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The Commons Problem under Uncertainty and Precaution

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Abstract

We study a commons problem under uncertainty, where individual actions affect the risk of a future damage event. We show that for risk-averse agents, an extra risk on the amount of the damage induces more precautionary actions in Nash equilibrium. Similarly, for prudent agents an extra risk in all states of the world induces more precautionary actions in Nash equilibrium. We show that this may lead to the result that small extra risks may increase welfare in Nash equilibrium and derive a condition on the relationship between actions and damage probability and the opportunity costs of precaution for this result to occur. The model applies to climate change, where the actions are the countries' carbon dioxide emissions causing the threat of climate damage, as well as to the COVID-19 pandemic, where physical social contacts cause the risk of an infection with the coronavirus. Data from a representative panel survey in Germany provide evidence that the empirical results are in line with the theoretical predictions.

Keywords: Risk Externalities, Precautionary Effort, Risk Aversion, Prudence, Uncertainty, Climate Change, COVID-19, Commons

1 Introduction

The private incentives to contribute to the avoidance of common risk is a key issue in many important problems. A prime example is climate change. The global emissions of carbon dioxide cause risks of climate damages – for example due to heat waves, droughts, or sea-level rise – around the globe. The Paris agreement rests on nationally determined contributions (NDCs) to mitigate carbon dioxide emissions to avoid the risks of severe climate damages. For this issue, the individual actors are nation states. The private incentives to contribute to, or reduce, risks in a common pool situation is highly relevant also at sub-global scales. The COVID19 pandemic is a striking example. Individual social contacts or social distancing contribute to the individual risk of an infection, and jointly determine the spread of the virus and thus have repercussions on all individual risks.

In this paper we develop a theory where individual actions of each individual contribute to the probabilities of future damaging events for the agent themselves, but also cause "risk externalities" on all others by affecting their risk of a damaging event as well. We derive the conditions for Nash equilibrium and show that individual actions are strictly higher than in the social optimum. We are in particular interested how extra zero-mean risks – on the size of the loss in case of a damage event, or on the outcomes in all states of the world – change behavior in Nash equilibrium. We show that for risk-averse agents, an extra risk on the amount of the damage induces more precautionary actions in Nash equilibrium. Similarly, for prudent agents an extra risk in all states of the world induces more precautionary actions in Nash equilibrium. We show that this may lead to the result that small extra risks may increase welfare in Nash equilibrium and derive a condition on the relationship between actions and damage probability and the opportunity costs of precaution for this result to occur.

The model applies to climate change, where the actions are the countries' carbon dioxide emissions causing the threat of climate damage, as well as to the COVID 19 pandemic, where physical social contacts cause the risk of an infection with the coronavirus. Data from a representative panel survey in Germany shows that the empirical results are in line with the theoretical predictions.

Our paper relates to the literature on common-pool resource use under uncertainty. Bramoullé and Treich (2009) set up a model where agents contribute to risky climate damage. They show that increasing the risk of damage will decrease individual emissions in Nash equilibrium and may thus alleviate the commons problem. Small risks can increase welfare in Nash equilibrium, as even for risk-averse individuals the beneficial effect of reduced climate damage may dominate. Also Barrett and Dannenberg (2014), McBride (2006), Tavoni et al. (2011), and Quaas and Baumgärtner (2008) show that risk-averse individuals may choose more conservative actions and thus uncertainty can help to alleviate the problem of external effects.

Here, we derive similar results a dynamic setting where the individual actions directly cause the risk of damaging events. We thus build on the literature on precautionary effort (Eeckhoudt et al., 2012), which has been applied to the case of climate change by Quaas et al. (2017), and extend it to explicitly study the commons problem in a setting where the individual actions by many agents affect the risks faced by all. Importantly, we not only derive new theoretical results, but test them using a unique panel data set obtained in a representative survey in Germany during the COVID-19 pandemic in 2020.

The next section develops the theoretical model and derives the main results in a series of propositions. Section 3 presents the data and shows that theoretical results are in line with empirical evidence. The final section concludes.

2 Theory

We build on previous models by Bramoullé and Treich (2009) and Quaas et al. (2017) developed for the issue of climate change. The generic theory that we develop on this basis is generally applicable for the private provision of public goods under uncertainty.

Consider a set of n individuals. We focus here on the case where agents are symmetric with respect to preferences and the risks they face.

The probability $p(c_i, \mathbf{c}_{-i})$ that agent $i \in \{1, ..., n\}$ is affected by a damaging event in the future depends on this agent's present action c_i , and on all other agents' actions, written as the vector \mathbf{c}_{-i} , with

$$\frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_i} > 0. \tag{1}$$

We assume that $p(c_i, \mathbf{c}_{-i})$ depends on c_j for all $j \neq i$ in a symmetric fashion and write

$$\frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_{-i}} := \frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_j} > 0 \quad \text{for all } j \neq i.$$
(2)

For the application on climate change, the actions can be interpreted as carbon dioxide emissions; for the application on the COVID-19 pandemic, they are to be interpreted as physical social contacts. The damaging event can be interpreted as materialization of severe climate change as in Quaas et al. (2017), or as an individual COVID-19 infection in the other application.

We use x to denote agent i's base level in the future, and $l(\mathbf{c})$ to denote the potential loss in case the damaging event occurs. The size of the expected loss is increasing in all agents' activities \mathbf{c} in a symmetric fashion, $l'(\mathbf{c}) > 0$. Here we assume both x and l to be identical across individuals, but empirically they may be varying across individuals.

We assume that the agents' Bernoulli utility function u(c, x) is increasing in both arguments and concave in c, $\partial^2 u(c, x)/\partial c^2 < 0$. Assuming that future utility is discounted at rate ρ , such that the discount factor is $\delta = 1/(1 + \rho)$, the agent's decision problem is written, using C to denote the agent's action in the second period, which s/he chooses after uncertainty about the damaging event is resolved

$$\max_{c_i} \left\{ u\left(c_i, x\right) + \delta \mathbb{E}_{\ell, \varepsilon} \left[p(c_i, \mathbf{c}_{-i}) \max_C \left\{ u(C, x - (1+\ell) \, l(\mathbf{c}) + \varepsilon) \right\} + (1 - p(c_i, \mathbf{c}_{-i})) \max_C \left\{ u(C, x + \varepsilon) \right\} \right] \right\}.$$
(3)

In addition to the risk of the damaging event, there are two further uncertainties: (a) the zeromean risk ℓ captures uncertainty about the size of the loss, and (b) the zero-mean risk ε captures a general risk in both states, i.e. with or without the loss event. The distributions of these risks may depend on the agents' actions as well, but we focus on the effect on the probability of the loss event. The interpretations are as follows: For climate change, the exact damage in case of a loss is uncertain (i.e. it is uncertain what is the damage once the heat wave comes), and there is general uncertainty about the future climate costs (for some countries there may also be benefits, e.g. Burke et al. 2015). In case of the COVID-19 application, the severity of the individual sickness is uncertain, and in general there is uncertainty in face of the pandemic, where anyone could be a winner (e.g. less ordinary flu) or loser (e.g. limits to the health care system are transgressed).

