	−51.342***	−95.599**	−56.671***	−33.135**	24.920***
	(16.494)	(12.995)	(36.920)	(16.782)	(14.594)	(7.847)
trust	28.909***	18.169***	76.062***	15.107*	18.830***	−11.521***
	(7.787)	(6.135)	(17.431)	(7.923)	(6.890)	(3.705)
IPI	2.504**	1.731*	7.080**	2.222*	0.808	−0.807
	(1.253)	(0.987)	(2.804)	(1.274)	(1.108)	(0.596)
log(gnipc)	1.066	3.311	−0.495	3.886	3.491	−1.077
	(2.608)	(2.055)	(5.837)	(2.653)	(2.307)	(1.241)
schooling	0.343	0.975*	5.863***	1.468**	−0.279	−1.101***
	(0.714)	(0.563)	(1.599)	(0.727)	(0.632)	(0.340)
urban	−0.122	−0.130*	−0.645***	−0.300***	−0.154**	0.143***
	(0.087)	(0.068)	(0.194)	(0.088)	(0.077)	(0.041)
Observations	69	69	69	69	69	69
R^2	0.470	0.602	0.674	0.506	0.301	0.587
Adjusted R^2	0.428	0.570	0.648	0.467	0.245	0.55 4
F Statistic	11.190***	19.021***	26.063***	12.899***	5.417***	17.921***

Note: *p<0.1; **p<0.05; ***p<0.01

4 Model

There are a continuum of individuals. At any given time an individual can be in one of many states. Here we focus on the decisions of those who are either susceptible but not yet infected, or infected and contagious but not yet sick (and hence do not yet know that they are contagious.) We refer to these groups as *susceptible* and *contagious*. Susceptible can catch the disease and contagious can infect others only if they go out. Even if they go out, susceptible are less likely to catch the disease if they protect themselves. Protection involves wearing a mask, using other protective equipment, washing hands, etc. It may also involve paying attention to staying away from other people. We assume that protection requires costly effort.

Another factor that lowers the likelihood of susceptible to become infected is the level of protection in the community. In the model below we assume that susceptible are less likely to catch the disease if average protection in their community is higher.

An individual may also be infected and sick. We assume that sick individuals simply stay at home or at a hospital. An individual may also recover (after having mild or severe symptoms). We assume recovered individuals become immune. Immune agents always choose to go out so their decision is not interesting.[8]

We normalize the total number of susceptible and contagious to 1 and index them by $i \in [0,1]$. We assume that the size of the contagious group is $\kappa \in (0,1)$.

Each individual i makes two decisions. The first is whether to go out or stay in. We normalize the benefit of staying in to zero. Individuals are heterogenous in terms of how much value they attach to going out. Individual i's value of going out relative to staying in is β_i which is distributed according to a distribution F over $[0,\overline{\beta}]$ with strictly positive density f. We denote the survival function of F by $\widetilde{F} = 1 - F$.

If individual i chooses to go out, then she decides how much effort to exert for protection. We denote the effort by $e_i \geq 0$. We let $\overline{e} = \frac{1}{\Pr(G)} \int_{i \in G} e_i di$ be the average effort exerted by the agents who go out where G is the set of agents who go out.

Individuals incur a cost from protection effort. Suppose e^N is the norm or the expectation of how much effort should be put for protection in the community. We assume that the cost that an individual experiences depends both on the absolute level of the effort and the individual's effort relative to the

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[8] If there are a substantial number of immune agents, in the empirical part we need to take them into account. We ignore this group in our empirical study for two reasons. First, it is not clear how much immunity is gained by those who contract the disease. Second, at this time, the number of immune agents is very small relative to the size of the population.

norm. We write the cost function as $c_D(e_i) + \eta c_N(e_i - e^N)$ where c_D captures the direct cost, c_N captures the cost of deviating from the norm. The additive form reflects the fact that changes in the norm do not influence the direct cost of effort. The parameter η reflects the importance of obeying the norm. When η is higher and individuals find it costlier to move away the social norm, we say that there is more trust in the society. We assume $c_D' > 0$ and $c_D'' \geq 0$, that is cost function is strictly increasing and convex, and $c_N(0) = 0$, $c_N'(e) < 0$ for $e < 0$, $c_N'(e) > 0$ for $e > 0$ and $c_N'' \geq 0$, that is, the cost of deviating from the norm is minimized at e^N and is strictly increasing if the effort moves away from the norm.

Let R be the infectiousness of the disease and π be the fraction of agents who go out. We assume that the probability of contracting the disease is a function of R, π and κ, as well as individual i's protection effort e_i and the average protection effort of the community $\overline{e}$. The probability of contracting the disease is then captured by a function $p(e_i, \overline{e}, \pi, R, \kappa)$. Since R and κ remain as exogenous parameters in the equilibrium analysis we suppress them in what follows and write this function as $p(e_i, \overline{e}, \pi)$. This probability is decreasing in the first two factors and increasing in the third, i.e. $p_1 < 0$, $p_2 < 0$ and $p_3 > 0$ where subscripts denote partial derivatives. We make the following intuitive assumptions about the second order derivatives of p :

- $p_{11} > 0$, that is, as protection effort goes up, the decrease in the probability of contracting the disease is declining,
- $p_{11} + p_{12} > 0$, which is automatically satisfied if individual and community protection are complements ($p_{12} > 0$) but is also satisfied if substitutability between the two is not too strong,
- $p_{13} \leq 0$, that is, as the proportion of people who go out increases, marginal impact of protection effort in lowering the probability of contracting the disease is larger.

Putting all this together we write the utility of going out as:

$$\beta_i - c_D(e_i) - \eta c_N(e_i - e^N) - p(e_i, \overline{e}, \pi) v$$

where v is the payoff loss associated with getting infected.[9]

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[9] In this static model we assume that there is no discounting. In a dynamic model v would incorporate the discount rate of getting sick in the future, although given the relatively short incubation period, individuals are not likely to discount the cost of getting sick by much.

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4.1 Equilibrium

Conditional on getting out agent i chooses e_i^* so that

$$c_D'\left(e_i^*\right)+\eta c_N'\left(e_i^*-e^N\right)+p_1\left(e_i^*,\overline{e},\pi\right)v=0 \tag{4}$$

In equilibrium all agents choose the same effort level so $e_i^*=\overline{e}$. Therefore the equilibrium level of effort is given by:

$$c_D'\left(\overline{e}\right)+\eta c_N'\left(\overline{e}-e^N\right)+p_1\left(\overline{e},\overline{e},\pi\right)v=0 \tag{5}$$

Let

$$\widehat{\beta}=c_D\left(\overline{e}\right)+\eta c_N\left(\overline{e}-e^N\right)+p\left(\overline{e},\overline{e},\pi\right)v.$$

All agents with $\beta_i\geq\widehat{\beta}$ choose to go out. Hence $\pi=\widetilde{F}\left(\widehat{\beta}\right)$, and in equilibrium the proportion of agents who go out is given by:

$$\pi=\widetilde{F}\left(c_D\left(\overline{e}\right)+\eta c_N\left(\overline{e}-e^N\right)+p\left(\overline{e},\overline{e},\pi\right)v\right) \tag{6}$$

where $\overline{e}$ is given by (5).

The equilibrium level of effort $\overline{e}$ may be more or less than the norm e^N depending on the net marginal cost (i.e., marginal cost of effort minus the marginal benefit from reducing the probability of infection) that each individual obtains when the community follows the norm. If the net marginal cost is positive, an individual can benefit from moving slightly away from the norm by lowering her effort. This change lowers the net overall cost since moving away from the norm has a zero first order effect. The following lemma formalizes this discussion.

