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by

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Abstract

We argue that the incentive structure of all individual and coordinated measures across countries to contain the Corona-pandemic is that of a weakest-link public good game. We discuss a selection of theoretical and experimental key results of weakest-link games and interpret them in the light of the Corona-pandemic. First, we highlight that experimental evidence does not support the assumption that coordination can be trivially solved, even among symmetric players. Second, we argue that for asymmetric countries the weakest-link game does not only pose a problem of coordination, but also a problem of cooperation. Third, we show how and under which conditions self-enforcing treaties can foster cooperation. We account for the possibility that countries make mistakes when choosing their actions. Finally, we provide a list of research gaps.

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1 Introduction

The world is facing the worst pandemic in a century[1], caused by a new form of coronavirus.[2] In a highly interconnect world, efforts to mitigate the effects of COVID-19 need to be coordinated, as an outbreak anywhere in the world puts all other countries at risk.[3] That is, if one country relaxes its control measures and provokes an outbreak, all other countries will be negatively affected. The same logic applies to regions within a country, or states in the US. In addition, even wealthy and developed countries in Europe have seen that individual efforts may not suffice to control an outbreak. The situation will be even worse if serious outbreaks occur in developing countries. This implies that cooperation, and not only coordination, is needed to address this pandemic.

Ideally, one would look at previous experiences to learn lessons on how to react to such a pandemic. However, serious pandemics are rare events and there is simply not enough evidence to draw statistically significant conclusions. Furthermore, COVID-19 may very well be the first serious pandemic in a truly interconnected world. Hence, theory and experimental results provide the best guidance available. For climate change, theory and experiments predicted that the burden-sharing approach followed in the Kyoto Protocol was not an effective strategy. It took the world almost twenty years to realize this and to change this approach. We may not have the luxury of such a delay in finding the right strategy to tackle COVID-19.

We argue below that the relevant incentive structure is that of a weakest-link public good game (Hirshleifer, 1983): the contribution of the agent that contributes the least determines the outcome for all.[4] In the context of the eradication of smallpox and other infectious diseases, Barrett (2016) argued that the incentives are best described by such a game. He focuses on a static (one shot) game in pure strategies with symmetric countries (all countries have the same choices and payoff functions) where every country chooses a vaccination level with the knowledge that there exists a critical vaccination level, above which the disease is eliminated within the country (see also Barrett 2003 and Barrett and Hoel 2007).[5] Instead of focusing on eradication, we argue that, in the context of the COVID-19 weakest-link game, incentives go beyond the eradication of the disease. Controlling outbreaks has this feature (e.g., social distancing, cellphone apps that trace contacts and the spread of the virus), individual decisions to wear a mask have this feature and providing a vaccine to all will eventually have this feature. In addition, given that there is no vaccine currently available, and that there are large

1 Most likely, the last pandemic of similar proportion was the so-called Spanish-flu that emerged in 1918. The world was at war and intercontinental travelling was rare.

2 Although the severity of this pandemic might recede in the coming months, there exists a large number of similar viruses that might provoke new pandemics. Thus, the issues discussed here will remain relevant in the years to come.

3 See "At Least 89 Vaccines Are Being Developed. It May Not Matter", New York Times, April 29, 2020.

4 There also exists a weaker-link version where the smallest contribution has the largest marginal influence on utility, followed by the second smallest contribution, and so on. We ignore this complication for simplicity. See for instance Arce and Sandler (2001) and Cornes and Hartley (2007).

5 This game has two non-cooperative equilibria in pure strategies when focusing on symmetric players. In the first ("bad") equilibrium, no country vaccinates any of its citizens. In the second equilibrium, all countries vaccinate their population above the level that ensures local eradication of the disease. Hence, in the second ("good") equilibrium, the disease is eradicated globally. These two equilibria are probably too extreme to be relevant for COVID-19, not only because there is no vaccine, but also because it is unlikely that all countries will be able to vaccinate a sufficient number of its population, due to a lack of sufficient resources. This is one reason that questions the assumption of symmetric players.

uncertainties about the date at which such a vaccine will be available (if ever), it is too early to focus on eradication. Thus, a more abstract weakest-link game is more relevant, as it is able to capture the incentives not only for eradication, but also for control and prevention measures. In such a framework, we show that coordination on the best possible outcome is far from trivial in a weakest-link game (even assuming symmetric players). In fact, abandoning the assumption that no country makes mistakes (i.e., introducing some realism into the analysis), a failure of coordination, implying the worst possible outcome in the game, is individually rational and completely in line with experimental results.