We simplify notation by writing $v(x) = \max_C \{u(C, x)\}$. Thus, the agent's decision problem is written as

$$\max_{c_i} \left\{ u\left(c_i, x\right) + \delta \mathbb{E}_{\ell, \varepsilon} \left[p(c_i, \mathbf{c}_{-i}) v(x - (1 + \ell) l(\mathbf{c}) + \varepsilon) + (1 - p(c_i, \mathbf{c}_{-i})) v(x + \varepsilon) \right] \right\}$$
(3)

An interior symmetric Nash equilibrium is characterized by

$$\frac{\partial u(c,x)}{\partial c} = \delta \frac{\partial p(c,\mathbf{c}_{-i})}{\partial c} \mathbb{E}_{\ell,\varepsilon} \left[v(x+\varepsilon) - v(x-(1+\ell)\,l(\mathbf{c})+\varepsilon) \right] \\ + \delta p(c,\mathbf{c}_{-i}) \mathbb{E}_{\ell,\varepsilon} \left[v'(x-(1+\ell)\,l(\mathbf{c})+\varepsilon)\,(1-\ell)\,l'(\mathbf{c}) \right]$$
(4)

The right-hand side is the marginal expected costs of c in terms of the increased probability of a loss event and the marginal damage in case of a loss event.

In the following we focus on the precautionary effort motive, and assume $l'(\mathbf{c}) = 0$. We have the following result.

Proposition 1. For risk-averse agents, v'' < 0, damage uncertainty ℓ decreases c.

Proof. If and only if v'' < 0, $\mathbb{E}[v(x - l + \ell + \varepsilon)] < v(x - l + \varepsilon)$. The opportunity costs on the right-hand side of (4) are thus higher if l is uncertain than if $\ell = 0$ in all cases. The marginal benefit of c, the right-hand side of (4) is strictly decreasing in c. Thus, higher opportunity costs lead to a lower c for all agents in Nash equilibrium.

Proposition 2. For prudent agents, v'' > 0, additional uncertainty ε decreases c.

Proof. Under prudence, the opportunity costs are higher with risk than without (Eeckhoudt and Schlesinger, 2006). As $\partial^2 u/\partial c^2 < 0$, c is lower under uncertainty about ε .

We define welfare as the sum of the expected utilities of the agents.

$$W(\mathbf{c}) = n \left(u(c_i, x) + \delta \mathbb{E}_{\ell, \varepsilon} \left[p(c_i, \mathbf{c}_{-i}) v(x - l + \ell + \varepsilon) + (1 - p(c_i, \mathbf{c}_{-i})) v(x + \varepsilon) \right] \right)$$
(5)

The social optimum is characterized by

$$\frac{\partial u(c,x)}{\partial c} = \delta \left(\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c} + (n-1) \frac{\partial p(c,\mathbf{c}_{-i})}{\partial c_{-i}} \right) \mathbb{E}_{\ell,\varepsilon} \left[v(x+\varepsilon) - v(x-l+\ell+\varepsilon) \right]$$
(6)

We have the following

Proposition 3. For small risks, and risk-averse agents v'' < 0, uncertainty about ℓ increases welfare in the Nash equilibrium if and only if

$$(n-1)\left(\frac{c\frac{\partial p(c_i,\mathbf{c}_{-i})}{\partial c_{-i}}}{p(c,\mathbf{c}_{-i})} - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c\partial c_{-i}}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}}\right) - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}} > -\frac{c\frac{\partial^2 u(c,x)}{\partial c^2}}{\frac{\partial u(c,x)}{\partial c}}$$
(7)

Proof. see Appendix A.

In case when all agents' actions have symmetric effects on the probability of a damaging event, the condition in Proposition 3 simplifies to

$$(n-1)\frac{c\frac{\partial p}{\partial c}}{p} - n\frac{c\frac{\partial^2 p}{\partial c^2}}{\frac{\partial p}{\partial c}} > -\frac{c\frac{\partial^2 u(c,x)}{\partial c^2}}{\frac{\partial u(c,x)}{\partial c}}$$
(8)

Proposition 4. For small risks, and prudent agents v'' > 0, uncertainty about ℓ increases welfare in the Nash equilibrium if and only if ((uncertainty about ℓ or ϵ ?))

$$(n-1)\left(\frac{c\frac{\partial p(c_i,\mathbf{c}_{-i})}{\partial c_{-i}}}{p(c,\mathbf{c}_{-i})} - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c\partial c_{-i}}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}}\right) - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}} > -\frac{c\frac{\partial^2 u(c,x)}{\partial c^2}}{\frac{\partial u(c,x)}{\partial c}}$$
(9)

Proof. see Appendix A.

Consider the example where

$$p(c_i, \mathbf{c}_{-i}) = \frac{\xi \, c_i \, \sum_{j \neq i} c_j}{\left((1 - \alpha) \, c_i^{\chi - 1} + \alpha \, \left(\sum_{j \neq i} c_j \right)^{\chi - 1} \right)^{\frac{1}{\chi - 1}}} = \xi \, \left((1 - \alpha) \, c_i^{1 - \chi} + \alpha \, \overline{c}_{-i}^{1 - \chi} \right)^{\frac{1}{1 - \chi}} \tag{10}$$

with parameters ξ , $\chi > 0$ and $\alpha \in (0,1)$, and where $\bar{c}_{-i} = \frac{1}{N-1} \sum_{j \neq i} c_j$ is the average activity of all others. Similar specifications are used in labor economics for the matching function of individuals seeking employment and vacancies (Hagedorn and Manovskii, 2008), and in natural resource economics to model mating in wildlife populations (using the specification $\chi = 2$, Pekkarinen et al. 2017). It seems sensible to use such a specification also for describing the communication of infectious diseases.