Lemma 1. *Suppose*

$$c_D'\left(e^N\right)+p_1\left(e^N,e^N,\pi\right)v\gtreqless 0,$$

then $\overline{e}\lesseqgtr e^N$.

Proof. Note that

$$c_D'\left(e\right)+\eta c_N'\left(e-e^N\right)+p_1\left(e,e,\pi\right)v$$

is increasing in e since

$$c_D''+\eta c_N''+\left(p_{11}+p_{12}\right)v>0.$$

Equilibrium effort satisfies

$$c_D'\left(\overline{e}\right)+\eta c_N'\left(\overline{e}-e^N\right)+p_1\left(\overline{e},\overline{e},\pi\right)v=0.$$

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Hence

$$c'_D\left(e^N\right)+p_1\left(e^N,e^N,\pi\right)v>0$$

then we must have $\overline{e}<e^N$. Other cases follow similarly. □

4.2 Comparative statics with respect to the norm e^N

We turn to comparative statics with respect to e^N. When e^N increases, it affects the equilibrium effort in several ways. First, there is a direct effect: agents would like to remain close to the norm so they increase their protection effort. There are also indirect effects. Since the community effort increases, it can substitute for individual effort and cause it to go down. This effect is not critical when the substitutability between the two is not too strong. In addition, there is a complex interaction between the increased individual effort and the proportion of agents who go out. If the increased effort leads to a large drop in the proportion of agents who go out, then agents might lower their protection efforts. If the density f at $\widehat{\beta}$ is not too large then this last effect is small. This would be the case when there is enough heterogeneity in agents' preferences for going out. The next proposition states the result.

Proposition 2. *The equilibrium effort $\overline{e}$ is increasing in e^N if the density at the threshold, $f\left(\widehat{\beta}\right)$, is low enough.*

Proof. Taking the total derivative of (6) with respect to e^N we obtain:

$$\frac{\partial\pi}{\partial e^N}\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_3v\right)=-f\left(\widetilde{F}^{-1}\left(\pi\right)\right)\left(-\eta c'_N+p_2v\frac{\partial\overline{e}}{\partial e^N}\right) \tag{7}$$

Let $A=c''_D\left(\overline{e}\right)+\eta c''_N\left(\overline{e}-e^N\right)+\left(p_{11}\left(\overline{e},\overline{e},\pi\right)+p_{12}\left(\overline{e},\overline{e},\pi\right)\right)v>0$. Taking the total derivative of (5) with respect to e^N we obtain:

$$\frac{\partial\overline{e}}{\partial e^N}A-\eta c''_N+p_{13}v\frac{\partial\pi}{\partial e^N}=0. \tag{8}$$

Combining (7) and (8) we obtain:

$$\frac{\partial\overline{e}}{\partial e^N}A=\eta c''_N-p_{13}v\frac{-f\left(\widetilde{F}^{-1}\left(\pi\right)\right)\left(-\eta c'_N+p_2v\frac{\partial\overline{e}}{\partial e^N}\right)}{\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_3v\right)},$$

or

$$\frac{\partial\overline{e}}{\partial e^N}\left(A-\frac{f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_{13}p_2v^2}{\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_3v\right)}\right)=\eta c''_N-\frac{f\left(\widetilde{F}^{-1}\left(\pi\right)\right)\eta c'_Np_{13}v}{\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_3v\right)}.$$

Since both A and c''_N are strictly positive, $\frac{\partial\overline{e}}{\partial e^N}$ is strictly positive if $f\left(\widetilde{F}^{-1}\left(\pi\right)\right)=f\left(\widehat{\beta}\right)$ is small enough. □

We next consider how an increase in e^N impacts the proportion of agents who go out, π.

Proposition 3. *The proportion of agents who go out in equilibrium, π, is increasing in e^N if*

$$\frac{\partial \overline{e}}{\partial e^N} p_2 v - \eta c_N' < 0. \tag{9}$$

Proof. Follows directly from (7). □

Suppose that when the norm increases, community protection goes up. Then an individual who goes out is less likely to contract the disease. The first term in (9) captures this effect. The second term is the decline in the cost of not obeying the norm. When $\overline{e} > e^N$, $c_N' > 0$ and when the norm goes up agents experience an overall increase in benefit from going out. When $\overline{e} < e^N$, $c_N' < 0$ and there is a tradeoff. Agents benefit through the higher community protection but lose because it becomes more demanding to obey the norm. Even in this case, when the first effect is stronger more agents choose to go out.

4.3 Comparative statics with respect to the importance of the norm η

The importance of the norm affects the equilibrium effort in several ways. The most important direct effect is that all agents move their equilibrium actions towards the norm. When the equilibrium action is below the norm this results in an increase in protection. When the equilibrium action is above the norm, however, it can lead to a decrease in the equilibrium action. If we interpret the norm as the ideal actions that policy makers would like people to adopt, it is likely that in most countries equilibrium level of protection is below the norm. As in the previous subsection, there is also an effect that works through the impact of η on π. However, this effect is low when the density f is not too large at $\widehat{\beta}$.

Proposition 4. *The equilibrium effort $\overline{e}$ is increasing in η if $\overline{e} < e^N$ and the density $f\left(\widetilde{F}^{-1}(\pi)\right) = f\left(\widehat{\beta}\right)$ is low enough.*

Proof. Taking the total derivative of (6) with respect to η we obtain:

$$\frac{\partial \pi}{\partial \eta}\left(1 + f\left(\widetilde{F}^{-1}(\pi)\right) p_3 v\right) = -f\left(\widetilde{F}^{-1}(\pi)\right)\left(c_N + p_2 v \frac{\partial \overline{e}}{\partial \eta}\right). \tag{10}$$

Let $A = c_D''(\overline{e}) + \eta c_N''\left(\overline{e} - e^N\right) + \left(p_{11}(\overline{e}, \overline{e}, \pi) + p_{12}(\overline{e}, \overline{e}, \pi)\right) v > 0$. Taking the total derivative of (5) with respect to η we obtain:

$$\frac{\partial \overline{e}}{\partial \eta} A + c_N' + p_{13} v \frac{\partial \pi}{\partial \eta} = 0. \tag{11}$$

Combining (10) and (11) we obtain:

$$\frac{\partial \overline{e}}{\partial \eta} A = -c_N' - p_{13} v \frac{-f\left(\widetilde{F}^{-1}(\pi)\right)\left(c_N + p_2 v \frac{\partial \overline{e}}{\partial \eta}\right)}{\left(1 + f\left(\widetilde{F}^{-1}(\pi)\right) p_3 v\right)},$$

or

$$\frac{\partial \overline{e}}{\partial \eta}\left(A-\frac{f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_{13}p_{2}v^{2}}{\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_{3}v\right)}\right)=-c_{N}'+\frac{f\left(\widetilde{F}^{-1}\left(\pi\right)\right)c_{N}p_{13}v}{\left(1+f\left(\widetilde{F}^{-1}\left(\pi\right)\right)p_{3}v\right)}.$$

Thus $\frac{\partial \overline{e}}{\partial \eta}$ is strictly positive if $c_N' < 0$ and $f\left(\widetilde{F}^{-1}\left(\pi\right)\right) = f\left(\widehat{\beta}\right)$ is small enough. Noticing that $c_N' < 0$ iff $\overline{e} < e^N$ completes the proof. ☐

We next consider how an increase in η impacts the proportion of agents who go out, π.

