Understanding Exponential Growth Amid Pandemic: An International Perspective

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Abstract

In light of the recent Coronavirus pandemic, this paper seeks to inform policy-makers by exploring what information is important for a public health campaign aiming to slow the spread of the virus. In particular, this paper estimates the extent to which the public understands exponential growth, and whether or not individuals who understand exponential growth are more willing to participate in measures to slow the spread of the virus. Using survey data from Chile, China, Italy, and the United States we find that, in general, the public has a poor understanding of exponential growth, but also that those who do have a better understanding of exponential growth are not more likely to participate in social distancing behavior than others. Instead, we find that an individual's degree of worry or fear is a much stronger predictor of willingness to take measures to slow the spread of COVID-19. Our results suggest that public health campaigns aimed at informing the public about growth rates or probabilistic risks of getting infected will be less effective than ones that make direct emotional appeals warning people about the dangers of COVID-19.

1 Introduction

An immediate priority of policymakers hoping to mount effective public health campaigns to slow the COVID-19 pandemic is to understand what kind of messages and public policy are effective in encouraging social distancing measures. Currently, information campaigns tend to be focused on messages such as "reducing the R_0" or "flattening the curve," which implicitly rely on individuals to have an understanding of how exponential growth works. Public understanding of how the recommended social distancing behaviors will result in a curbing of the virus is crucial for effectively encouraging the public to adhere with public health recommendations. This leads us naturally to two research questions: 1) to what extent does the public understand exponential growth, and 2) are individuals with a better understanding of exponential growth more likely to adhere to measures intended to slow the spread of COVID-19 - and if not, then what does predict adherence?

If an individual mis-perceives the risks of COVID-19 – for example, believing that the virus spreads much slower than it actually does – they may under-estimate the benefits of social distancing measures, and thus engage in a sub-optimal level of social distancing (Gigerenzer et al., 2007; Allcott et al., 2020). On the other hand, previous behavioral research suggests that the technical comprehension of a risky choice under uncertainty poorly explains revealed preferences, and that often the emotional response of an individual regarding that risky choice dictates behavior. Viscusi (1990) provides an example of this phenomenon in the context of choosing to smoke, while Kahan et al. (2012) provide an example in the context of climate change concern. In this paper, we use survey data from four countries to investigate whether individuals' behaviors in response to COVID-19 are affected by their understanding of exponential growth, or whether the emotional feelings towards the Coronavirus, such as fear or worry, may instead be more predictive.

Previous research has found that while people tend to have a general understanding of exponential growth, they have difficulty applying the concept at scale (Podkul et al., 2020). This result is in line with related literature on basic numeric and financial literacy. For example, the S&P financial literacy survey (Klapper et al., 2015), which includes basic numeracy, reports that only 1 in 3 adults worldwide are financially literate, and even in advanced economies, such as the United States, this result only changes to a little over half of adults who are financially literate. Importantly, Lusardi (2008) reports that poor financial decision making can be linked to a lack of basic financial literacy. Our results similarly report that only a small proportion of the samples we survey understand exponential growth. These facts suggest that one avenue for improving compliance to public health recommendations would be to improve the numeracy of the general public to ultimately help individuals better understand the risks of not social distancing (i.e. exponential growth in disease prevalence).

Our results, however, do not support a hypothesis that those who better understand exponential growth are more likely to engage in social distancing behaviors. In general, this result is consistent across countries. We also find that personal anxiety and degree of worry over COVID-19 is strongly correlated with engaging in social distancing measures. Our results imply that rather than making cost-benefit decisions regarding COVID-19 and social distancing behaviors, based on objective risk factors such as disease prevalence or the rate of spread, individuals seem to be basing their decisions more on their personal degree of worry over and personal fears of catching the virus. The lack of connection between exponential growth understanding and social distancing behaviors, along with the fact that understanding of exponential growth is generally uncorrelated with worries about COVID-19 (Podkul et al., 2020), suggests that mis-perceptions about the spread or prevalence of COVID-19 are *not* driving differences in social distancing behaviors across groups. Our results thus imply that public health campaigns aimed at informing the public about virus growth rates or probabilistic risks of getting infected will be less effective than ones that make direct emotional appeals to warn people about the dangers of COVID-19.

The paper proceeds as follows: In Section 2 we describe the survey data; in Section 3 we detail the exponential growth understanding question and report the top line results from each country; Section 4 explores the relationship between the exponential growth understanding and emotional attitudes with social distancing behaviors; and in Section 5 we discuss our findings and their application to public health policy.

2 Survey Data

2.1 International Surveys (Chile, China, and Italy)

The international survey data from Chile, China, and Italy was collected via samples recruited into the Nuffield CESS Online subject pool from late April 2020 to early May 2020.[1] The recruitment was such that there was sufficient variation in exposure to COVID-19; this was achieved by balancing the sample in terms of the infection rate in the respondent district and the distance from the COVID-19 epicentre district. Potential respondents in Chile and Italy were recruited via Facebook Ad manager and those in China were recruited on Weibo and WeChat. The number of respondents (and estimated margin of error) in the Chile sample is 991 (± 3.1%), in the Italian sample is 775 (±3.5%), and in the Chinese sample is 1,500 (±2.5%).[2]

[1] The Chile, China, and Italy survey data will be made available through the Nuffield CESS GitHub repository.
[2] Margin of error calculations are outlined in Appendix A.

2.2 U.S. Survey

The U.S. survey data used in this project was collected from April 16, 2020 to May 1, 2020 by 0ptimus Analytics using the Dynata online web panel.[3] During the time in the field, the 0ptimus panel interviewed 3,614 respondents who were interviewed for their opinions on a variety of questions related to COVID-19 and other political topics. Panel respondents were contacted according to joint target quotas calculated using the most recent U.S. Census Bureau's Current Population Survey (CPS) by age group, Census region, and gender and according to marginal target quotas by education and race. Final survey results were weighted to be representative of U.S. adults in two steps: first, using post-stratification to account for daily joint quota non-response and, second, by an iterative proportional fitting algorithm to weight the final sample according to CPS marginal distributions on gender (Male/Female), race (White/Black/Hispanic/Other), education (Less than HS Diploma/Some College or Associate's Degree/College Degree/Post-Graduate Degree), age group (18–34/35–44/45–64/65+), and Census region (Northeast/Midwest/South/West). All data below from the U.S. survey are weighted to be representative of all U.S. adults. The overall margin of error for topline results below is calculated as ±1.8 percentage points with a design effect of 1.2.