With this specification, condition (7) becomes, using symmetry, i.e. $c_i = c_j = c$ for all i, j:

$$\alpha > \eta, \tag{11}$$

where η is the elasticity of marginal utility of c. As in Bramoullé and Treich (2009), for given $\eta < 1$ and α , there is a value of n such that the condition is violated (holds) if the number of agents is smaller (larger) than that number.

3 Empirical Evidence

As explained above, the social distancing behavior and the risks of COVID-19 infections are a commons problem that is well described by the theory developed in the previous section. Here, we present panel data on individual social distancing behavior that has been collected in 2020.

3.1 Data

The data was collected in an online survey experiment with more than 3,000 Germans in March, August, and December 2020.¹ The survey respondents are representative for the German population in terms of gender, age, education, and income. Besides the ability to recruit a representative sample, the online format also avoid any selection bias in the risk preferences of the recruited subjects,² and allows data collection periods independent on any governmental regulations.

Our first data collection period was run from March 20.–27., 2020. This coincided with... The second data collection period took place from August 21.–30., 2020. Finally, we run a third data collection period from December 09.–22., 2020. Figure 1 shows the daily number of infected persons with the SARS-CoV-2 virus, which leads to the disease COVID-19, averaged over the past 7 days.

To elicit behavioral responses and to quantify reductions in physical social contacts, we asked respondents: "Compared to the same week last year, by what percentage have you reduced or increased your physical, social contacts this week?". In the survey, we defined "physical, social contacts" as situations in which the respondent came closer than two metres to others. We collected responses on a 15-point log-scale ranging from "reduction to zero" to "increasing by 10%" which corresponds to a range of physical social contacts, relative to normal, in the interval [0; 1.1].³

Besides the intrinsic motivation to engage in defense measures, external factors like governmental regulations could also affect private defense measures and potentially crowd out some of the intrinsic motivation (see, e.g., Yan et al., 2020). We test for this by comparing differences in responses for those who participate in the survey before and after a contact ban for Germany has been announced on Sunday, March 22, 2020. While the announcement took place roughly in the middle of our data collection period, this leaves approximately half of the respondents unaffected by the contact ban, and at least some share of the week in question subject to regulation for the other half.

Table 1 shows descriptive statistics.

¹This survey has been pre-registered at the AEA RCT Registry (https://doi.org/10.1257/rct.5573-1.1).

²Risk-averse subjects may not participate in on-site laboratory sessions even if those were running during the pandemic.

³The answer items were: "reduction to zero, ..., reduction to one hundredth, ..., reduction to one tenth, ..., halving, ..., reducing by 10%, ..., reducing by 1%, unchanged, increasing by 1%, ..., increasing by 10%".



Figure 1: Data collection periods and the daily infections in Germany during 2020

Notes: Graph shows the number of infections with SARS-CoV-2 in Germany during 2020. The black line shows a smoothed trend over the past 7 days and the gray line the daily reported numbers. The latter have a higher volatility due to non- and under-reporting of local incidences during weekends. The yellow areas indicate our data collection periods. Data from Robert Koch Institut (2020).

Table 1: Descriptive statistics.

	All		Wave	
		1	2	3
Age	51.33	50.07	51.82	52.16
Female	0.48	0.51	0.47	0.46
Change contacts this week (indiv)	6.27	4.83	7.95	6.22
Avg. daily num. persons $<2m$	12.62		13.54	11.75
Num. residents in county	355732.23	351118.37	357292.74	359049.52
OxGRT Stringency Index	67.32	72.68	57.75	70.57
Avg. change contacts this week (county)	6.28	4.85	7.96	6.22
Median change contacts this week (county)	5.98	4.18	8.06	5.94
Avg infections next 7d (county)	319.03	153.09	45.88	738.52
Avg deaths next 7d (county)	3.87	6.74	0.08	4.37
Ratio: avg. infected / avg. deaths next 7d (county)	312.80	45.24	2171.02	272.12
Observations	10065	3502	3126	3437

Notes: Table shows mean values.

3.2 Estimating model parameters

We estimate the model parameters with data from our survey.

First, we estimate equation (1). The change in the number of physical social contacts of an individual c_i is given directly by the survey. In particular, we use the relative number of contacts during our first data collection which we measured on a logarithmic scale.⁴ As a measure for the future individual risk p_i , we use the information about a positive test result for the coronavirus until our second and third data collection period. We expect that individuals who have more contacts increase their future individual risk and are thus more likely to receive a positive test for SARS-CoV-2. Therefore, we estimate:

$$\ln(p_{it}) = (1 - \alpha) \ln(c_{it}) + \mathbf{X}_{it} + \epsilon_{it}$$
(12)

Table 2 shows our results. As expected, we find a positive effect of contacts on future risk. While the number of positive tested participants has been low during our second data collection period, we prefer the model in Columns (4)-(6). It suggests that an increase in the number of contacts by 1 percent during March 2020 increases the probability to get tested positive by the end of December 2020 by 0.19 percentage points (?) (Col. 4) or **add: marginal effects** (Col. 5 + 6). Coming back to equation 1 and our model parameters, this suggest $(1 - \alpha) =$.

A concern with the results in Table 2 are omitted variables. If there are confounding factors, that jointly determine the level of contacts in March 2020 and the test result, this will lead to a biased estimate. We adress this concern in two ways. First, we control for age, gender, education, and the existence of health issues. Second, we provide a second estimation following an instrumental variable (IV) approach. To this end, we instrument the change in contacts during March 2020. In Table ?? we show IV results with the instrument being a dummy indicating if participants engage in blue collar work. The first stage reveals that blue collar workers reduce their contacts less than all other employed individuals which turn increases their probability to get tested positive for the coronavirus. Once we control for more covariates, however, the effect turns insignificant.

 $^{{}^{4}}$ We asked: "" with anwers ranging form . . .