Proposition 5. *The proportion of agents who go out in equilibrium, π, is increasing in η iff*

$$c_N + p_2 v \frac{\partial \overline{e}}{\partial \eta} < 0. \tag{12}$$

Proof. Follows directly from (10). ☐

The intuition for this result is similar to the corresponding one for an increase in e^N. The first term in (12) corresponds to the increase in obeying the norm due to its increased importance. The second term is the gain through the change in community protection when $\overline{e}$ increases. When the second effect dominates, more people go out in communities where obeying the norm is more important.

5 Conclusion

In this paper we demonstrate empirically that in countries where people trust others, mobility during the Covid-19 pandemic has been relatively high. We suggest a simple reason for this behavior. When people trust that others will spend the effort and care to protect against the disease, they feel more confident about going out without taking too much risk of contracting the disease. As a result in countries where either norms about protective behaviors against the disease are more demanding or people put more weight on obeying the norm, people may go out more.

One of the messages that come out of our analysis is that trust and norms can be a double edge sword. When norms become more demanding, everyone takes more precuation against the disease. Since these actions have a positive externality in reducing the probability of contracting the disease, overall response might be to go out more. This change in behavior may improve or lower overall welfare. Interestingly, a planner whose goal is to minimize the number of people who contract the disease or keep the number below a certain threshold may prefer weaker norms.

There are many questions left for future research. How would incorporating norms influence the dynamics of the spreading of the disease? Our model is static, but it can relatively easily be incorporated into a standard SIR model to answer this question. What are optimal policies for a planner? As mentioned above correct policies depend on the planner's goals. However, even for a planner whose goal is to maximize total welfare, optimal policy mix is not obvious. What would be a good mix of mobility restrictions, minimum protection requirements and encouraging changes in the norm? The answer to this question depends among other factors on how much information the planner has about the preferences of the agents.

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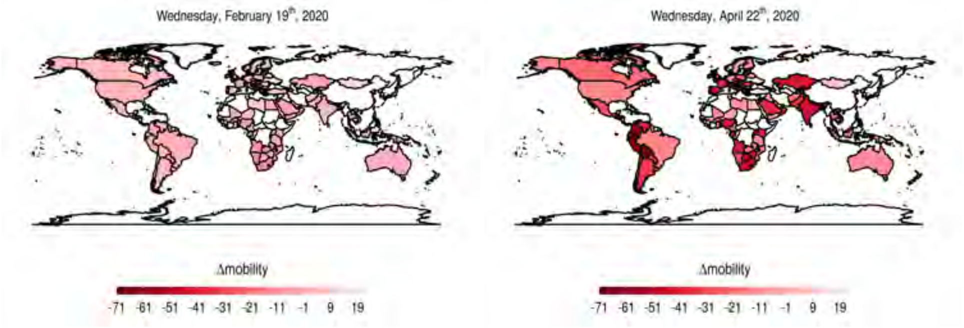
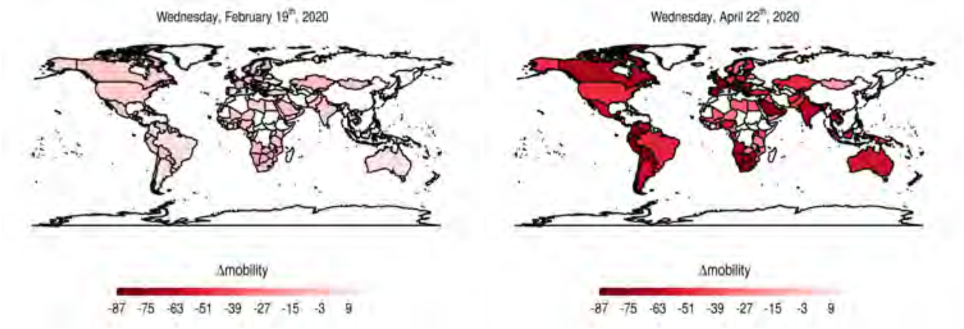
6 Appendix

Mobility heat-maps for the remaining four areas



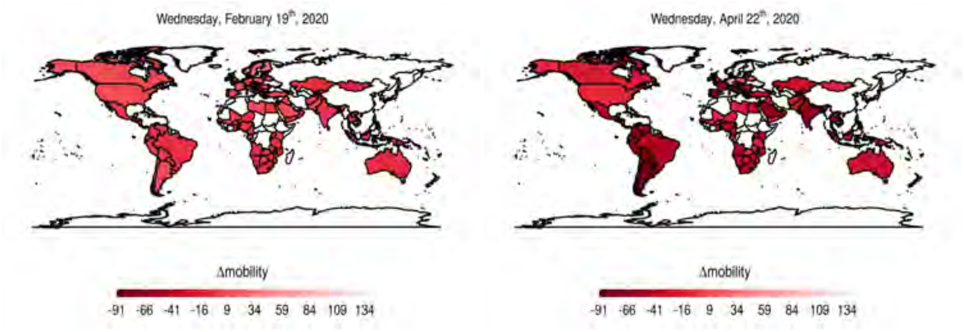
(a) (b)

Figure 6: Changes in mobility around groceries and phramacies



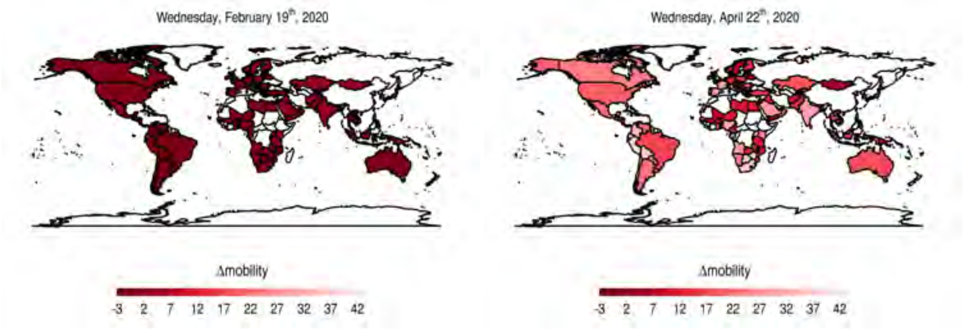
(a) (b)

Figure 7: Changes in mobility around transit stations



(a) (b)

Figure 8: Changes in mobility around parks



(a) (b)

Figure 9: Changes in mobility around residential areas

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Assessing the spread of the novel coronavirus in the absence of mass testing

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This note outlines a simple method for estimating the spread of the COVID 19 virus in the absence of data on test results for a large, random sample of the population. It applies the method to the UK, and other countries, and finds that to match data on daily new cases of the virus, the estimated model favours high values for the number of people infected but asymptomatic. That result is very sensitive to whether the transmission rate of the virus is different for symptomatic and asymptomatic cases, something about which there is significant uncertainty. This illustrates how difficult it is to estimate the spread of the virus until very large samples of the population can be tested. Nonetheless, there is evidence that the infection may have spread far enough to mean that the trajectory of falling new cases could be maintained with some easing of restrictions.

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1 Introduction

There is significant uncertainty about the degree to which the novel coronavirus (COVID19) has spread and infected people who show no obvious symptoms. This has very significant policy implications - Stock 2020 shows that different policies aimed at controlling the virus can have very different effects on the numbers who become infected and show symptoms depending on the proportion of those who are asymptomatic. It is those with symptoms who are at risk of death from the virus and so the relative size of the populations of symptomatic to asymptomatic amongst the infected is of enormous significance to welfare, including mortality rates, and to policy (Fauci, Lane, and Redfield 2020).