2.3 Between Country Context at the time of the Survey

Table 1 reports COVID-19 cumulative cases for each country during data collection, along with the increase in the case rate and the average reported willingness to wear a face mask. Italy and the United States had significantly higher cumulative cases of COVID-19 during the time that the survey was conducted, compared to Chile and China, and the United States and Chile were experiencing the quickest growth rate during this period.[4] Table 1 also shows that there were relatively low case levels and minimal virus growth rate in China compared to the other countries. It is important to caveat this with two highly relevant subtleties. Firstly, China had experienced its virus peak much earlier than the other countries in our sample (for example, on 01/02/2020 China had almost 12,000 cumulative cases, whereas the United States and Italy both had under 10, and Chile had none), which may explain why the mask wearing rate is relatively high despite the comparatively low cumulative case rate in this period. Secondly, the cases in China were not uniformly distributed across the country. A clear example of a virus epicentre is Wuhan, and we note that the mask wearing rate in this city is higher than the national average, at 94%. In Hubei, the province in which Wuhan is located, the confirmed cases per 100k people were 115.5, throughout the sampling period.

[3]The U.S. survey data will be made available through the 0ptimus GitHub repository.
[4]Data source: `https://github.com/CSSEGISandData`

Country	Survey Field Dates	Cases - Start	Cases - End	Rate Increase	Mask Wearing
United States	16/04/2020 - 01/05/2020	183.5	314.5	+71.4%	N/A*
Chile	17/04/2020 - 07/05/2020	48.4	126.6	+161.6%	92%
China	22/04/2020 - 02/05/2020	5.89	5.90	+0.12%	91%
Italy	23/04/2020 - 08/05/2020	310.7	357.9	+15.2%	71%

Notes: Cases are cumulative and per 100k people. Data from the COVID-19 Data Repository by the Center for Systems Science and Engineering (CSSE) at Johns Hopkins University.
The dataset compiles national health data from official governmental agencies and media.
The mask wearing column displays the average self-reported likelihood of wearing a mask.
*Comparable mask wearing data is unavailable from the U.S. survey.

Table 1: COVID-19 Case Prevalence and Survey Dates

For further context of the countries' relative 'stages' of the pandemic we report cumulative cases on 01/07/2020. The United States had over 800 cases per 100k of the population on July 1st, Chile had just under 1.5k per 100k people, Italy had below 400 cases per 100k people, and China had just under 6 per 100k. Thus, we can note that at the time of the survey field dates, China was in its end stage of the pandemic, having been contained by the local authorities, whereas the virus was relatively novel in both the United States and Chile, spreading exponentially. Italy was the initial epicenter of COVID-19 in Europe, having the virus noticed and lockdown measures implemented in early March; thus Italy was also further in a further 'stage' of the pandemic compared to the United States and Chile.

3 Understanding Exponential Growth

To explore the public's understanding of exponential growth related to the coronavirus pandemic, we measured survey respondents' ability in assessing how quickly a disease could spread given a particular rate of spread. Rather than asking respondents to calculate a particular value (see, e.g., Podkul et al. (2020)), we provided a set of responses that permitted respondents to provide their best estimate regarding how quickly a disease can spread within a community. Specifically, we asked respondents:

'Suppose you live in a city of 1 million people, and someone comes down with the flu. That person infects two people on the first day, and after that each infected person affects two more people on average per day. About how long would it take for the entire city of 1 million people to be infected?':

Two weeks	Three weeks	Four weeks	Two months	A year (12 months)	More than two years

where the answer options were randomized between shortest to longest and longest to shortest.

This closed-ended survey question, which this project uses for measuring respondent understanding of exponential growth, has three significant features. First, the parameters outlined in the text are relatively simple (e.g. "that person infects two people...") thereby easing the calculative burden placed on survey respondents. Second, the survey question is not about the COVID-19 pandemic. By establishing that the question asks about the flu, we are implicitly asking respondents not to consider what they know about the current outbreak's R_0. Lastly, by providing general time ranges as the multiple-choice options, we are able to gauge respondents' general understanding of exponential growth rather than their precise calculations.

3.1 Comparing Exponential Understanding Across Countries

Table 2 reports the answers to this exponential growth question by country. Across the four countries surveyed, only in Italy did a plurality of respondents answer the correct response ("Three weeks"), whereas a plurality of respondents in the other three countries answered an option that was nearly twice as long as the correct answer ("Two months"). In the sample from Italy, 22.1% selected "Three weeks" and over a majority of the respondents selected an option that was one month or less. In Chile (14%), China (17.5%), and the United States (13.3%), fewer respondents selected the correct answer. Additionally, a majority of respondents in the Chile, China, and U.S. samples selected an answer that was more than two months. Although there are not major differences across the four countries, respondents in the United States were the least likely to answer the question correctly. That is, when it came to identifying exponential growth when it came to disease spread, U.S. respondents were about nine percentage points behind Italian respondents and about four percentage points behind Chinese respondents. Although the estimate for the United States was lower than Chile, it was not statistically distinguishable.

Country	**Two weeks**	**Three weeks**	**Four weeks**	**Two months**	**Six months**	**A year (12 months)**	**More than two years**
Chile	6.6%	14%	18.7%	22.4%	16.9%	11.3%	10.2%
China	10.4%	17.5%	20.5%	24.4%	15.2%	7.8%	4.2%
Italy	8.9%	22.1%	20%	19%	15.1%	8.4%	6.6%
United States	7.5%	13.3%	18%	25.8%	17.6%	10.9%	6.9%

Table 2: Exponential Understanding Measure Responses by Country (Toplines)

As a point of comparison, roughly 40% of people worldwide have a *basic* understanding of compound interest, in the sense that they can differentiate it from simple interest (Klapper et al., 2015). Our findings are thus consistent with this evidence, since it will be an even smaller proportion of the population who are able to not only differentiate linear growth and exponential growth, but to also pinpoint the the extent of the difference. These initial topline results already suggest that, in general, the public does not have a sophisticated understanding of exponential growth, particularly in the context of disease spread.

3.2 Demographic Analyses

Table 3 presents a tabulation of how each country's various demographic groups performed on the exponential growth question. Each cell indicates the percentage within that group who were able to correctly identify "Three weeks" as the correct answer. When it comes to age group there were no statistical differences across demographic subgroups in their ability to answer the correct response. On gender, there was a consistent split (with males reporting the correct answer more than females in each sample); this difference was statistically distinguishable in Chile, Italy and the United States.

	Chile	**China**	**Italy**	**United States**
Gender				
Female	12.5%	16.8%	17.3%	10.7%
Male	16.9%	18.1%	28.5%	16.1%
Age Group				
18-34	13.4%	17.1%	24.5%	13.8%
35-44	15.3%	18.2%	18.9%	11.9%
45-64	14.8%	17.1%	18.1%	12.1%
65+	*	*	*	15.9%
Education				
HS or Less	*	*	*	10.4%
Some College	8.3%	13.8%	19.2%	13.1%
College or More	16.0%	19.8%	24.0%	17.6%
$N =$	991	1,500	775	3,614

Note: * indicates there were fewer than 50 respondents.

Table 3: Subgroup Percentage Selecting "Three Weeks"

The gender differential is not unique to our results. The S&P survey (Klapper et al., 2015), for example, reports that on average men are more financially literate than woman. Similar evidence is found in Lusardi and Mitchell (2009), where, on average, women fared worse than men in simple questions of numeracy, and understanding concepts such as compound interest and inflation.