The analysis in Barrett (2016) concludes on a rather positive note, as smallpox was eradicated. However, as already discussed in Barrett (2003), there is no guarantee that this result will hold for all diseases. Therefore, Barrett (2003) already discusses the usefulness of (cooperative) institutions to coordinate on eradication. This may be viewed as "cooperation to coordinate" on one of the individually rational equilibria for symmetric players. We will show below that, once asymmetric countries are introduced in the analysis, this type of cooperation is not sufficient: additional cooperative efforts in the form of transfers are needed to achieve the first-best outcome. Fortunately, when cooperative institutions are introduced, all the different analytical frameworks (theory and experiments) discussed below support the idea that cooperation has a role to play in bringing countries to the first-best outcome in a perfect world, or at least closer to the first-best outcome in a less than perfect world.

There has been extensive research on the incentives of cooperation in weakest-link games, both theoretical and experimental. However, our goal is not to review this vast literature. Instead, we focus on some key results which we have obtained in previous research and interpret them in the light of the Corona-pandemic. The remainder of this article is organized as follows. Section 2 presents the weakest-link game in the absence of treaties. First, theoretical results obtained in the absence of mistakes are discussed. Then, experimental results are presented, that are at odds with those theoretical results. The last sub-section shows that behavioral theory, based on the assumption that agents may make (small) mistakes, is able to reconcile theoretical and experimental results. As section 2 essentially rationalizes the failure of coordination in the absence of treaties, as observed in the lab, section 3 discusses possible solutions, focusing on the role that treaties might have in fostering cooperation. Finally, section 4 concludes and highlights relevant research gaps.

2 The Problem: Coordination Failure

2.1 Non-cooperative Theory without Mistakes

Let the payoff function of player $i \in N$ be given by

$$\Pi_i(Q, q_i) = B_i(Q) - C_i(q_i) \qquad (1)$$
$$Q = \min_{i \in N}\{q_i\}$$

where Q denotes the public good provision level, which is the minimum provision level over all players and q_i denotes the individual provision level of player i. In our context, the public good is the intensity and quality of virus control.[6] Benefits $B_i(Q)$ depend on the smallest

6 Different countries have adopted different strategies when confronted with COVID-19. Lockdowns have been more severe in Spain than in Sweden, which implies different economic costs. Also, the provision of ICU beds, including ventilators, for all patients in need has been very different across countries. The same will be true for measures of mass vaccination, once a vaccine will be available.

contribution and costs, $C_i(q_i)$, depend on the individual contribution of player i. In a general theoretical setting, benefits are typically assumed to be concave and costs strictly convex such that the payoff function is strictly concave with a unique interior maximum from player i's perspective. This maximum, which we denote by q_i^A, can be viewed as the optimal provision level under autarky (i.e., $B_i^{'}(q_i^A) = C_i^{'}(q_i^A)$). Generally, if benefit and cost functions are different, autarky provision levels will be most likely different. Hence, we have $q_{min}^A = q_1^A \leq q_2^A \leq .... \leq q_n^A$, indexing players according to their autarky levels.

If we denote by $Q_{-i,min}$ the minimum provision level of all players except i, then the optimal response of player i is to match $Q_{-i,min}$ as long as $Q_{-i,min} \leq q_i^A$. As payoffs are concave, any provision level below $Q_{-i,min}$ would imply a lower payoff to player i, and the same is true for any provision level above $Q_{-i,min}$, as this would entail only additional costs but no additional benefits. For any level $Q_{-i,min}$ above player i's autarky level, i.e., $Q_{-i,min} > q_i^A$, player i will stick to his/her autarky level as player i cannot be forced to provide more than q_i^A. Hence, player i matches all provision levels up to level q_i^A. Thus, all provision levels with $q_i = q_j$ for all $i, j \in N$ from zero up to q_{min}^A are Nash equilibria. Given the concavity of players' payoff functions, the Pareto-optimal Nash equilibrium is obtained when all players match q_{min}^A, $q_{min}^A = q^* = q_i^* = q_j^*$ for all $i, j \in N$ and $i \neq j$ (Cornes, 1993; Cornes and Hartley, 2007; Vicary, 1990; Vicary and Sandler, 2002).