The degree of uncertainty about that asymptomatic rate is large enough to mean that neither 0.3 or 0.9 is outside the range of plausible values, though the implications of those two numbers are very different. Li *et al.* 2020 estimate that 86 per cent of all infections were undocumented prior to the Wuhan travel shutdown (on January 23, 2020). In contrast, estimates based on infections amongst passengers on the cruise ship Diamond Princess put the proportion of asymptomatic (or near asymptomatic) cases at around 50 per cent. Manski and Molinari 2020 report enormous ranges for the possible values of the infection rates in Illinois, New York and Italy. As of April 6th 2020 these ranges are estimated as [0.001, 0.517], [0.008, 0.645], and [0.003, 0.510] respectively.

While large scale testing of a random sample of the population would greatly narrow the range of plausible values for the asymptomatic proportion of the infected (Stock 2020), such testing seems some way off in most countries. In most countries, including the the USA and the UK, testing up to the end of April 2020 was concentrated on those who display symptoms or are at high risk; it was certainly not random.

In this note we implement a simple version of the SIR (susceptible-infected-recovered) model to estimate the asymptomatic rate from data on the non-random sample of those tested. We use data from the UK, where relatively few of those showing no symptoms had been tested up to the end of April 2020, to provide highly provisional estimates of the asymptomatic proportion of the infected. We find quite striking differences between what the simple model suggests is the asymptomatic rate and the much lower estimates based on the limited data of (near) random sampling.

We also apply the model to the US, Italy, Spain, France and Sweden. The results for those countries are similar to the UK - the value of the asymptomatic rate that seems to best fit the data is very high; far higher than is estimated based on the limited amount of results from more widespread testing which went beyond those who showed symptoms.

We consider what might account for such differences and find that the degree to which the asymptomatic spread the virus - and whether it is substantially lower than for the symptomatic - is of great significance. There is limited evidence on this which makes it hard to assess the spread of the virus, creating great challenges for policies on easing "lockdown" measures. If the spread of the virus is wide, and had been a factor in the observed decline of new cases up to the end of April, an easing of restrictions poses fewer risk of a sharp upwards spike in infections. However, the confidence interval for the estimated ratio of the numbers of infected with mild (or no) symptoms to the numbers of symptomatic is quite wide.

2 The Model

We use a version of the SIR model which closely follows Stock 2020. At each point in time the population is made up of three distinct groups: those who are currently infected (I_t); those who are susceptible (S_t) and those who have recovered (R_t). We assume a constant population and that the death rate is low enough to mean that this is reasonable. We also assume that some constant proportion (π_a) of those infected do not develop symptoms – or that they are so mild as to count as asymptomatic. There is some evidence that the degree to which the asymptomatic are infectious may be different from those who have symptoms (Ferguson *et al.* 2020), but we will initially assume that the transmission rates are the same for all those infected. We denote the population of the symptomatic infected at time t by I_{st} and the asymptomatic as I_{at} such that $I_t = I_{st} + I_{at}$. The evolution of S_t, I_t and R_t in discrete time is given by the dynamic system:

$$\Delta S_t = -\beta_t I_{t-1} \frac{S_{t-1}}{N} \tag{1}$$

$$\Delta R_t = \gamma I_{t-1} \tag{2}$$

$$\Delta I_t = \beta_t I_{t-1} \frac{S_{t-1}}{N} - \gamma I_{t-1}, \tag{3}$$

ΔS is the change in the population of the susceptible; N is the total population, β_t is the transmission rate of the virus at a time t (the mean number of people an infectious person will infect per unit time) and γ is the rate of recovery. The initial infection rate over the infectious period, the reproduction number, is defined as $R_0 = \frac{\beta_t}{\gamma}$. We assume that the infectious group I_t is made up of symptomatic and asymptomatic groups in fixed proportions such that

$$I_{st} = (1 - \pi_a) I_t \tag{4}$$

and

$$I_{at} = \pi_a I_t. \tag{5}$$

The number of new cases at time t (y_t) can be calculated as

$$y_t = \Delta I_t + \gamma I_{t-1}. \tag{6}$$

New cases are the sum of the change in the number of outstanding cases plus the numbers recovered. The number of new symptomatic cases (y_{st}) is

$$y_{st} = (1 - \pi_a)(\Delta I_t + \gamma I_{t-1}) = (1 - \pi_a)\left(\beta_t I_{t-1} \frac{S_{t-1}}{N}\right). \tag{7}$$

We make the key assumptions that: a large fraction of the symptomatic are tested; that a small proportion of the asymptomatic are tested; and that the test is reliable. This would mean that the observable number of those who test positive would closely track the quantity

(y_{st}). The strategy that we pursue is to use the data on the numbers of new cases who test positive for the virus and to assume that this closely follows the true number of newly infectious symptomatic people. We then seek the values of the parameters of the model - and in particular π_a - that give a predicted y_{st} that matches the data. The strategy is similar to that adopted in the study by Lourenço *et al.* 2020 who estimated that a high proportion of the UK population may have been infected even by early March 2020. But there are two important differences with the procedure we follow. First, we use data on the numbers of those who test positive (in the UK and in other countries) as the variable we are trying to match; the Gupta study used the number of deaths. There would seem to be significant ambiguity over assignment of the cause of death to the virus, perhaps more than over whether a positive test is reliable or not. Second, the study based on deaths looked at a short period when deaths were low and rising fast by early March. We use data on tests up the end of April by which time nearly 500,000 had been tested in the UK and around 175,000 had tested positive (according to data from the Office of National Statistics).

To implement the estimation of the model we need to make assumptions about the transmission rate of the virus β_t and the recovery rate γ. The transmission rate will not have been constant because of policy measures introduced to slow the spread of the infection. In the UK "lockdown", which began on March 23rd, has been strict and social distancing will likely have brought it down significantly. Similar policies were adopted at various times in March 2020 in other countries. We assume a constant value of β_t before the lockdown date (of β_0), followed by a gradual reduction in the β_t value after this date to simulate the effect the measures have on transmission. The initial value of β_0 is derived from assumed values of the initial reproduction rate R_0 and the recovery rate γ, using the relation $\beta_0 = \gamma R_0$. We try all values for an initial transmission rate ranging from 2.2 up to 3.9 at intervals of 0.005. We try three values of the recovery rate implied by half lives of the period of infectiousness - that is the number of days it takes for half an initial number of infected people to recover - of 4 days, 6 days (as used by Stock 2020) and 8 days. The corresponding three values of γ are 0.159, 0.109 and 0.0833.

We assume that after the lockdown date there is a lag until the value of β_t starts to change from β_0. The lag is between the lockdown measures starting and the impact on the numbers testing positive for the virus. That lag reflects several distinct factors: it must include the lag in the impact on new infections, the lag before symptoms show, the lag before testing the symptomatic and finally the lag before results are known and recorded in the daily measure. We set the overall lag at 14 days, but also assess sensitivity of results to shorter lags. After this lag, β decays exponentially towards a value of β_L, the post lockdown asymptotic β. The time path for β_t can be expressed as

$$\beta_t = \begin{cases} \beta_0, & \text{if } t \leq t^* \\ \beta_0 - (\beta_0 - \beta_L)(1 - e^{-(t-t^*)\lambda}) & \text{if } t > t^*, \end{cases} \tag{8}$$

where t^* is the lockdown time plus the 14 day lag period and λ is the speed of adjustment in β after lockdown measures begin to take effect. We assume that once the lockdown does begin to affect numbers testing positive it quite quickly reaches its full effectiveness, bringing the transmission rate down so that half of its long run impact on β comes through in 3 days, implying that $\lambda = 0.231$.

For given values of γ, β_0 and λ we search for the values of the two free parameters - β_L and π_a - so as to maximise the fit of the model. We chose those two free parameters to minimise the sum of squared deviations between the daily data on the numbers of new positive tests for the virus and the model prediction of that number (y_{st}). The parameters we fit are a measure of how effective the lockdown is in bringing down the infection rate (measured by how much lower β_L is relative to β_0) and the ratio of those infected with no symptoms to the total population of the infected (π_a).