In spite of our observation that women tend to perform worse than men in understanding exponential growth, we find that women in our sample are more likely to participate in social distancing measures, such as mask wearing. Finally, when it comes to education, there were some notable differences between "Some College" and "College or More" - these differences were statistically significant in all samples.[5]

[5] We note that the samples in Chile, China and Italy have exceptionally small numbers of respondents with high school education or below. We believe that the reason for this is the recruitment strategy. Participants were recruited via social media platforms and tend to be relatively young and well educated.

4 Exponential Growth and Distancing Behaviors

We focus on four key social distancing behaviors: 1) wearing a mask, 2) avoiding going to crowded places, 3) not permitting children to go to school, and 4) avoiding hospitals.[6] For each of the behaviors, we ask respondents to identify the probability (between 0 and 100) that they would voluntarily (i.e. "without any mandate from the authorities") engage in each behavior. We want to test whether a better understanding of exponential growth, as indicated by a more correct answer to the exponential growth question in the survey, is predictive of engaging in social distancing behaviors.

4.1 International Context

Figures 1-4 visualise the raw relationship between understanding of exponential growth and the average willingness to participate in various measures to slow down the virus spread in Chile, China, and Italy. Recall that a correct understanding of exponential growth is captured by the correct question response of "Three weeks", although there is also a general ordinal ranking of the 'degree of correctness'. Specifically, for the options which are above the correct response, selecting a longer measure of time corresponds to being less correct than a shorter, although perhaps still incorrect, belief.

The primary observation to be made of these figures is that willingness to adhere to public health measures has little variation with understanding of exponential growth. This leads us naturally to consider which factors do motivate the public to adhere with social distancing measures.

[6]Avoiding hospitals ought to be considered different than other activities, considering that for some people it may be worth it to go to a hospital despite the increased risk of catching or spreading COVID-19 by doing so. Policy-makers would want to ensure that those who are better off hospitalized than not will seek out the appropriate medical treatment in hospital.