		Wave 2			Wave 3	
	OLS (1)	Logit (2)	Probit (3)	OLS (4)	Logit (5)	Probit (6)
Rel. contacts to normal (W1)	0.0010^{*} (0.001)	$\begin{array}{c} 0.0418^{**} \\ (0.021) \end{array}$	0.0984^{*} (0.053)	0.0018^{**} (0.001)	0.0342^{*} (0.018)	$\begin{array}{c} 0.0879^{**} \\ (0.042) \end{array}$
Age	-0.0003^{**} (0.000)	-0.0157^{**} (0.006)	-0.0423^{***} (0.016)	-0.0008*** (0.000)	-0.0182^{***} (0.005)	-0.0472^{***} (0.012)
Female	-0.0001 (0.004)	-0.0310 (0.170)	-0.1235 (0.440)	$0.0026 \\ (0.006)$	$0.0462 \\ (0.137)$	$\begin{array}{c} 0.1255 \ (0.333) \end{array}$
Having health issues	$\begin{array}{c} 0.0133^{***} \\ (0.005) \end{array}$	$\begin{array}{c} 0.5330^{***} \\ (0.184) \end{array}$	$\begin{array}{c} 1.4124^{***} \\ (0.479) \end{array}$	0.0166^{**} (0.006)	$\begin{array}{c} 0.3895^{**} \\ (0.152) \end{array}$	$\begin{array}{c} 0.9844^{***} \\ (0.365) \end{array}$
University degree	0.0000 (.)	0.0000 (.)	0.0000 (.)	0.0000 (.)	0.0000 (.)	0.0000(.)
A-levels / vocational training	-0.0130^{**} (0.006)	-0.7772^{**} (0.386)	-2.0831^{*} (1.081)	-0.0096 (0.009)	-0.2125 (0.227)	-0.6032 (0.569)
Secondary school	-0.0088^{*} (0.005)	-0.3516 (0.222)	-1.0543^{*} (0.595)	0.0013 (0.008)	0.0244 (0.176)	$0.0844 \\ (0.421)$
Secondary general school	$0.0028 \\ (0.006)$	$0.0548 \\ (0.210)$	$\begin{array}{c} 0.0910 \\ (0.524) \end{array}$	-0.0048 (0.009)	-0.0929 (0.209)	-0.2936 (0.518)
No degree	-0.0145 (0.043)	0.0000 (.)	0.0000 (.)	-0.0226 (0.044)	0.0000 (.)	0.0000 (.)
Median change cont. in county	0.0003 (0.001)	$0.0094 \\ (0.047)$	0.0327 (0.118)	-0.0000 (0.002)	$\begin{array}{c} 0.0051 \\ (0.043) \end{array}$	-0.0006 (0.103)
Observations N_Positive	$\begin{array}{c} 2377 \\ 22 \end{array}$	$\begin{array}{c} 2372 \\ 22 \end{array}$	$\begin{array}{c} 2372 \\ 22 \end{array}$	$\begin{array}{c} 2148 \\ 41 \end{array}$	$\begin{array}{c} 2139\\ 41 \end{array}$	$\begin{array}{c} 2139\\ 41 \end{array}$

Table 2: Contact reduction on the risk of a future virus infection.

Standard errors in parentheses

Notes: Dependent variable: Binary indicator of being tested positive at our 2nd or 3rd data collection period. The relative number of contacts to normal **in the past week** is given on a log scale and ranges from reduction to zero (1) to increase by 10 percent (15).

* p < 0.1, ** p < 0.05, *** p < 0.01

	w/out o	controls	W/	/ controls
	Wave 2 (1)	Wave 3 (2)	Wave 2 (3)	Wave 3 (4)
Rel. contacts to normal (W1)	0.0098^{*} (1.651)	$0.0065 \\ (0.539)$	0.0077 (1.084)	0.0037 (0.267)
Age			-0.0004 (-1.485)	-0.0012** (-2.508)
Female			$\begin{array}{c} 0.0049 \\ (0.649) \end{array}$	0.0041 (0.309)
Having health issues			$\begin{array}{c} 0.0198^{***} \\ (2.920) \end{array}$	0.0451^{***} (4.165)
University degree			0.0000 (.)	0.0000 (.)
A-levels / vocational training			-0.0135^{*} (-1.649)	-0.0131 (-1.019)
Secondary school			-0.0108 (-1.424)	$0.0054 \\ (0.466)$
Secondary general school			$\begin{array}{c} 0.0070 \\ (0.701) \end{array}$	-0.0035 (-0.229)
No degree			-0.0130 (-0.211)	-0.0122 (-0.152)
Observations First_stage_F-Stat.	$1571 \\ 28.33$	$1353 \\ 14.52$	$\frac{1553}{6.10}$	$1343 \\ 5.00$

Table 3: Contact reduction on the risk of a future virus infection. (IV Approach)

t statistics in parentheses

Notes: Dependent variable: Binary indicator of being tested positive at our 2nd or 3rd data collection period. **Instrument: Binary dummy if engaged in blue collar work.** Sample only includes employed participants. The relative number of contacts to normal in the past week is given on a log scale and ranges from *reduction to zero* (1) to *increase by 10 percent* (15).

* p < 0.1, ** p < 0.05, *** p < 0.01

	Blue Collar			Positive COVID-19 Test?			
	No	Yes	p-value	No	Yes	p-value	
Education							
Studium	0.30	0.08	$(0.000)^{***}$	0.21	0.30	(0.162)	
Abitur	0.25	0.12	$(0.000)^{***}$	0.22	0.15	(0.119)	
Realschule	0.34	0.48	$(0.000)^{***}$	0.32	0.38	(0.394)	
Hauptschule	0.11	0.33	$(0.000)^{***}$	0.24	0.16	(0.122)	
Kein Schulabschluss	0.00	0.00	(0.673)	0.01	0.02	(0.507)	
Monthly household income (in EUR)							
< 1,500	0.09	0.18	$(0.000)^{***}$	0.20	0.15	(0.235)	
1,500 - 3,000	0.35	0.47	$(0.000)^{***}$	0.39	0.41	(0.769)	
3,000 - 4,000	0.26	0.23	(0.151)	0.20	0.25	(0.445)	
$\geq 4,000$	0.30	0.12	$(0.000)^{***}$	0.20	0.20	(0.902)	
Employment status							
Full-time	0.71	0.59	$(0.000)^{***}$	0.42	0.63	$(0.002)^{**}$	
Part-time	0.22	0.29	$(0.003)^{**}$	0.14	0.21	(0.164)	
Marginal / irregular empl.	0.07	0.12	$(0.002)^{**}$	0.04	0.00	$(0.000)^{***}$	
Not employed	0.00	0.00	(.)	0.40	0.16	$(0.000)^{***}$	
Occupation							
Self-employed	0.14	0.00	$(0.000)^{***}$	0.10	0.12	(0.777)	
Blue-collar worker	0.00	1.00	(.)	0.30	0.33	(0.665)	
White-collar worker	0.77	0.00	$(0.000)^{***}$	0.54	0.50	(0.589)	
Civil servant	0.06	0.00	$(0.000)^{***}$	0.04	0.02	(0.215)	
Apprentice / trainee	0.03	0.00	$(0.000)^{***}$	0.02	0.04	(0.432)	
Household size							
1 person	0.08	0.07	(0.531)	0.17	0.10	(0.112)	
2 persons	0.48	0.45	(0.395)	0.51	0.29	$(0.001)^{***}$	
3 persons	0.24	0.26	(0.472)	0.17	0.28	(0.086)	
4 persons	0.15	0.16	(0.766)	0.10	0.28	$(0.004)^{**}$	
$\geq 5 \text{ persons}$	0.05	0.06	(0.473)	0.05	0.05	(0.875)	
Household members < 18 years							
0 members	0.66	0.62	(0.085)	0.76	0.47	$(0.000)^{***}$	
1 member	0.20	0.23	(0.142)	0.14	0.29	$(0.014)^*$	
2 members	0.11	0.12	(0.447)	0.08	0.22	$(0.011)^*$	
$\geq 3 \text{ members}$	0.03	0.03	(0.875)	0.02	0.02	(0.771)	
Household members > 60 years							
0 members	0.75	0.76	(0.633)	0.57	0.72	$(0.015)^*$	
1 member	0.14	0.15	(0.665)	0.20	0.16	(0.331)	
≥ 2 members	0.11	0.09	(0.228)	0.22	0.12	$(0.023)^*$	
Observations	1266	485	1751	3349	63	3412	