3 Sensitivity to key assumptions and calibration

Before showing results we stress that our model relies on a number of key assumptions.

We assume that those who have been tested up to the end of April 2020 are overwhelmingly those with symptoms and that a very high proportion of those who have significant symptoms are tested. Neither assumption is an exact approximation to reality in the UK or elsewhere for a number of reasons. In the UK there has not been an entirely consistent policy on testing in hospitals - some test those who present symptoms, others with sufficient resources have done more widespread testing of patients regardless of symptoms. But, overall, relatively few in the UK with no symptoms have been tested up to the end of April 2020, and a high proportion of those with symptoms serious enough to be admitted to hospitals have been tested.

For the UK the model is initialised on data from the 31st of January, the date on which the first non zero value of positive test cases is recorded. At this time, testing was only applied to those who had travelled to certain regions of China and presented with symptoms and therefore data in the first week or so may not be fully representative of all symptomatic cases. Nevertheless, the criteria for testing was quickly widened. The data we have on recorded positive tests is clearly imperfect but it is the closest available to the model variable y_{st}.

We rely on estimates of R_0 and of γ to generate a value for β_0. There is considerable uncertainty about both. At the lower end of the ranges of values used in simulations are those chosen by Ferguson *et al.* 2020, who assume a value of 2.4, and Lourenço *et al.* 2020 who take figures centred around 2.25 or 2.75. Stock 2020, who draws on estimates using data from Wuhan, uses a much higher figure for simulations with a pre-shutdown value for R_0 of 3.8. The range of estimates of R_0 from several studies is between 2.2 and as high as 3.9. A team at the London School of Hygiene and Tropical Medicine found 11 published estimates of R0 for Covid-19, which averaged 2.68 with a standard deviation of 0.57 (see Paul Taylor, London Review of Books, May 2020, vol 42, no 9). The range we use for simulations is 2.2 to 3.9 - values outside this range gave a poor fit to the data for all countries we analysed for any values of the other parameters. For our estimate of γ we assume the half life of the infection as x days and therefore that γ satisfies the equation $(1-\gamma)^x = 0.5$. We take x as 4, 6 or 8 days - a range which encompasses those used in several studies.

As noted above we assume that once lockdown begins beta is reduced so that it declines asymptotically towards a value that would then be maintained as long as the lockdown remains in place (β_L in our equations). Our choice of the speed with which beta declines towards its steady-state value, after the initial lag, is such that the transition is fairly rapid, corresponding to a half life of 3 days ($\lambda = 0.231$).

A final key assumption is that new symptomatic infections are generated from the total current population of the infected (symptomatic and asymptomatic) and that the degree of infectiousness is the same across the infected. The number of new cases of those with symptoms will therefore be higher, for a given number of existing infected people with symptoms, the higher is the asymptomatic rate (π_a). It is also higher the larger β is. It is this dependence which allows us to use data on the numbers of newly tested infected with symptoms to infer something about π_a and also to learn about the impact of policy (the lockdown) from the change in the trajectory of new cases after it came into effect.

The data we try to fit is the number of new infections recorded where we assume that all such new cases have some symptoms. Testing of people with no symptoms has (up to late April 2020) been relatively small scale in the countries we analyse and to a large extent limited to those at high risk. There has been no very large scale testing of a reliably random sample of the population. We use a grid search to find the values of the two unknown and free parameters (β_L and π_a) to minimise the root mean squared deviation between the observations and (y_{st}), given the choice of other parameters.

4 Results

Figure 1 shows the data on new cases of those testing positive for the virus in the UK. The data start on January 31st. The data is from the Office for National Statistics. (The spike in reported new cases on 11/04/2020 coincides with an expansion in testing capacity).

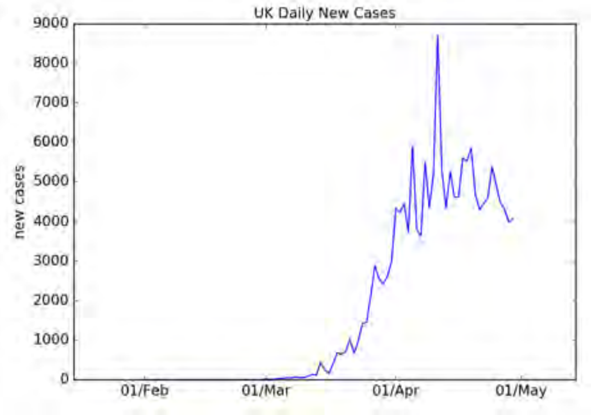

Figure 1. Time series of daily new positive COVID19 cases recorded in the UK between January 31st and April 30th 2020.

Figure 2 shows the best fit of the model when we set the half life of the infection to 6 days (γ=0.109). The best fit for this value of γ was when $R_0 = 2.5$ and β_L and π_a are 0.1928 and 0.996 respectively. These values imply that the transmission rate started to turn down sharply by the end of first week of April, some 2 weeks after the lockdown began. The value for π_a is very high - implying that there are around 250 people who have had the infection with no symptoms (or very mild symptoms) for every person infected with symptoms. If that were true then by April 20th - by which time around 120,000 had tested positive for the virus (and the great majority of whom had shown symptoms) close to 45% of the UK population might have had the virus.

Figure 3 shows the root mean square error of the model for all combinations of parameters π_a and β_L. The shape of this measure of fit illustrates several things. The dark shaded area on the far right of the figure (highest RMS errors) suggest the lockdown had an impact. The steeply downward sloping bands of different shades suggest that in terms of fitting the data if one increases (reduces) the assessed effectiveness of the lockdown the assumed asymptomatic rate would be lower (higher). In other words, to fit the data reducing the estimate of the share of the asymptomatic (π_a) can be partially offset by raising the assumed effectiveness of the lockdown (reducing β_L).

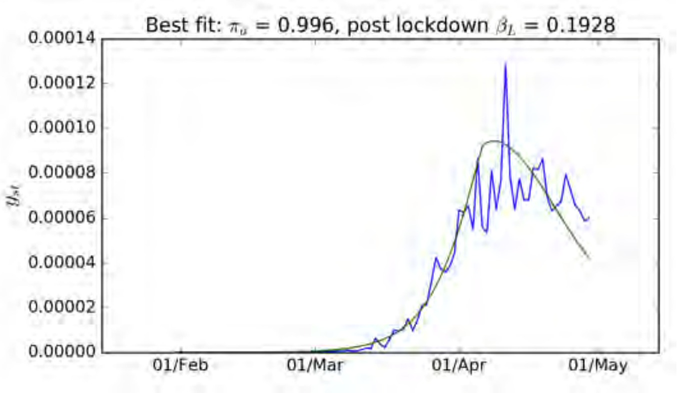

Figure 2. Results from the free parameter optimisation of the model with $\gamma = 0.109$. **a**: UK new case data from figure 1 given as a proportion of total population (blue) and model simulation for y_{st} that gives the best fit to the UK data (green).

Figure 4 shows the model fit to the UK data when we set the half life of the virus at 8 days (γ =0.0833). The best fit here was with a value of R0 of 2.95 and β_L and π_a of 0.1598 and 0.996 respectively. Once again the best fit value of π_a is very high and once again it implies that approximately 45% of the UK population may have been infected by late April. Figure 5 shows the parameter combinations that have a goodness of fit within 10% of the best pair of values; once again these are bunched fairly closely around the best fit values with all such pairs generating a value of π_a close to 0.996. The fit of the model deteriorates so sharply when we set the half life of the virus to be only 4 days that we do not show those results.