If all players have the same benefit and cost function, then $q_i^A = q_j^A$ for all $i, j \in N$, $i \neq j$. In this particular case, the Pareto-optimal Nash equilibrium is identical to the social optimum. Hence, focusing on pure strategies, there is no need for cooperation, only coordination is required to settle for the Pareto-optimal Nash equilibrium. This should prove easy as all interests are aligned. Interestingly, all experimental evidence of which we are aware proves this result wrong, as we report in subsection 2.2. Before turning to this evidence, let us briefly discuss another complication, namely asymmetry.

If players perceive benefits differently and face different costs, which is most likely the case in reality, then autarky provision levels will be different. In other words, players have different preference regarding the "optimal" provision level. Even if we make the heroic assumption that all players settle for the Pareto-optimal Nash equilibrium, this will no longer be socially optimal. As one can show that the socially optimal provision level, Q^{**} with $q_i^{**} = q_j^{**} = Q^{**}$ for all $i, j \in N$, $i \neq j$ lies between the minimum and maximum autarky provision level over all players (Caparrós and Finus, 2020), the difference between the socially optimal and the Pareto-optimal Nash equilibrium provision level can be quite large. Accordingly, coordination is no longer sufficient, and cooperation is needed in order to overcome or at least mitigate the loss of global welfare emerging if players behave non-cooperatively.

The COVID-19 has shown that inequalities matter. In Europe, countries with comparatively weaker sanitary systems and with social behavior with more proximity between people, have been hit hardest. As a result, respiratory equipment was shipped across countries and even patients were moved between countries. Furthermore, Europe is considering, for the first time,

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At an abstract level, all these differences can be summarized in a single variable indicating the intensity and quality of virus control.

raising money by issuing bonds secured by all 27 members.[7] This is a form of transfer, a monetary transfer in our abstract framework. At the global scale, inequalities are far starker, and cooperation will be even more critical. A formal analysis of the role of cooperation can be found in Section 3.

2.2 Experimental Evidence

In experiments, it is important to keep things simple. Therefore, most papers assume a linear payoff function of the following form.

$$\Pi_i(Q, q_i) = bQ - cq_i + K \qquad Q = \min_{i \in N}\{q_i\} \tag{2}$$

with K a constant scale parameter; $b > 0$ a benefit parameter, $c > 0$ a cost parameter and $b > c$ for positive Nash equilibrium provision levels. A further simplification emerges if discrete provision levels are assumed. For instance, in Van Huick et al (1990) seven provision levels, $q_i = \{1,2,3,4,5,6,7\}$, are considered. In our context, this implies to summarize the different degrees of intensity and quality of virus control into a set of discrete actions. For $n = 8$ players, $b = 20$, $c = 10$ and $K = 60$, the payoff matrix is given in Table 1. In their terminology, choosing a contribution level means choosing a number.

Table 1 about here

In Table 1, the payoff which a player obtains for a given number depends on the smallest number chosen among all players, i.e., the minimum. For instance, if a player chooses the highest number 7, she will earn 130 if all players choose 7. However, if the lowest number chosen by others is 6, she will earn only 110. In our context, even if country *i* goes for the maximum possible level of virus control, if other countries do not follow the same strategy, there is a risk that COVID-19 will eventually affect country *i*, and this impact will be higher the smaller the number chosen by other countries.

All Nash equilibria lie on the diagonal, and all players choosing 7 is the Pareto-optimal Nash equilibrium. In a given row, all entries to the right of the diagonal entry imply a lower payoff to player i, as other players choose a lower number than player i. The larger the difference between the own number q_i and the minimum number of all others $Q_{-i,min}$, the larger will be the loss compared to $q_i = Q_{-i,min}$. Only for $q_i = 1$, $Q_{-i,min} < q_i$ this is not possible and hence player i is sure to receive a payoff of 70.

Caparrós et al (2020) run experiments in 8 or 9 cohorts for payoffs as given in Table 1, with 8 subjects in each cohort over 20 rounds. Their results are in line with Van Huick et al (1990), Feri et al (2010) and many others (see Devetag and Ortmann 2007 for an overview). In experiments, typically, not only the minimum number, which determines the benefits of subjects, but also the average number is analyzed, which can be viewed as proxy of the average degree of coordination. The experimental results obtained in Caparrós et al (2020) are as follows:

1) Average and minimum numbers decline with the number of rounds.

[7] See "'Europe Finally Got the Message': Leaders Act Together on Stimulus", New York Times, June 4, 2020.

2) Average numbers approach values below 2, and minimum numbers approach quickly values close to 1.