Table 4: Descriptive statistics by infection status

Notes: Table shows mean values and results of t-tests.

Next, we specify the utility function as

$$u(c,x) = \frac{1}{1-\eta} c^{1-\eta} + v(x),$$
(13)

such that $\eta > 0$ is the elasticity of marginal utility.

3.3 Testing hypotheses

First, Table 5 provides evidence that individual behavior is consistent with the predictions of the Nash equilibrium, equation (4). Respondents who face a higher risk of an infection (measured in

	Pa	st	Planned		
	Contacts	Hand cleaning	Contacts	Hand cleaning	
Deaths in past 7d (log)	-0.128^{***} (-9.563)	0.065^{***} (5.882)	-0.216*** (-13.274)	$0.174^{***} \\ (12.261)$	
Observations	9747	9720	9749	9719	

Table 5: Private public good contributions and objective indivividual risk

 $t\ {\rm statistics}\ {\rm in}\ {\rm parentheses}$

Notes: Fixed effects regressions. Covariates include a constant.

* p < 0.1, ** p < 0.05, *** p < 0.001

terms of the number of COVID-19 related deaths in the county) reduce contacts to a greater extent and clean hands to a greater extent than individuals who live in safer counties.

Table 2 provides empirical evidence for Proposition 1. It shows that the willingness to take health risks is positively correlated to the number of physical social contacts. Respondents who care less about an extra health risk thus undertake riskier actions, both for the contacts in the past week and for the contacts planned for the next week. Similarly, respondents who report a higher willingness to take health risk seem to engage less in the protective activity of hand cleaning, although this effect is not statistically significant.

4 Conclusion

In this paper we have extended the theory of endogeneous risks in a commons setting, where each agent's activities affect the risks faced by all others as well. Such a setting prevails in many important problems, including climate change and the recent COVID 19 pandemic. We have derived conditions under which risk, risk aversion, and prudence alleviate the commons problem. In particular we have shown that an extra risk can increase welfare even for risk-averse agents. Complementing the recently expanding literature on the role of risks and in particular tipping points in climate change (Barrett and Dannenberg, 2014; Cai and Lontzek, 2019), we provide a general theory and hypotheses that may inform climate policies.

	Pa	st	Plan	ned	
	Contacts	Contacts Hand cleaning		Hand cleaning	
Will. health risk	0.123***	-0.038	0.056^{*}	-0.001	
	(3.956)	(-1.538)	(1.813)	(-0.033)	
Observations	10107	10084	10112	10079	

Table 6: Private public good contributions and risk aversion (I)

t statistics in parentheses

Notes: Fixed effects regressions. Covariates always include age, gender, educ, health issue and a wave dummy. Further covariates may include HH income (4 groups), HH size (5 groups), and the number of friends and family members. Each willingness ranges from 1 (not willing) to 11 (very willing).

* p < 0.1, ** p < 0.05, *** p < 0.001

Table 7:	Private	public g	ood	contributions	and	subje	ective	indiv	ividual	risk	(I)).
		1 ()				• • • •					· · ·	/

		Past	Planned			
	Contacts	Hand cleaning	Contacts	Hand cleaning		
Prob. get infected	$0.003 \\ (0.993)$	0.013^{***} (5.229)	0.006^{*} (1.785)	0.009^{***} (3.370)		
Prob. get ill	0.013^{***} (3.902)	$0.000 \\ (0.009)$	0.009^{**} (2.547)	$0.004 \\ (1.310)$		
Prob. get endangered	0.006^{*} (1.771)	0.015^{***} (5.192)	0.007^{*} (1.800)	0.008^{**} (2.318)		
Observations	9913	9899	9917	9889		

 $t\ {\rm statistics}$ in parentheses

Notes: Fixed effect regressions. Covariates include a wave dummy.

* p < 0.1, ** p < 0.05, *** p < 0.001

We applied the theory to the case of the COVID 19 pandemic, using unique panel data from a representative household survey in Germany. We estimate model parameters and test the model implications. Preliminary evidence suggests that extra uncertainty about health consequences of a corona infection would increase individual precautionary efforts to avoid an infection, but the effect on the overall infection rates would not have been strong enough to increase overall welfare.

Appendix

A Proof of proposition 3

For a small risk, i.e. small values of ℓ and ε , we get from a Taylor series expansion to the second order

$$W(\mathbf{c}) \approx n \left(u(c_i, x) + \delta \left(v(x) + v''(x) \sigma_{\varepsilon}^2 - p(c_i, \mathbf{c}_{-i}) \omega \right) \right)$$
(14)

where we used the abbreviation

$$\omega := v(x) + v''(x)\,\sigma_{\varepsilon}^2 - v(x-l) - v''(x-l)\,\left(\sigma_{\ell}^2 + \sigma_{\varepsilon}^2\right) \tag{15}$$

which is the expected utility loss in case of a damaging event.