The parameter space in figure 5 shows the best fit parameters (red dot) and also the parameter combinations that generate a root mean squared error within 10% of the best value. This is illustrative of the degree of uncertainty around the best fit values of the two parameters. However, it is difficult to construct precise confidence regions around the best-fit parameter estimates. Under restrictive assumptions, the parameter space within which the

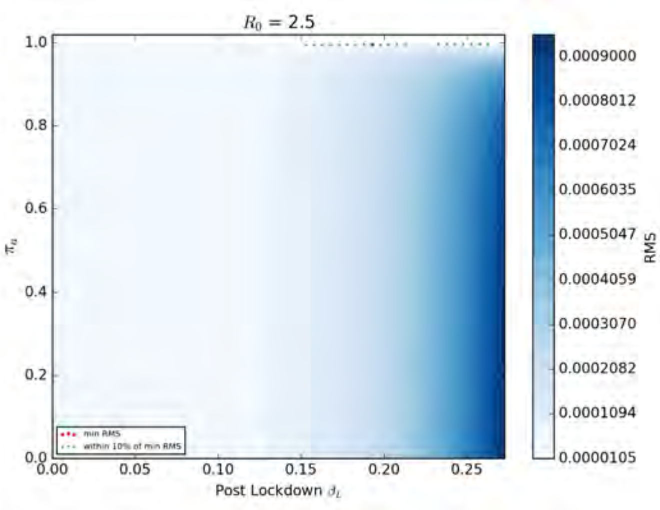

Figure 3. RMS difference between UK new case data and y_{st} for all combinations of π_a and β_L for simulations with $\gamma = 0.109$. The combination that gives the lowest RMS value (the best fit) is shown as a red dot. The combinations that give and RMS value within 10% of the minimum RMS are shown in green.

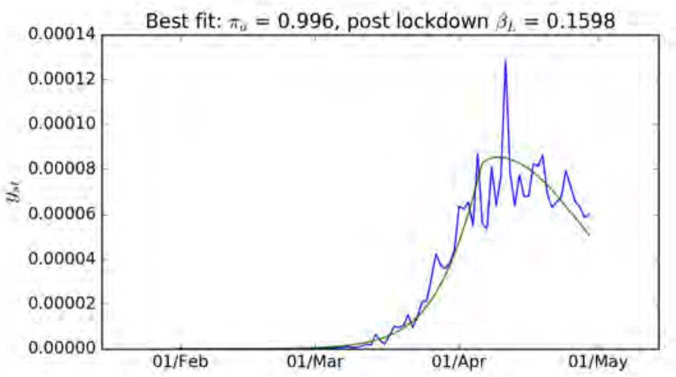

Figure 4. Like figure 2 with $\gamma = 0.0833$

standard error of the model is within 10% of the best fit would very likely contain the true parameter values. Standard tests based on the assumption of independent and normally distributed residuals between data and the fit of the model would imply a small chance of parameters lying outside this area. The statistic $T(ln(\frac{RSS_r}{RSS^*}))$, where RSS^* is the unrestricted minimum residual sum of squares, RSS_r is the sum of squared residuals at some other restricted value of the parameters and T is the sample size (in this case number of days we run the simulation over) would follow a χ^2 distribution if all the ideal assumptions for OLS estimation were satisfied. At a T value of 90 the 1% confidence region for that statistic with two estimated parameters would include only values where the standard error of the

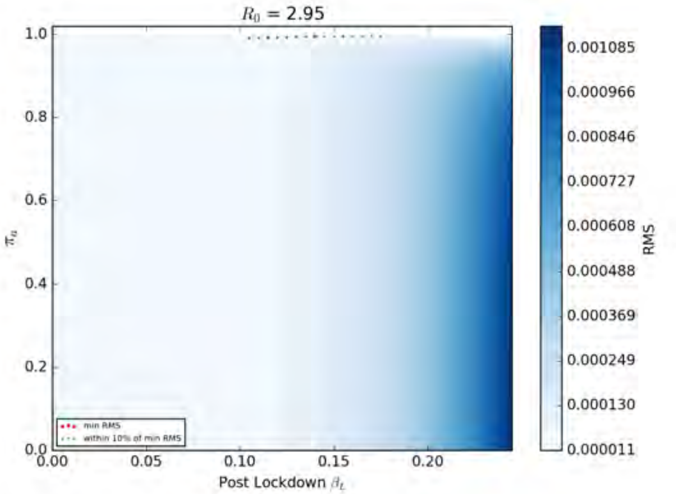

Figure 5. Like figure 3 with $\gamma = 0.0833$

model were within around 5.2% of the best value. An F version of this test, based on the statistic $[\frac{(RSSr-RSS*)}{k}]/[\frac{RSS*}{T-k}]$ and where $T = 90$, $k = 2$ would imply a 1% confidence region including parameters generating a standard error no more than around 5.6% above the best fit value. However, the conditions for these parametric methods to be a reliable guide to the uncertainty over parameter estimates do not hold: the model is highly non-linear and the values of state variable used to generate predictions of y_{st} - that is I_{t-1} and S_{t-1} - are themselves generated using the estimated parameters. To overcome this, we use a simple bootstrap technique to judge confidence intervals for the parameters. We take the set of T squared residuals between data and the model using the best fit parameter values and also construct T squared residuals at some other point in the parameter space we wish to compare to. We construct a pooled square residual dataset by combining the two sets (giving $2T$ values), from which we randomly draw 2 samples (without replacement) each of size T. For each pair of samples we calculate the mean difference between them. We repeat this 10,000 times and construct the frequency distribution of outcomes. We then calculate where the actual mean difference in squared residuals between the two parameter estimates is in this sample distribution. An example of such a distribution is shown in figure 6. It is produced by taking the point in figure 5 which gives the best fit and comparing the residuals to another point in parameter space defined by ($\pi_a = 0.9$ and $\beta_L = 0.007$). This value of β_L is chosen as it minimises the RMS for $\pi_a = 0.9$. The mean of the distribution of constructed differences in sums of square residuals is very close to zero (its expected value) and the actual difference in squared residuals based on the two sets of parameter estimates lies at around the 91st percentile of the distribution. We find this to be the case when the best fit parameters are compared to all combinations of values when β_L is lower than approximately 0.12 and π_a is less than 0.9. This suggests that these regions of parameter space can be rejected but only

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with moderate (90%) confidence.

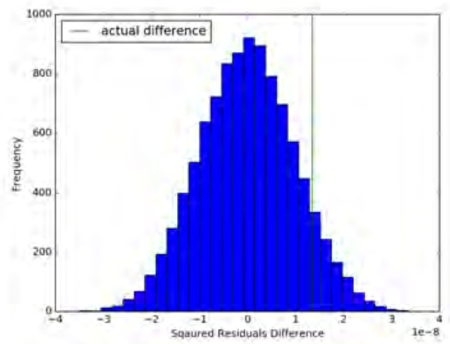

Figure 6. Frequency distribution (produced using the bootstrap method) of squared residual differences between points in parameter space defined by the best fit from figure 5 where $\pi_a = 0.996$ and $\beta_L = 0.1598$ and the point at $\pi_a = 0.9$ and $\beta_L = 0.07$. The Green line represents the actual difference between mean squared residuals of the fits and lies at the 91st percentile of the distribution.