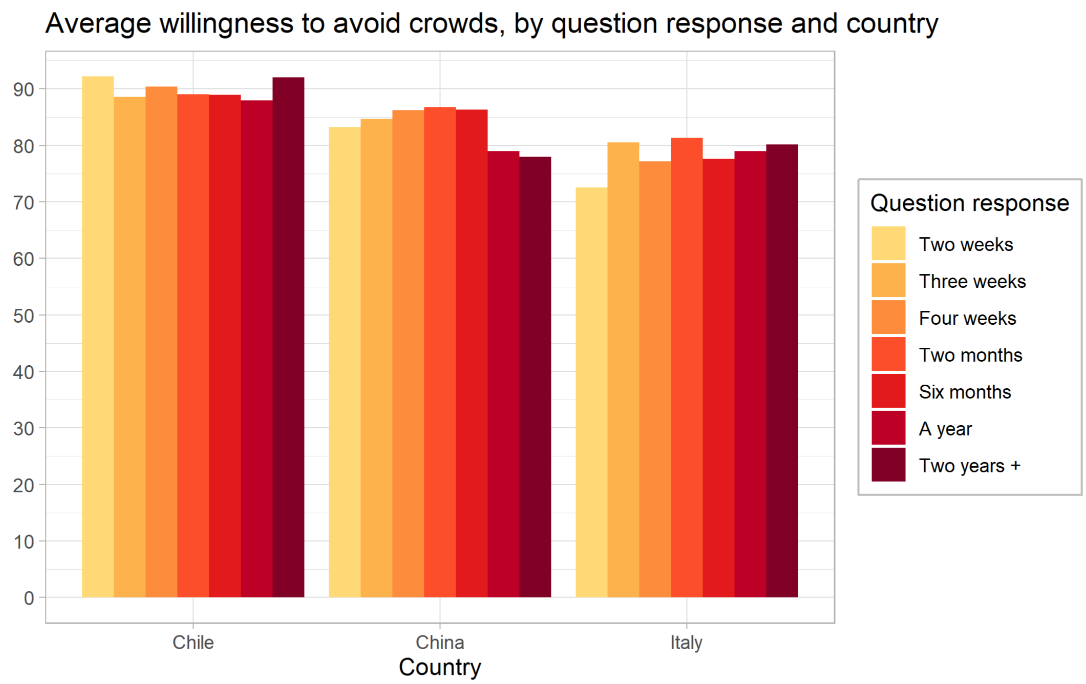

Figure 1: Avoiding Crowds

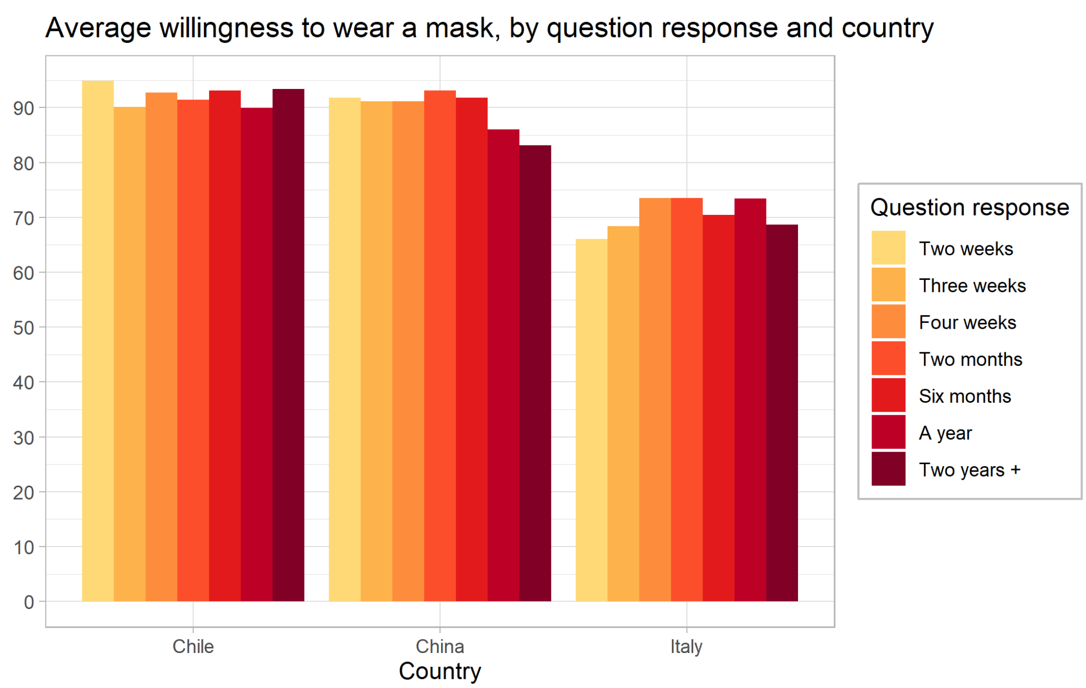

Figure 2: Wearing a Mask

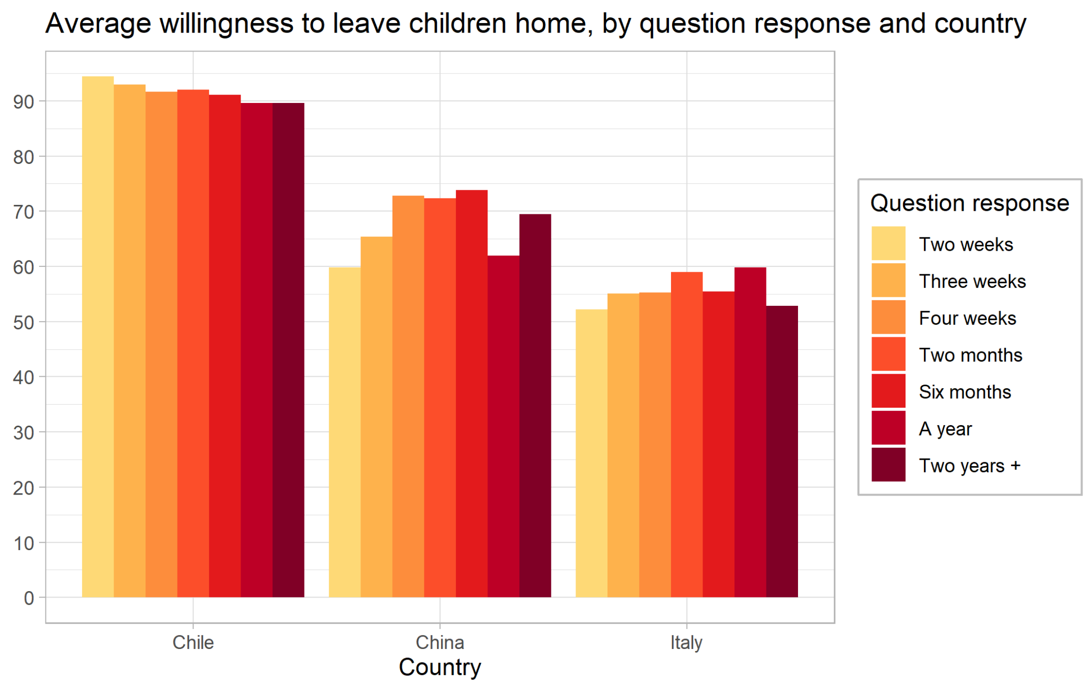

Figure 3: Leaving Children Home

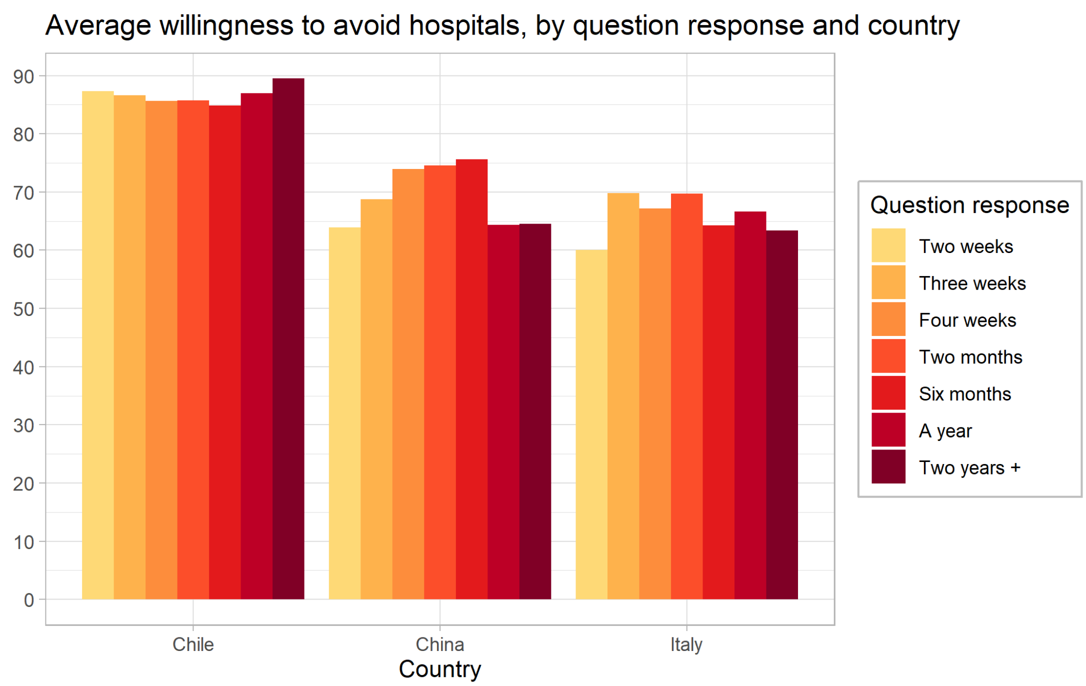

Figure 4: Avoiding Hospitals

In Figure 1, we can observe that there is minimal within country variation in average willingness to avoid crowds, by question response. The most notable observation is that, in China, those who has the 'most incorrect' beliefs, selecting 'A year' or 'Two years +' were notably less willing to avoid crowds than those who had closer to the correct understanding of exponential growth.

Figure 2 similarly visualises only small within country variation in average willingness to wear a mask, by question response. Again, we can note that those in China who had the 'most incorrect' beliefs were particularly less likely to voluntarily wear a mask than others. On the other hand, those in Italy with closer to accurate understanding, selecting two or three weeks, were also less likely to wear a mask than others in the country.

Figure 3 also reports relatively mixed relationships. In Chile, it looks as if there is a weak negative relationship between average willingness to leave children at home and increasingly incorrect beliefs. There is no clear pattern between question response and willingness to leave children at home in China (if anything, it appears that those in China with closer to correct beliefs are less likely to leave children at home) and the relationship is generally flat in Italy.

Finally, Figure 4 once again reports mixed evidence. The pattern between willingness to avoid hospitals and question response is negligible in Chile, besides those who had the most incorrect beliefs, who were marginally more willing to avoid hospitals than others in the country. The observed pattern in China is remarkably unexpected, since those with the closest to correct and least the close to correct beliefs were the least willing to avoid hospitals, whereas those who overestimated the time that exponential growth takes by a smaller margin were the most willing to avoid hospitals. In Italy, the pattern is seemingly random, with little variation, although we note that those who had the belief that exponential growth is even quicker than the reality were less likely than others in Italy to willingly avoid hospitals.

To explore these relationships more formally, we estimate a series of multiple linear regressions to help uncover the correlative associations between exponential growth understanding and the dependent variables of respondents' self-reported proclivities to take COVID-19 related precautions. We estimate a separate model for each dependent variable for each country. If individuals are making rational risk-benefit tradeoffs with relation to social distancing behaviors, we would expect that those with more accurate beliefs about the potential disease spread would engage in more social distancing after controlling for confounding factors.