The condition for the symmetric Nash equilibrium becomes

$$\frac{\partial u\left(c,x\right)}{\partial c} = \delta \,\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}\,\omega\tag{16}$$

Thus, as $c_j = c$ for all j,

$$\left(\frac{\partial^2 u(c,x)}{\partial c^2} - \delta \left(\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2} + (n-1)\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c \partial c_{-i}}\right)\omega\right)\frac{\partial c}{\partial \sigma_\ell^2} = -\delta \frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}v''(x-l),\tag{17}$$

which confirms $\partial c/\partial \sigma_{\ell}^2 < 0$ (note that the term in brackets on the left-hand side of the equation is negative due to the second-order condition of utility maximization).

Similarly,

$$\left(\frac{\partial^2 u(c,x)}{\partial c^2} - \delta \left(\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2} + (n-1)\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c \partial c_{-i}}\right)\omega\right)\frac{\partial c}{\partial \sigma_{\varepsilon}^2} = \delta \frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}\left(v''(x) - v''(x-l)\right), \quad (18)$$

which confirms $\partial c / \partial \sigma_{\varepsilon}^2 < 0$ whenever v''' > 0.

Using the condition for the symmetric Nash equilibrium (16), Welfare in Nash equilibrium changes with σ_{ℓ}^2 as follows:

$$\frac{1}{n}\frac{\partial W(\mathbf{c})}{\partial \sigma_{\ell}^2} = -\delta\left(n-1\right)\frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_{-i}}\frac{\partial c}{\partial \sigma_{\ell}^2}\omega + \delta p(c, \mathbf{c}_{-i})v''(x-l)$$
(19)

This is positive if and only if

$$0 < \delta(n-1) \frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_{-i}} \frac{\delta \frac{\partial p(c, \mathbf{c}_{-i})}{\partial c} v''(x-l)}{\frac{\partial^2 u(c, x)}{\partial c^2} - \delta \left(\frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c^2} + (n-1) \frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c \partial c_{-i}}\right) \omega}{\omega} \omega + \delta p(c, \mathbf{c}_{-i}) v''(x-l)$$
(20)

$$(n-1)\frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_{-i}}\frac{\delta \frac{\partial p(c, \mathbf{c}_{-i})}{\partial c} v''(x-l)}{\frac{\partial^2 u(c, x)}{\partial c^2} - \delta \left(\frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c^2} + (n-1) \frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c \partial c_{-i}}\right)\omega}{\omega}\omega + p(c, \mathbf{c}_{-i}) v''(x-l) > 0$$
(21)

$$\frac{\delta\left(n-1\right)\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c_{-i}}}{\frac{\partial^{2}u(c,x)}{\partial c^{2}}-\delta\left(\frac{\partial^{2}p(c,\mathbf{c}_{-i})}{\partial c^{2}}+(n-1)\frac{\partial^{2}p(c,\mathbf{c}_{-i})}{\partial c\partial c_{-i}}\right)\omega}{\omega}\omega+p(c,\mathbf{c}_{-i})<0$$
(22)

$$\delta \,\omega \left(n-1\right) \frac{\partial p(c, \mathbf{c}_{-i})}{\partial c} \,\frac{\partial p(c_i, \mathbf{c}_{-i})}{\partial c_{-i}} + p(c, \mathbf{c}_{-i}) \,\left(\frac{\partial^2 u\left(c, x\right)}{\partial c^2} - \delta \,\omega \,\left(\frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c^2} + (n-1) \,\frac{\partial^2 p(c, \mathbf{c}_{-i})}{\partial c \,\partial c_{-i}}\right)\right) > 0 \tag{23}$$

Using η to denote the elasticity of marginal utility with respect to c, this condition becomes

$$\delta \,\omega \,c \,\left((n-1) \,\frac{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c} \,\frac{\partial p(c_i,\mathbf{c}_{-i})}{\partial c_{-i}}}{p(c,\mathbf{c}_{-i})} - \frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2} - (n-1) \,\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c \,\partial c_{-i}} \right) > \eta \,\frac{\partial u\left(c,x\right)}{\partial c} \tag{24}$$

and using the condition for the symmetric Nash equilibrium (16),

$$c\left((n-1)\frac{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c_{-i}}}{p(c,\mathbf{c}_{-i})} - \frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2} - (n-1)\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c \partial c_{-i}}\right) > \eta \frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}$$
(25)

$$(n-1)\left(\frac{c\frac{\partial p(c_i,\mathbf{c}_{-i})}{\partial c_{-i}}}{p(c,\mathbf{c}_{-i})} - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c\partial c_{-i}}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}}\right) - \frac{c\frac{\partial^2 p(c,\mathbf{c}_{-i})}{\partial c^2}}{\frac{\partial p(c,\mathbf{c}_{-i})}{\partial c}} > \eta$$
(26)

B Correlation Analysis

		Outcome: Number of deaths in next 7 days							
	# FF (1)	# FF > 60 (2)	HH inc to Feb (3)	Health status (4)	Will vacc. (5)	Time Pref. (6)			
Contacts this week (indiv level)	9.772 (117.485)	25.429 (568.319)	-1.246 (0.886)	-1.496^{**} (0.668)	-2.776 (3.622)	-0.975 (0.878)			
Observations	9139	9106	5718	5716	5695	4967			

Table 8: Estimate for $(1 - \alpha)$ via an IV approach.

Standard errors in parentheses

Notes: IV estimation for a panel. Fixed effects on the subject level. Instruments are number of friends and family members (1), the number of friends and familiy members above 60 (2), the monthly hh income compared to February 2020 (3), self-reported health status (4), willingess to vaccinate (5), the revealed time preferences from the staircase method from Falk et al. (6). Standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.001

	Outcome: Prob. to get infected						
	# FF > 60 (1)	HH inc to Feb (2)	Working time home (3)	Protect FF (4)			
Contacts this week (indiv level)	$0.616 \\ (4.837)$	-3.432 (2.762)	-1.059 (1.637)	-2.192^{*} (1.327)			
Observations	9859	6487	3961	9652			

Table 9: Estimate for $(1 - \alpha)$ via an IV approach. (II)

Standard errors in parentheses

Notes: IV estimation for a panel. Fixed effects on the subject level. Instruments are given in the column titles. Standard errors in parentheses.