While the parameter space that generates a standard error within 10% of the best fit value (green dots) suggests that parameters significantly far from the red dot do significantly less well in accounting for the UK data (conditional on the wide range of assumptions we have made), the interval at a less than 10% significance level defined by our bootstrapping method is relatively wide and encompasses low values of π_a. Using these intervals, one could reject a value of π_a below 0.9 at the 10% level, but not at higher levels. In short, one cannot be sure that the main reason why test cases of those newly infected turned down was because a large fraction of the population had already been infected (very high π_a) rather than a low value of β_L (a very effective lockdown).

Nonetheless, as we describe in more detail below, we consistently find the best fit for the data (for both the UK and other countries) is for a very high value of π_a.

5 Results for France, US, Italy, Spain and Sweden

We estimated the same model for other countries where up to the end of April 2020 testing had largely confined to those with symptoms or those at high risk. Data for those testing positive comes from the Johns Hopkins data bank. Dates at which measures to reduce the spread of the virus became severe (the lockdown date) were taken from the Blavatnik Centre at Oxford university which has constructed an index of the severity of measures. We choose the date at which that index rises most sharply to be our starting date for lockdown measures. The dates used are outlined in table 1. For the US, the date is problematic because actions vary substantially across states.

The estimated impact of the measures (along with the asymptomatic) rate is freely estimated for each country. Since lockdown measures differ significantly across countries (mild in Sweden; severe in France) we expect estimates of the difference between β_L and β_0 could be substantial across countries. We would expect smaller differences in the estimated

Country	Lockdown Date
France	16 March
Spain	10 March
Italy	23 February
Sweden	19 March (partial lockdown)
USA	16 Mar (localised lockdown)

Table 1. Lockdown dates for various countries used for simulations.

asymptomatic rate, π_a

Figures 7-11 show the fit of the model for each country. The most striking result is that the values of π_a that best fit the national data on positive tests for the virus are consistently at very high levels - generally around 0.995 (though lower for the USA). As with the UK results, taken at face value this would mean that there are 200 or so people who have had the virus with few symptoms for every infected person who has had symptoms.

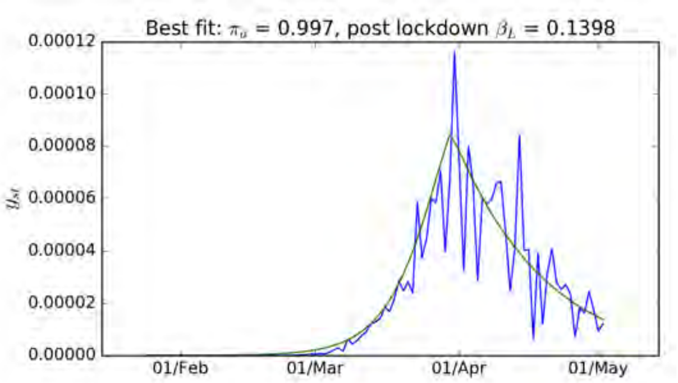

Figure 7. Model simulation for y_{st} that gives the best fit to data from France. $R_0 = 2.95$ and $\gamma = 0.083$

But what is equally striking, and much less reassuring, is that these best-fit estimates for π_a are much higher than those based on the rather limited test results from countries that went beyond testing only those with symptoms and which are therefore closer to being based on a random sample of the population. Ultimately tests based on a large and random sample of the population is the only way to be confident about how far the virus has spread. Evidence based on test results from what is closer to a random sample (even if the sample size is not large and the sample not truly representative of the whole population) should be given great weight. Those results suggest a value of π_a very much lower than the values we find to fit the data on tests when most of those tested had symptoms. Some cross country studies based on deaths associated with the virus (for example Flaxman *et al.* 2020) also suggest a significantly

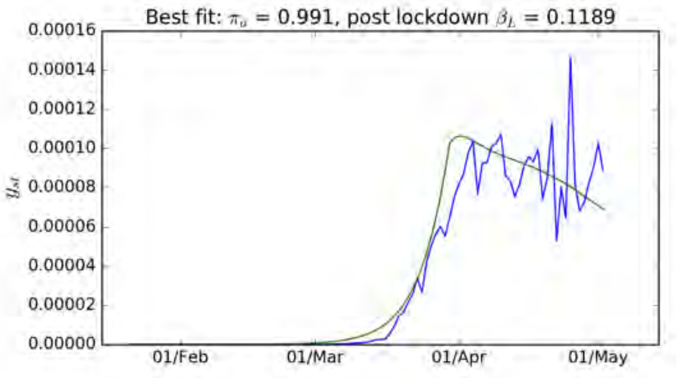

Figure 8. Model simulation for y_{st} that gives the best fit to data from USA. R_0 = 3.3 and γ = 0.083

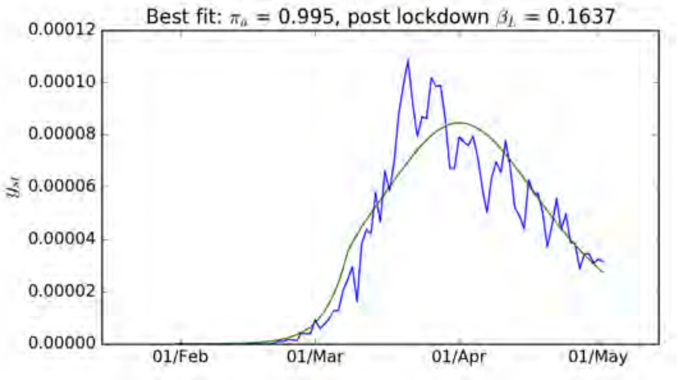

Figure 9. Model simulation for y_{st} that gives the best fit to data from Italy. R_0 = 3.9 and γ = 0.083

lower value of π_a than we find best fits the data on test results.

6 Interpretation, caveats and implications

If it is really the case that those who have been infected but are asymptomatic may be 200 times as numerous as those who develop symptoms (and who are therefore more at risk) then based on the numbers who have tested positive with symptoms it would seem likely that a high proportion of the UK population (60% or so by end April 2020) had already been infected and that a substantial proportion then had some sort of immunity. This would be very good news. It would mean that the rate of new infections would be likely to die down, even if there was some rise in β as severe lockdown conditions were to be eased. Figure 12 illustrates by showing how the number of UK new daily symptomatic infections (y_{st}) would evolve based on the model parameters (using R0=2.95; γ =0.0833 which generates best fit values for π_a and β_L of 0.996 and 0.1598 respectively) and assuming that the infection rate

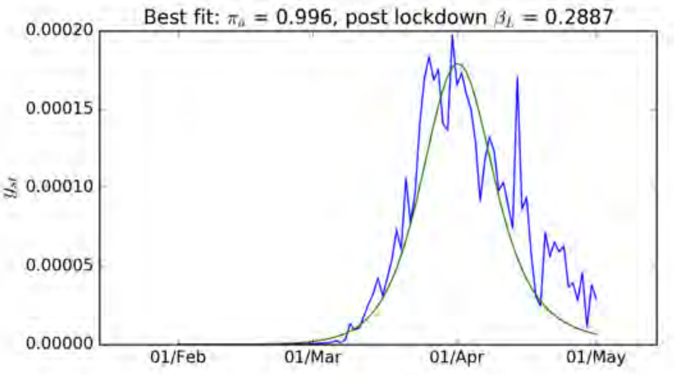

Figure 10. Model simulation for y_{st} that gives the best fit to data from Spain. $R_0 = 3.9$ and $\gamma = 0.083$

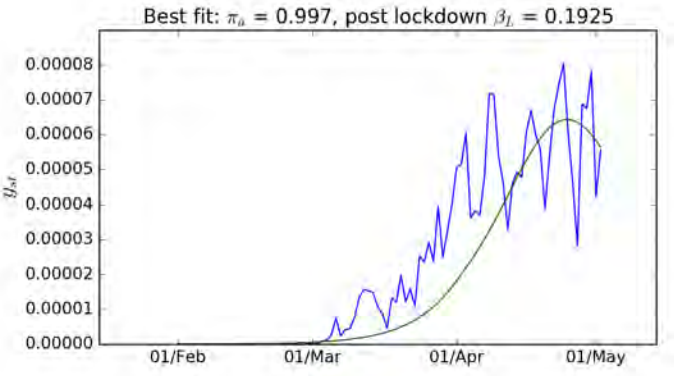

Figure 11. Model simulation for y_{st} that gives the best fit to data from Sweden. $R_0 = 2.5$ and $\gamma = 0.083$

moves half way back to β_0 from early May to simulate some partial relaxation of lockdown measures.