The key independent variable of interest for measuring respondents' understanding of exponential growth is the measure described in Table 2 above. In order to examine possible trends across survey responses, we include each item response as its own independent variable within the model (leaving out the modal midpoint of "Two months" as the reference category). Though our analyses will specifically highlight the relationship of selecting "Three weeks" (the correct answer response) with the different reported social distancing behaviors; we will also explore trends across answer choices.

Additional covariates included in the model include demographics (gender, education, race, age, age-squared, and income) and a respondents' self-reported health. Finally, we also include a measured labeled "Horrified by COVID," which indicates whether a respondent reported they "agreed" with the statement "I feel horrified because of COVID-19."[7] The "Horrified by COVID" term is necessary to include as a control for individual level fear/emotion, which may correlate with beliefs about the speed at which a virus can spread, as well as the outcome variables we consider. While we expect Horrified by COVID to also be positively correlated with social distancing, it is an open question as to whether beliefs about risk - as proxied by the answers to the exponential growth questions - or personal fear and worried will be a stronger factor in predicting social distancing behaviors.

The sections that follow report the results from this analysis using the samples from Chile, China, and Italy. Following, a similar analysis using the United States sample will be introduced and explained.

[7]Respondents were asked to report, on a ten point scale, how much they agree with the statement "I feel horrified because of COVID-19". We constructed a dummy variable which takes on the value 1 if the respondent chose a value above the median response within their country, and 0 otherwise. Please refer to Appendix B for the distribution of question responses.

4.2 Chile

	Dependent variable			
	P(Wear Mask)	P(Avoid Crowds)	P(Children at Home)	P(Avoid Hospital)
	(1)	(2)	(3)	(4)
Exponential Growth Response				
Two weeks	3.05	1.99	-0.39	-2.89
	(2.86)	(3.55)	(3.65)	(3.94)
Three weeks	1.28	2.26	1.32	-0.11
	(2.19)	(2.71)	(2.79)	(3.01)
Four weeks	4.37**	1.81	-0.82	-2.10
	(2.08)	(2.58)	(2.66)	(2.87)
Six months	2.78	1.14	-2.23	-2.04
	(2.05)	(2.54)	(2.62)	(2.82)
A year (12 months)	-3.78*	-1.09	-4.59	-0.06
	(2.29)	(2.84)	(2.93)	(3.15)
More than two years	2.05	2.83	-3.79	2.02
	(2.32)	(2.87)	(2.96)	(3.19)
Overall Health				
Poor	5.03	1.92	-5.29	-0.51
	(3.86)	(4.78)	(4.93)	(5.32)
Fair	-0.48	-1.75	-1.57	0.21
	(1.62)	(2.01)	(2.07)	(2.23)
Very Good	-2.10	-3.73*	-2.66	-1.61
	(1.66)	(2.06)	(2.13)	(2.29)
Male	-2.59*	-2.95*	-2.80	-4.95***
	(1.36)	(1.69)	(1.74)	(1.87)
High Educ.	4.34***	3.08	2.60	6.32***
	(1.53)	(1.90)	(1.96)	(2.11)
Horrified by COVID	-0.50	1.32	0.85	0.57
	(1.36)	(1.68)	(1.73)	(1.87)
Demographic Controls	X	X	X	X
DV Mean	92.04	89.59	91.57	86.32

Demographic controls include race, age, age squared, and income. N=675.
*p<0.1; **p<0.05; ***p<0.01

Table 4: Social Distancing Behaviors and Exp Growth, in Chile

Table 4 reports the estimated coefficients for the four multiple linear regression models described above.

Regarding the central research question of the project, the results do not seem to indicate any clear relationship between a respondents' answer to the exponential growth question and their self-reported social distancing behaviors. Specifically, those who selected the correct response of "Three weeks" do not have any statistically distinguishable patterns of behavior as compared to the base group of those who selected "Two months." Across each of the four models, two coefficients from the exponential growth question are statistically significant at conventional levels: those who answered "Four weeks" are more likely to report wearing and mask and those who answered "A year" are less likely to do so when controlling for other factors. While these coefficients are in the hypothesized direction relative to the base case, there are no clear patterns when analyzing them in the context of the coefficients for other responses. For example, those who selected "A year" reported they were 3.8% less likely to wear a mask ($p < 0.1$) but those who selected an even longer time frame ("More than two years") reported they were 2% more likely to wear a mask ($p > 0.1$).

In the Chilean sample, there are other noteworthy patterns among the additional covariates. In particular, we identify a consistent positive relationship between being highly educated and following through with social distancing behaviors (although these relationships are only statistically significant in the wear mask and avoid hospital models). We also note a consistent gender gap in this sample where males are less likely to report following social distancing measures ($cf.$ Reny (2020)). For example, males report they are 2.6% less likely to wear a mask when controlling for other factors. Finally, we also note that we do not see a clear relationship in this sample between being horrified by COVID and social distancing measures.

4.3 China

	Dependent variable			
	P(Wear Mask)	P(Avoid Crowds)	P(Children at Home)	P(Avoid Hospital)
	(1)	(2)	(3)	(4)
Exponential Growth Response				
Two weeks	-1.64	-2.88*	-12.54***	-9.94***
	(1.47)	(1.71)	(2.80)	(2.55)
Three weeks	-3.09**	-2.89**	-7.50***	-6.54***
	(1.27)	(1.47)	(2.40)	(2.19)
Four weeks	-1.74	-0.37	0.98	-1.33
	(1.23)	(1.43)	(2.34)	(2.13)
Six months	-1.39	-0.56	-0.59	-0.83
	(1.36)	(1.57)	(2.57)	(2.35)
A year (12 months)	-6.79***	-6.95***	-8.93***	-7.76***
	(1.70)	(1.97)	(3.22)	(2.94)
More than two years	-6.84***	-6.39**	-2.11	-8.76**
	(2.33)	(2.71)	(4.42)	(4.03)
Overall Health				
Poor	-2.44*	0.20	-3.30	-0.65
	(1.32)	(1.53)	(2.50)	(2.28)
Fair	-1.70	-0.59	-0.04	2.89
	(1.15)	(1.34)	(2.18)	(1.99)
Very Good	0.11	-4.69	-8.53	-17.99**
	(4.55)	(5.28)	(8.62)	(7.86)
Male	0.51	0.73	0.43	-0.80
	(0.83)	(0.97)	(1.58)	(1.44)
High Educ.	3.35***	3.18***	1.16	1.71
	(0.89)	(1.03)	(1.68)	(1.53)
Horrified by COVID	-0.12	2.27**	6.84***	7.73***
	(0.83)	(0.97)	(1.58)	(1.44)
Demographic Controls	X	X	X	X
DV Mean	91.07	84.88	69.22	71.25

Demographic controls include race, age, age squared, and income. N=1,301.
*p<0.1; **p<0.05; ***p<0.01

Table 5: Social Distancing Behaviors and Exp Growth, in China

Table 5 reports the findings from the China sample as described above. On the relationship between exponential growth understanding and reported social, the results indicate a curvilinear relationship when holding all else equal. Those who correctly identify the "Three Weeks" response are actually less likely to report social distance behaviors when compared to the base group of "Two months." Similarly, we find fairly consistently a negative relationship between choosing a longer time horizon (a year or more) and following social distance procedures. For example, those who correctly identified three weeks reported they were about 6.6 percentage points less likely to avoid a hospital ($p < 0.01$) while respondents who said a year (7.8 percentage points) or more than two years (8.8 percentage points) reported similar behaviors.