Thus, there is no doubt, coordination is not as easy and straightforward as theory, based on the assumption that players do not make mistake, predicts. Coordination on Pareto-superior outcomes does not emerge in the lab.

What about countries? Although European countries seem to have improved their coordination during the course of the crisis, at the peak of the pandemic, coordination was far from ideal, even prohibiting the export of medical equipment across EU countries. Regarding the near future, Trump has announced that the US, the largest contributor, will leave the WHO, imperiling future global efforts to provide vaccines for all. Focusing on the experience with previous diseases, coordination on smallpox eradication was relatively successful because it had many attributes that facilitated coordination (as discussed in Barrett 2003). In addition, at least from the point of view of the developed world, smallpox implies a small degree of disruption of the economy. However, COVID-19 has affected the economy and the social structure of almost all countries around the globe to an (until recently) unimaginable degree. To some extent, translating the success of coordination on smallpox to successful coordination (plus cooperation) on COVID-19 may be as difficult as translating the cooperation formula that was successful for the ozone layer (the Montreal Protocol) to a much more complex problem like climate change.

2.2.3 Non-Cooperative Behavioral Theory with Mistakes

In order to explain the failure of coordination for symmetric payoffs in experiments, Caparrós et al (2020) suggest to consider a Quantal Response Equilibrium (QRE) which is a Nash equilibrium in mixed strategies based on a probabilistic choice function (McKelvey and Palfrey 1995). The idea is that decisions are stochastic, all actions have a positive probability and the probability of choosing non-optimal actions is inversely related to the possible loss. Hence, players assume that they and others may make mistakes, which may be very small, but with a non-zero probability; the probability of "costly errors" is lower than that of "cheap errors". For a logit specification, the sensitivity of players to errors is measured by an "error parameter" λ. Larger values of λ imply a larger sensitivity to errors and make non-optimal choices less likely. For $\lambda = 0$, choices are purely random and for $\lambda \to \infty$ choices are perfectly rational.

Let us call p_{xy} the probability that if player *i* selects *x* the minimum is *y*. For instance, in Table 1, the probability of receiving a payoff of 70 when choosing number 1 is one, $p_{11} = 1$. That is, this is a save choice. The probability p_{22} of receiving a payoff of 80 when choosing number 2 is the probability that none of the seven other players chooses 1. The probability of receiving a payoff of 60 because at least one other player chooses 1 is therefore $1 - p_{22}$. The expected payoff when choosing 2 is therefore $p_{22} \cdot 80 + (1 - p_{22}) \cdot 60$. When choosing higher numbers, it is clear that the probability that none of the other players chooses a lower number than player i exponentially decreases. (That is, p_{77} will be smaller than p_{22}.) Hence, already for very low values of λ, the equilibrium yields a probability larger than 0.99 of playing 1. In other words, it is rational in a less than perfect world that players do not coordinate on the Pareto-optimal Nash equilibrium. In fact, it is (perfectly) rational to play save, with the consequence of the worst Nash equilibrium emerging. This explains why coordination is not trivial.

Mistakes are part of human behavior, and when confronted with a new problem, such as COVID-19, individuals, organizations and countries are likely to make mistakes. The WHO has modified its advice on several occasions, as new evidence came in (Chu et al., 2020). The UK modified its initial strategy (which was based in the objective of herd immunity) and many consider now that the lax approach followed by Sweden was probably a mistake.[8] Hence, a theoretical framework that allows for mistake is probably very relevant for the analysis of the Corona-pandemic. This implies that both, experiments and theory, predict that coordination will fail, resulting in the worst possible outcome. Given this somber prediction, the next section discusses possible ways out.

3 Possible Solution: Treaties

3.1 Cooperative Theory without Mistakes

Let us now assume that players have the possibility to join a treaty. Consider the simple cartel formation game, which may be regarded as the workhorse model used to analyze international environmental agreements.[9] In the first stage, players decide whether to join a treaty or whether to remain an outsider. This leads to a coalition structure $C=\{S,k,...,l\}$ with coalition S and some singleton players if S is not the grand coalition. In the second stage, players choose their contribution levels. The coalition is assumed to act as one player and hence its autarky provision level q_S^A follows from the maximization of the aggregate payoff over all coalition members, which leads to the first order condition $\sum_{i\in S} B_i^{'}(q_S^A)=\sum_{i\in S} C_i^{'}(q_S^A)$. Non-members' autarky provision levels q_k^A are the same as without a treaty and follow from $B_k^{'}(q_k^A)=C_k^{'}(q_k^A)$ as explained above. As before, all provision levels with $q_S=q_k=q_l$ from zero up to the lowest autarky provision q_{min}^A, $q_{min}^A=min\{q_S^A,q_k^A,...,q_l^A\}$, are Nash equilibria, with the Pareto-optimal Nash equilibrium if coalition S forms given by $q_{min}^A=q^*(S)=q_S^*=q_k^*=q_l^*$.