* p < 0.1, ** p < 0.05, *** p < 0.001

		Outcome: P	rob. to get endangered
	HH inc to Feb (1)	Time Pref (2)	Patience (3)
Contacts this week (indiv level)	0.484 (1.905)	1.120 (2.357)	-0.117 (0.504)
Observations	6415	5553	9806

Table 10:	Estimate for	$(1-\alpha)$	via an IV	approach.	(III)
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Standard errors in parentheses

Notes: IV estimation for a panel. Fixed effects on the subject level. Instruments are given in the column titles. Standard errors in parentheses. * p<0.1, ** p<0.05, *** p<0.001

	Change in contacts			Number of deaths			
	this week			in next $7d$			
	ρ	p-value	N	ρ	p-value	N	
Age	-0.004	0.696	10125	-0.026	0.012*	9291	
Education	0.009	0.369	10112	-0.027	0.010**	9283	
HH size (persons)	-0.029	0.004**	9763	0.020	0.064	8948	
HH members above 60	0.004	0.714	9759	-0.040	0.000***	8946	
Friends and family (persons)	-0.059	0.000***	10107	-0.000	0.990	9274	
Friends and family above 60	-0.046	0.000***	10065	-0.009	0.398	9241	
Monthly hh inc relative to Feb. 2020	0.046	0.000***	6572	-0.010	0.436	5741	
Employment status	-0.020	0.053	9345	-0.030	0.006**	8472	
Working time at employer	0.054	0.001***	4021	-0.055	0.001**	3517	
Share working time spend at home	-0.093	0.000***	4021	0.065	0.000***	3517	
Religious group	0.006	0.827	1448	-0.001	0.962	1123	
Q8: Level of fear at the moment	-0.203	0.000***	10113	0.088	0.000***	9225	
Q12: Investment into risky lottery	0.029	0.003^{**}	10177	-0.022	0.033^{*}	9291	
Q13: Having health issues	-0.020	0.042^{*}	10066	-0.013	0.201	9219	
Health status (self-reported)	0.066	0.000***	6570	-0.012	0.366	5739	
Q15a: Willingness to get tested	-0.098	0.000***	10147	0.074	0.000***	9265	
Number of COVID-19 tests	-0.000	0.989	6530	0.101	0.000***	5702	
Tested positive for COVID-19	0.005	0.670	6531	0.019	0.144	5707	
Q14: Already corona infection?	0.055	0.000^{***}	10003	-0.076	0.000^{***}	9142	
Q16a: Probability to get infected	-0.048	0.000^{***}	10086	0.033	0.001^{**}	9216	
Q16b: Probability to get slightly ill if infected	0.046	0.000^{***}	9924	0.039	0.000^{***}	9074	
Q16c: Probability to get in acute danger	-0.064	0.000^{***}	9924	-0.026	0.013^{*}	9074	
Q28: Number of infections among ff	-0.004	0.727	6554	0.051	0.000^{***}	5725	
Q28: Number of ff hospitalized	0.033	0.306	988	0.000	0.995	818	
Q28: Number of ff died	0.040	0.208	981	0.000	0.997	810	
Q19: To protect me	-0.027	0.006^{**}	10108	0.004	0.714	9227	
Q19: To protect family and friends	0.044	0.000^{***}	9857	-0.021	0.044^{*}	9015	
Q19: To protect others	0.024	0.017^{*}	9700	-0.004	0.725	8873	
Q24: Number of tails	-0.005	0.614	10177	0.020	0.053	9291	
Q8: Level of fear at the moment	-0.203	0.000^{***}	10113	0.088	0.000^{***}	9225	
Exp. 'back to normal' date	0.015	0.221	6533	-0.029	0.029^{*}	5703	
Q40: Willingness to get vaccinated voluntarily	-0.117	0.000^{***}	6546	-0.005	0.710	5716	
Agreement compulsory vacc.	-0.051	0.000^{***}	6564	-0.078	0.000^{***}	5734	
Falk: Time pref	-0.043	0.001^{**}	5674	-0.001	0.964	4986	
Falk: Patience	-0.094	0.000^{***}	10168	0.073	0.000^{***}	9280	
Falk: Neg reciprocity (I)	0.026	0.034^{*}	6554	-0.021	0.116	5724	
Falk: Neg reciprocity (II)	-0.065	0.000^{***}	10159	0.057	0.000^{***}	9277	
Falk: Altruism	-0.129	0.000***	10160	0.058	0.000***	9275	

Notes: Change in contacts ranges from reduction to zero (1) to increase by 10 percent (15).

	Change in contacts			Prob			
	this week			get infected			
	ρ	p-value	Ν	ρ	p-value	Ν	
Age	-0.004	0.696	10125	-0.149	0.000***	10048	
Education	0.009	0.369	10112	-0.051	0.000***	10033	
HH size (persons)	-0.029	0.004^{**}	9763	0.072	0.000***	9688	
HH members above 60	0.004	0.714	9759	-0.119	0.000***	9685	
Friends and family (persons)	-0.059	0.000***	10107	0.057	0.000***	10030	
Friends and family above 60	-0.046	0.000***	10065	-0.006	0.531	9988	
Monthly hh inc relative to Feb. 2020	0.046	0.000***	6572	0.018	0.140	6509	
Employment status	-0.020	0.053	9345	-0.133	0.000***	9271	
Working time at employer	0.054	0.001^{***}	4021	0.032	0.046^{*}	3977	
Share working time spend at home	-0.093	0.000***	4021	-0.007	0.653	3977	
Religious group	0.006	0.827	1448	0.047	0.076	1424	
Q8: Level of fear at the moment	-0.203	0.000^{***}	10113	0.205	0.000^{***}	10033	
Q12: Investment into risky lottery	0.029	0.003^{**}	10177	0.039	0.000^{***}	10098	
Q13: Having health issues	-0.020	0.042^{*}	10066	0.001	0.927	9990	
Health status (self-reported)	0.066	0.000^{***}	6570	-0.073	0.000^{***}	6507	
Q15a: Willingness to get tested	-0.098	0.000***	10147	0.113	0.000***	10083	
Number of COVID-19 tests	-0.000	0.989	6530	0.119	0.000***	6468	
Tested positive for COVID-19	0.005	0.670	6531	0.047	0.000***	6469	
Q14: Already corona infection?	0.055	0.000***	10003	0.141	0.000***	9925	
Q16a: Probability to get infected	-0.048	0.000^{***}	10086	1.000		10098	
Q16b: Probability to get slightly ill if infected	0.046	0.000^{***}	9924	0.147	0.000^{***}	9925	
Q16c: Probability to get in acute danger	-0.064	0.000^{***}	9924	0.231	0.000^{***}	9925	
Q28: Number of infections among ff	-0.004	0.727	6554	0.014	0.263	6491	
Q28: Number of ff hospitalized	0.033	0.306	988	-0.027	0.406	952	
Q28: Number of ff died	0.040	0.208	981	-0.027	0.410	945	
Q19: To protect me	-0.027	0.006^{**}	10108	-0.049	0.000^{***}	10029	
Q19: To protect family and friends	0.044	0.000^{***}	9857	0.011	0.294	9782	
Q19: To protect others	0.024	0.017^{*}	9700	0.044	0.000^{***}	9625	
Q24: Number of tails	-0.005	0.614	10177	-0.013	0.180	10098	
Q8: Level of fear at the moment	-0.203	0.000^{***}	10113	0.205	0.000^{***}	10033	
Exp. 'back to normal' date	0.015	0.221	6533	0.027	0.030^{*}	6470	
Q40: Willingness to get vaccinated voluntarily	-0.117	0.000***	6546	0.117	0.000***	6483	
Agreement compulsory vacc.	-0.051	0.000^{***}	6564	0.057	0.000^{***}	6501	
Falk: Time pref	-0.043	0.001^{**}	5674	0.083	0.000***	5626	
Falk: Patience	-0.094	0.000***	10168	0.130	0.000***	10091	
Falk: Neg reciprocity (I)	0.026	0.034^{*}	6554	0.075	0.000***	6491	
Falk: Neg reciprocity (II)	-0.065	0.000***	10159	0.102	0.000***	10080	
Falk: Altruism	-0.129	0.000***	10160	0.100	0.000***	10081	