Similar to the Chilean sample, the findings in Table 5 also note a fairly consistently positive relationship between being highly educated and reported social distancing behaviors. Specifically in the wear masks and avoid crowds models, educated respondents reported they were 3.4 percentage points and 3.2 percentage points more likely to follow social distancing, respectively (both $p < 0.05$). Unlike the Chilean case, however, we find that respondents who are "Horrified by COVID" are much more likely to report following social distancing behaviors. The estimated coefficients identify a positive, statistically significant relationship between fear of COVID and social distance practices when it comes to avoiding crowds, keeping children at home, and avoiding hospitals holding all else equal.

4.4 Italy

	Dependent variable			
	P(Wear Mask)	P(Avoid Crowds)	P(Children at Home)	P(Avoid Hospital)
	(1)	(2)	(3)	(4)
Exponential Growth Response				
Two weeks	-3.08	-6.66	-5.65	-5.91
	(5.03)	(4.07)	(5.65)	(5.20)
Three weeks	-0.34	1.47	-0.27	2.67
	(3.88)	(3.14)	(4.36)	(4.01)
Four weeks	1.59	-4.43	-3.33	-2.82
	(3.95)	(3.20)	(4.44)	(4.09)
Six months	-2.72	-3.03	-3.88	-6.78
	(4.27)	(3.45)	(4.80)	(4.41)
A year (12 months)	-0.61	-5.14	-2.38	-5.61
	(5.10)	(4.12)	(5.73)	(5.27)
More than two years	-4.27	-1.58	-8.59	-7.09
	(5.67)	(4.59)	(6.37)	(5.87)
Overall Health				
Poor	-0.72	11.10*	9.52	-5.37
	(8.14)	(6.59)	(9.15)	(8.42)
Fair	-2.20	-3.63	-1.54	-0.24
	(3.51)	(2.84)	(3.95)	(3.63)
Very Good	0.86	-0.45	3.71	7.27**
	(2.85)	(2.31)	(3.20)	(2.95)
Male	-1.29	-2.05	2.16	-4.42
	(2.60)	(2.10)	(2.92)	(2.69)
High Educ.	-0.23	2.68	5.08*	3.85
	(2.61)	(2.11)	(2.93)	(2.70)
Horrified by COVID	11.02***	5.96***	9.40***	8.34***
	(2.53)	(2.05)	(2.84)	(2.62)
Demographic Controls	X	X	X	X
DV Mean	70.93	78.66	56.22	66.98

Demographic controls include race, age, age squared, and income. N=649.
*p<0.1; **p<0.05; ***p<0.01

Table 6: Social Distancing Behaviors and Exp Growth, in Italy

The estimates in Table 6 report the findings from these models for the Italian sample. Similar to the

Chilean sample, this analysis again fails to find a clear relationship between respondents' understanding of exponential growth and their reported proclivities to follow through with social distancing behaviors. For example, the estimated coefficients for the correct answer ("Three weeks") are directionally inconsistent across the four models. For example, those who properly understood the rate of exponential growth reported lower rates of mask wearing ($p > 0.05$) but higher rates of avoiding crowded places ($p > 0.05$). Nevertheless, although the standard errors are somewhat high which precludes any statistical significant conclusion, it is nonetheless worth noting that there does appear to be a somewhat consistent relationship for those who over-estimate how long it takes disease to spread. That is, those who reported "Six months," "A year," and "More than two years" were less likely to report wearing a mask, avoid crowds, leave children at home, and avoid hospitals compared to the base group ceteris paribus. Future research with expanded sample sizes may be able to explore this relationship more carefully.

One of the major findings from the Italian sample is that there is a very strong relationship between being horrified by COVID and reporting social distance behaviors when controlling for other factors. The coefficient on this measure is statistically significant across all models ($p < 0.01$). For example, those who are scared of COVID report they are 11 percentage points more likely to wear a mask compared to those who are not horrified. Especially compared to Chile and China, this relationship appears to be the strongest in Italy, indicating that social distancing is more likely to be driven by fear than by a technical understanding of exponential spread.

4.5 United States

We examine survey data from the United States using the same theoretical framework explored above. We use somewhat different specifications for the United States because the survey questions (beyond the exponential growth item) differed from those used in Chile, China, and Italy. Very similar results emerge, though partisanship plays a greater role in the United States for the dependent variables examined.

To measure social distancing attitudes, this analysis turns to two survey questions that were fielded alongside the exponential growth question described above. The first survey question measures whether respondents were worried about restrictions being lifted too quickly or too slowly. Specifically, it asked respondents: "Are you more worried that the United States may loosen restrictions too quickly and the virus will spread quicker, or loosen restrictions too slowly and the economy will get worse?" with two possible answer options: 1) "More worried about loosening restrictions too quickly" and 2) "More worried about loosening restrictions too slowly". The second survey question asks respondents "Do you support or oppose having stay at-home restrictions in your area at this time?" The first question captures attitudes related to the anxieties associated with re-opening plans, the second questions narrowly focuses on the policy question of stay at-home orders.

To control for the potentially confounding effects caused by demographics, this analysis of the U.S. sample controls for age group, highest level of education, race, gender, and geographic region (measured by the U.S. Census region). Additionally, given the politicization of COVID-19 issues in the United States, especially concerning public policies, this analysis also controls for respondents' self-reported party identification. Finally, to best approximate the variable above labeled "Horrified by COVID" which is interpreted as measuring a respondent's general fear surrounding the virus, we include an additional measure indicating how respondents report their "worry" about COVID-19. Specifically, this *Corona Worry* measure is developed from a question which asks, "How worried are you about the possibility that you or your family members may contract coronavirus?" with the options "Very worried," "Somewhat worried," "Not too worried," "Not worried at all," and "Someone in my family is already infecteed." For ease of interpretation, our analysis collapses the responses "Very worried" and "Somewhat worried" as well as collapse "Not too worried" and "Not worried at all." Respondents who selected "Someone in my family is already infected" ($< 1\%$ of the sample during these field dates) were excluded from this analysis.

We estimate two models. The first relates attitudes about loosening restrictions to understanding of exponential growth, and the second relates support for stay at-home orders to understanding of exponential growth. Table 7 below presents the two logit models for each of the dependent variables described above. Model 1 analyzes the dependent variable of Loosen Restrictions, which equals 0 when a respondent says they are worried about restrictions loosening too slowly and equals 1 when a respondents is more worried about restrictions loosening too quickly. In Model 2 the dependent variable of Stay At-Home Restrictions equals 1 when a respondent supports such restrictions and 0 when a respondent does not support the restrictions.