The reason that this projection shows such a decline in new cases is that the R number implied by the model would be comfortably under 1 by the end of April 2020 if the proportion of the population that is susceptible had already dipped down by as much as is implied by as high a value of π_a of 0.996. The final figure illustrates the trajectory of R implied by the model parameters π_a and β_L that best fit the UK data.

But why should results of the SIR model designed to fit the UK test data (and which also seem to best fit data from Italy, Spain, France, Sweden and the US) suggest a much higher rate of the spread of the virus than test data from countries that have done more widespread (closer to random) testing? One answer is purely mechanical: if one wants to fit a model that tracks the data on positive tests it must be one where the number of infections rises very fast early on (a relatively high R0 and β_0). But the number of new infections amongst those tested in the UK and other countries (a very high proportion of whom had symptoms) did turn around

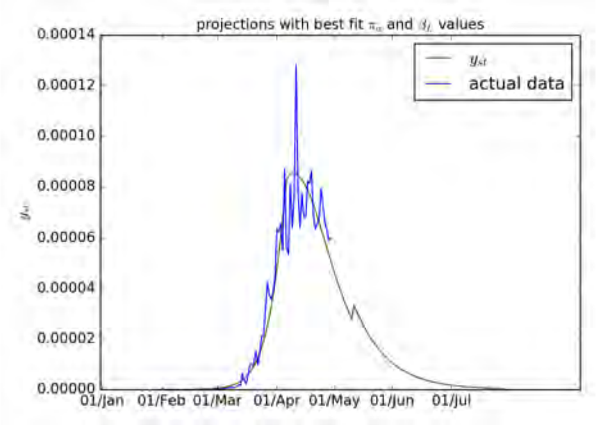

Figure 12. Actual and predicted (y_{st}) new cases. The model is run with $R_0 = 2.95$, $\gamma = 0.0833$ and an increase in beta on May 10th half way back to β_0

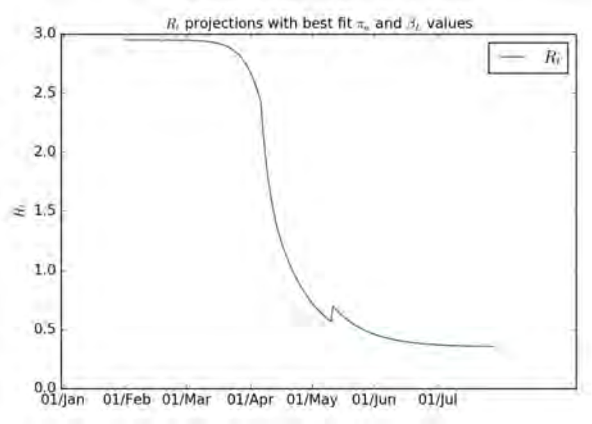

Figure 13. Forward projection of R_t which is defined as $\frac{\beta_t S_t}{\gamma N}$. The model is run with $R_0 = 2.95$, $\gamma = 0.0833$ and an increase in beta on May 10th half way back to β_0

quite sharply in April. There are two things in the model that between them can account for this turn: a big reduction in β as a result of the lockdown and a large and rising population of people who had already been infected which brings the susceptible population down fast as we moved through April. The only way the latter effect could be significant is if the population of those who have had the virus but had never been tested was very substantial.

Is it possible that we have made assumptions which force the model to explain much more of the slowdown in new positive test cases by a fast rise in the immune population (which implies a very large group have had the virus with few symptoms) rather than attribute it to a very effective lockdown? One factor may be significant: we have assumed a 14 day delay between the start of the lockdown and its beginning to affect the rate of new positive tests for the virus. If that lag were much smaller, more of the turn around in new cases might be attributed to the lockdown and correspondingly less to a rise in mass immunity. But in fact, when we halve the lag between the start of the lockdown and its effect on β we still find that the value of π_a that best fits the data remains very close to 1.

There is, however, one assumption that does have a significant impact on the estimated asymptomatic rate. This is the assumption that β is the same for both symptomatic and asymptomatic groups. If the rate at which the asymptomatic infect people is significantly lower than for the symptomatic, the best way for our SIR model to explain the UK data is to have a much lower number of asymptomatic (π_a). If the transmission rate of the asymptomatic is one half that of the symptomatic, but the weighted average of the two keeps the overall β as it was, π_a falls to approximately 0.5. But, the fit of the model deteriorates and the RMS error is around 16% higher than the lowest value obtained in simulations with identical transmission rates.

There is limited evidence that the transmission of the virus is weaker for those with few symptoms (Li *et al.* 2020). But, it is clear that it matters for modelling the spread of the virus (Park *et al.* 2020). The influential Imperial College study (Ferguson *et al.* 2020) does assume a lower asymptomatic transmission rate (by 50%). The analysis of Gupta and her team (Lourenço *et al.* 2020), designed to explain the early spread of the virus in the UK, appears to assume a common transmission rate amongst the infected. That study suggested that the asymptomatic were a very high proportion of the infected and that the virus had spread very widely by early March. Our study suggests that estimates of the spread of the virus that best account for the data are sensitive to whether the transmission rate is assumed to be the same for asymptomatic and symptomatic groups.

We have found that when trying to match data on the recorded cases of the virus our model appears to favour high values of π_a (the asymptomatic proportion of the total infected people). This is a consistent finding across a number of scenarios where we vary the mean transmission rate, the recovery rate and lockdown measures. It is only when the transmission rate for the asymptomatic is much lower than for the symptomatic that the best fitting estimate of π_a is reduced. These two facts lead to two conclusions: First, that previous estimates of π_a near 0.9 (Li *et al.* 2020), or even higher, are consistent with versions of a simple SIR model designed to track results of tests for the virus in the UK and other countries; but we do not make the stronger claim that the evidence clearly proves such a high value. Second, that reliable modelling of the evolution of the spread of the virus requires accurate measurement of transmission rates for symptomatic and asymptomatic groups and is sensitive to whether these are different.

Finally our results indicate that it is hard to be very confident about which of two quite different factors is the primary reason why a corner has been turned in the trajectory of new cases of positive tests for the virus: i. that the lockdown is very effective; ii. that the infection has spread so far that new infections naturally slow down. In all of the countries whose data we analysed, the best fit to that data favours the second explanation and that there have been a very large number of asymptomatic infected for each infected person with symptoms. But in no cases can the alternative hypothesis be rejected with very high (0.05 or 0.01) confidence. The data by no means overwhelmingly reject the hypothesis of a value of π_a lower by enough to mean that the main cause of the slowdown (and then reversal) in the arrival of new positively tested cases of the virus were the measures taken to curb it. But there is another way of looking at the same results. This is that there is evidence that the infection may have spread far enough to mean that the trajectory of falling new cases could be maintained with some easing of restrictions.

Policy on how far to ease restrictions will inevitably have to be made in a fog of considerable uncertainty.

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