Notes: Change in contacts ranges from reduction to zero (1) to increase by 10 percent (15).

Table 13: Correlation Analysis (III).
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	Change in contacts			Prob		
	this week			get endangered		
	ρ	p-value	Ν	ρ	p-value	N
Age	-0.004	0.696	10125	0.318	0.000***	9891
Education	0.009	0.369	10112	0.050	0.000***	9876
HH size (persons)	-0.029	0.004**	9763	-0.088	0.000***	9543
HH members above 60	0.004	0.714	9759	0.232	0.000***	9540
Friends and family (persons)	-0.059	0.000***	10107	-0.039	0.000***	9875
Friends and family above 60	-0.046	0.000***	10065	0.074	0.000***	9831
Monthly hh inc relative to Feb. 2020	0.046	0.000***	6572	0.013	0.288	6439
Employment status	-0.020	0.053	9345	0.209	0.000***	9145
Working time at employer	0.054	0.001***	4021	-0.041	0.010**	3950
Share working time spend at home	-0.093	0.000***	4021	0.032	0.042^{*}	3950
Religious group	0.006	0.827	1448	-0.023	0.382	1405
Q8: Level of fear at the moment	-0.203	0.000***	10113	0.203	0.000***	9872
Q12: Investment into risky lottery	0.029	0.003**	10177	-0.032	0.001**	9939
Q13: Having health issues	-0.020	0.042^{*}	10066	0.386	0.000***	9834
Health status (self-reported)	0.066	0.000***	6570	-0.380	0.000***	6437
Q15a: Willingness to get tested	-0.098	0.000***	10147	0.055	0.000***	9923
Number of COVID-19 tests	-0.000	0.989	6530	0.029	0.020^{*}	6403
Tested positive for COVID-19	0.005	0.670	6531	-0.025	0.042^{*}	6401
Q14: Already corona infection?	0.055	0.000***	10003	-0.000	0.998	9766
Q16a: Probability to get infected	-0.048	0.000***	10086	0.231	0.000***	9925
Q16b: Probability to get slightly ill if infected	0.046	0.000***	9924	-0.429	0.000***	9939
Q16c: Probability to get in acute danger	-0.064	0.000***	9924	1.000		9939
Q28: Number of infections among ff	-0.004	0.727	6554	0.001	0.967	6421
Q28: Number of ff hospitalized	0.033	0.306	988	-0.025	0.442	946
Q28: Number of ff died	0.040	0.208	981	-0.025	0.441	939
Q19: To protect me	-0.027	0.006^{**}	10108	0.065	0.000***	9871
Q19: To protect family and friends	0.044	0.000^{***}	9857	-0.049	0.000^{***}	9625
Q19: To protect others	0.024	0.017^{*}	9700	-0.057	0.000^{***}	9469
Q24: Number of tails	-0.005	0.614	10177	-0.046	0.000^{***}	9939
Q8: Level of fear at the moment	-0.203	0.000^{***}	10113	0.203	0.000^{***}	9872
Exp. 'back to normal' date	0.015	0.221	6533	0.044	0.000^{***}	6402
Q40: Willingness to get vaccinated voluntarily	-0.117	0.000^{***}	6546	0.307	0.000^{***}	6413
Agreement compulsory vacc.	-0.051	0.000^{***}	6564	0.247	0.000^{***}	6431
Falk: Time pref	-0.043	0.001^{**}	5674	-0.003	0.800	5573
Falk: Patience	-0.094	0.000^{***}	10168	-0.000	0.963	9928
Falk: Neg reciprocity (I)	0.026	0.034^{*}	6554	0.021	0.085	6422
Falk: Neg reciprocity (II)	-0.065	0.000^{***}	10159	0.040	0.000^{***}	9925
Falk: Altruism	-0.129	0.000^{***}	10160	0.066	0.000^{***}	9926

Notes: Change in contacts ranges from reduction to zero (1) to increase by 10 percent (15).

C Reweighting of deaths

Approach:

$$\begin{pmatrix} 0km & 5km & 10km \\ 5km & 0km & 20km \\ 10km & 20km & 0km \end{pmatrix} \Rightarrow \begin{pmatrix} 0.0255 & 0.0242 & 0.0209 \\ 0.0242 & 0.0255 & 0.0231 \\ 0.0209 & 0.0231 & 0.0255 \end{pmatrix} \times \begin{pmatrix} 10 \\ 0 \\ 5 \end{pmatrix} = \begin{pmatrix} 10 * 0.0255 + 0 * 0.0242 + 5 * 0.0209 \\ \dots \\ \dots \\ \dots \end{pmatrix}$$

Weights are given by:

$$weight_d = \frac{exp(-\delta \times d)}{\sum_{d=0}^{dlim} exp(-\delta \times d)}$$







Figure 3: Death rates during Wave 3

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