The U.S. data show a statistically meaningful relationship between support for social distancing policies regarding the virus and understanding of exponential growth. In both models, the effects are statistically significant and positive, consistent with the notion that when people understand exponential growth they will be more supportive of measures aimed at preventing an outbreak of the epidemic. Support is not only a matter of getting the answer to the question correct; rather, it is driven by the rate of spread that people believe would occur. Those who over-estimate the rate of exponential say that they are more supportive of the policy measures than those who hold correct beliefs about exponential growth rates.

For ease of interpretation, Figure 5 produces the predicted probabilities for each model in Table 7 when setting control variables to their modal responses with error bars representing two standard errors above

	Dependent variable:	
	Loosen Restrictions	Support Stay At-Home
	(1)	(2)
Exponential Growth Response		
Two weeks	0.426	0.246
	(0.326)	(0.397)
Three weeks	0.730***	0.596*
	(0.254)	(0.313)
Four weeks	0.102	−0.161
	(0.222)	(0.261)
Six months	−0.0002	−0.399
	(0.218)	(0.252)
A year (12 months)	−0.563**	−0.019
	(0.268)	(0.340)
More than two years	0.130	−0.521
	(0.332)	(0.358)
Party ID		
Republican	−0.463***	−0.327
	(0.176)	(0.209)
Democrat	0.688***	0.357
	(0.195)	(0.232)
Corona Worry	1.308***	1.447***
	(0.151)	(0.177)
Education		
Some College or Associate	−0.119	−0.070
	(0.187)	(0.225)
College Grad	−0.081	−0.225
	(0.207)	(0.240)
Post-Grad	−0.385	−0.238
	(0.248)	(0.297)
Male	−0.212	−0.482***
	(0.151)	(0.178)
Age Group		
35-44	0.134	−0.103
	(0.230)	(0.267)
45-64	0.162	0.072
	(0.201)	(0.237)
65+	0.405*	0.679**
	(0.235)	(0.298)
Constant	−0.565*	0.147
	(0.314)	(0.364)
Demographic Controls	X	X
DV Mean	0.73	0.83
Observations	1,125	1,120
Log Likelihood	−570.285	−436.698

Additional demographic controls include race and geographic region.
*p<0.1; **p<0.05; ***p<0.01

Table 7: Logit Models: Association between Understanding Exponential Growth and Coronavirus Attitudes in the U.S.

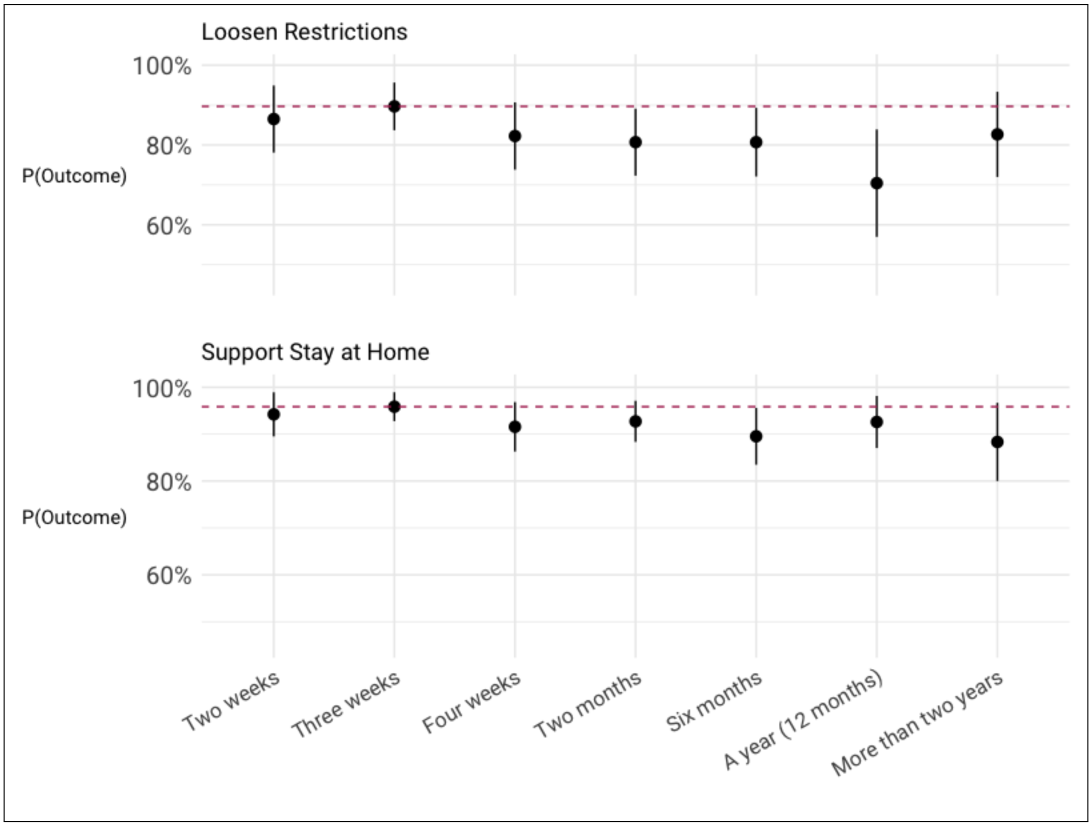

Figure 5: Predicted Probabilities from Table 7 for Independent partisans at the modal demographic groups.

and below each estimate. Compared with the results from the international survey data, we find a fairly clear correlation between understanding exponential growth and worrying about restrictions opening up too quickly. For example, those who answered the question correctly (three weeks) were predicted 89.7% likely to be worried about loosening restrictions too quickly while those who answered the exponential growth question incorrectly (such as those who answered "A year") were nearly twenty percentage points less likely to share the same worries, ceteris paribus.

Additionally, we also note that both partisanship and Corona Worry remain fairly large factors in explaining the degree of caution in people's attitudes toward public health policies. For example, Republicans express less caution and Democrats express more caution than Independents, although this relationship is only statistically significant when looking at the Loosen restrictions Model. The estimated coefficient on Corona Worry, however, is statistically significant (and fairly large in magnitude) in both models – indicating that those who are worried about coronavirus are also more inclined to report cautious attitudes, even when controlling for the respondents' ability to understand exponential growth.[8]

[8]Related to the finding regarding Corona Worry, we also estimated a model with Corona Worry as the Dependent Variable with the same covariates as in Table 7. These findings followed similar trends as Models 1 and 2. Specifically, the estimates indicated a lack of a clear relationship between understanding exponential growth and one's proclivity for worrying about the virus.

5 Summary and Implications for Public Health Policy

5.1 Summary

The analysis described in the previous sections of this paper finds only weak evidence that those who have correct, or closer to correct, understanding of exponential growth are more likely to participate in measures to slow the spread of the virus, or to avoid hospitals. Moreover, where we do find evidence that having correct, or closer to correct, beliefs does increase the chance of participating in measures to slow the virus spread, the estimates of marginal effects are not overwhelmingly large.

Specifically, in Chile, China, and Italy, having a more accurate understanding of exponential growth does not correspond to engaging in more social distancing behaviors. In general, those who believe that the rate of spread will be faster rather than slower do not engage in more social distancing behaviors. In the United States, while we find that exponential growth understanding has a statistically significant effect on policy attitudes regarding COVID-19, these effects are relatively small, with large majorities of all groups supporting stay-at-home orders and voicing concern about loosening restrictions too quickly.

As mentioned in section 3.2, we find that women in our sample are more likely to participate in social distancing measures, such as mask wearing, despite poorer average performance in understanding exponential growth. For example, in Chile men were on average 90.6% willing to wear a mask compared to an average of 92.9% for women. Similarly in China the number was 90.7% for men and 91.5% for women, and in Italy it was 68.5% for men and 72.6% for women.[9] In Chile and China, being in the high education category also tended to increase the probability of engaging in social distancing behaviors, though again the effects are small and not consistent across countries nor specific behaviors. In the United States, men were more likely to worry about loosening restrictions too slowly (30.1%) compared to women (24.6%). U.S. women were also six percentage points more likely to support local stay at-home orders (86% support among women and 80% support among men).

5.2 Implications for Public Health Policy

Our results suggest that a public health campaign seeking to improve public understanding of exponential growth, particularly in relation to virus spread, may not be the most effective use of resources. Despite the fact that many individuals do not have a strong grasp of exponential growth and hence may not accurately understand the true benefits of social distancing, those who do understand exponential growth do not generally behave differently than those who don't. The analysis presented here is consistent with a behavioral framework where people rely more on emotional affect and heuristics to make decisions, rather than a

[9] Section 4 reports statistically significant effects of gender only in Chile.

standard choice-utility model with risk and uncertainty. Therefore, better informing the public of exponential growth and probabilities of infection seem unlikely to have a significant effect on compliance rates.

For a policy-maker concerned with minimising the prevalence of COVID-19, and hence maximising the proportion of the population engaging in social distancing measures, a more optimal public-health campaign may instead appeal to the public sense of emotion, which can dominate traditional notions of rational choice. In line with previous research on compliance with public health recommendations during pandemics (Bults et al., 2015), the degree of personal fear and worry about catching COVID-19 was strongly correlated with adhering to social distancing behaviors. Directly activating emotional fear and anxiety over the coronavirus by accurately informing the public of the dangers of COVID-19 would likely be more effective at helping slow its spread. We also suggest future research on which kinds of people 'follow their emotions and heuristics' the most, for example exploring whether the effects of fear on complying with social distancing measures varies with demographics, such as education and gender.

Previous behavioral research implies a similar recommendation. In the context of smoking, Slovic (2001) questioned whether those who smoke are indeed 'rational actors or rational fools'. Despite evidence (Viscusi, 1994) that smokers not only understand the risks associated with smoking, but in fact overestimate the risks, Slovic (2001) posits that the statistical understanding of risk is not the only factor influencing the smokers choices. Guiding judgements and heuristics are also used, particularly the emotional feelings associated with smoking. Weinstein et al. (2007) similarly reports evidence that the *feelings* associated with risk are a particularly significant predictor of vaccination against influenza. A popular public health policy designed to reduce the prevalence of smoking is mandatory warning labels on cigarette packages, and in many countries mandatory pictorial warnings as well, (for example: European Parliament, 2014). Images on cigarette packages are mandated to increase the salience of the risks associated with smoking, increasing the smokers conscious awareness of the risks and appealing to their emotions (for a discussion of the motivation for, and effectiveness of, pictorial warnings on cigarette packages, see Moodie et al., 2015; O'Connor, 2019; Popova et al., 2018). These campaigns are more effective at deterring smoking because they activate an emotional response from individuals, not unlike the emotional appeals made by companies to sell smoking as "cool" or by advocacy organizations to brand smoking as a dependency (see, e.g., Vallone et al., 2017). A similar technique could be used to activate fears surrounding COVID-19 in order to help induce more social distancing behaviors to stop the pandemic.

One concern with emotional appeals in the public health realm is that they may be seen as manipulative by the public, with health officials seen as exaggerating risks. Health organizations need to balance urgency and seriousness of their recommendations with a longer-term continuation of public trust. As such, they try to avoid deception or manipulation to advance public health guidelines. For example, one of the core

"Communication Principles" of the Center for Disease Control in the United State is that the "CDC does not use trickery or deceptive communication techniques to advance public health recommendations or its reputation."[10] We are not recommending that the CDC or that health organizations exaggerate to the public in order to stoke fear and increase social distancing behaviors, but rather that they should tailor their message about the real dangers of COVID-19 to evoke an emotional response from individuals, in addition to informing them of steps they can take to effectively reduce the risk that they and others will become infected. In this sense, our policy recommendation follows the 'libertarian paternalism' principle popularised by Thaler and Sunstein (2009) - we suggest that policy-makers ought to consider emotions and heuristics when devising public health policy, nudging the public in their best interest and the national interest.

[10] https://www.cdc.gov/about/organization/communication-principles.html

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Appendix A

Chile, China and Italy data

The general topline margin of error is calculated using the following formula:

$$MOE = z_{0.975}\sqrt{\frac{0.5(1-0.5)}{n-1}}$$

Here, z_α denotes the quantile function of the standard normal distribution, where α is the confidence level.

United States data

The general topline margin of error is calculated using the following formula:

$$MOE = \sqrt{D_{eff}} * z_{0.975}\sqrt{\frac{0.5(1-0.5)}{n-1}}$$

where D_{eff} is the reported design effect (Kish 1965).

Appendix B

The following tables provide the distributions, by country, of responses to the question asking respondents to what extent they agree with the statement 'I feel horrified because of COVID-19'.

Chile

Horrified Value	Count	Percent	Cumulative Percentage
1	131	13.22	13.22
2	136	13.72	26.94
3	104	10.49	37.44
4	93	9.38	46.82
5	124	12.51	59.33
6	98	9.89	69.22
7	90	9.08	78.30
8	92	9.28	87.59
9	49	4.94	92.53
10	74	7.47	100.00
#Total	991	100.00	NA

China

Horrified Value	Count	Percent	Cumulative Percentage
1	114	7.60	7.60
2	151	10.07	17.67
3	143	9.53	27.20
4	154	10.27	37.47
5	188	12.53	50.00
6	208	13.87	63.87
7	196	13.07	76.93
8	159	10.60	87.53
9	141	9.40	96.93
10	46	3.07	100.00
#Total	1500	100.00	NA

Italy

Horrified Value	Count	Percent	Cumulative Percentage
1	251	32.39	32.39
2	165	21.29	53.68
3	88	11.35	65.03
4	69	8.90	73.94
5	52	6.71	80.65
6	54	6.97	87.61
7	39	5.03	92.65
8	18	2.32	94.97
9	20	2.58	97.55
10	19	2.45	100.00
#Total	775	100.00	NA