Suppose all players, including coalition S are able to coordinate on this Pareto-optimal Nash equilibrium between coalition S and all single players. Accordingly, payoffs are given by $\Pi_1(q^*(S)),\Pi_2(q^*(S)),...,\Pi_n(q^*(S))$. Moving back to stage 1, coalition S is stable if

(3) internal stability: $\Pi_i(q^*(S))\geq \Pi_i(q^*(S\setminus\{i\})) \quad \forall\, i\in S$

(4) external stability: $\Pi_j(q^*(S))\geq \Pi_j(q^*(S\cup\{j\})) \quad \forall\, j\notin S$

hold simultaneously. That is, no treaty-member should have an incentive to leave coalition S (internal stability) and no non-member should have incentive to join coalition S (external stability).

Clearly, coalition S can only make a difference to no cooperation if S includes the player with the smallest autarky provision level, which we denoted by q_1^A above. (Recall player 1 can veto any provision level above q_1^A) We call this an effective coalition. The equilibrium provision level of such an effective coalition $q^*(S)$ will be either the coalition's autarky provision level q_S^A or the smallest provision level among the outsiders q_l^A, which, in any case, implies that the equilibrium provision level is above player 1's autarky provision level, i.e., $q_1^A<q^*(S)$. Hence, player 1's payoff in coalition S falls short of that under no cooperation when player 1

8 See "Sweden Stayed Open. A Deadly Month Shows the Risks", New York Times, May 15, 2020.

9 This literature is surveyed in Finus and Caparrós (2015), and the most influential papers are collected in this volume.

determines the equilibrium, $q^* = q_1^A$. Since a coalition which is not profitable to all players is not internally stable, no effective coalition is stable in the absence of transfers.

With compensation payments among coalition members of the form

(5) $T_i = \alpha_i \sum_{k \in S \setminus \{i\}} \sigma_k(S) - (1-\alpha_i)\sigma_i(S)$ with $\sigma_i(S) = \Pi_i(q^*(S)) - \Pi_i(q^*(S \setminus \{i\}))$

each player in S receives after transfer payments payoff $\Pi_i^T(q^*(S)) = \Pi_i(q^*(S \setminus \{i\})) + \alpha_i \sigma(s)$, with $\sigma(s) = \sum_{i \in S} \sigma_i(S)$ called the total surplus of coalition S and $\alpha_i > 0$ a share where shares add up to one, i.e., $\sum_{i \in S} \alpha_i = 1$. Hence, each member receives after transfer payments his/her free-rider payoff $\Pi_i(q^*(S \setminus \{i\}))$ plus a share α_i of the total surplus $\sigma(s)$. The total surplus is the total payoff obtained by coalition S minus the sum of free-rider payoffs of its members. Hence, if the total surplus $\sigma(s)$ is positive, we can conclude that coalition S is internally stable if the transfer scheme in (5) is employed.[10]

The particular form of the transfer scheme in (5) implies that a coalition member i receives a share α_i of the surplus generated by other coalition members and the second term captures the idea that member i has to pay a share $(1-\alpha_i)$ of the surplus that the coalition generates to player i.

Given the transfer scheme in (5), one can ask five questions (Caparrós and Finus, 2020).

1) *Does an effective stable coalition exist?* The answer is yes, even though it is not possible to exactly predict which particular coalition is stable at such a general level.
2) *How does the distribution of autarky provision levels within coalition S affect stability?* Distributions which are positively skewed favor stability. That is, distributions with autarky provision levels with many players having an autarky provision close to the average over all players in S and one or two players with an autarky level well above this average are conducive to stability. Players with an autarky provision level well above the average pay net transfers to all players for staying on board.
3) *Can the grand coalition, i.e., the coalition including all players be stable?* The answer is affirmative. One can show that one outlier at the top is sufficient that the grand coalition is stable.
4) *How does stability and the gains from cooperation relate?* As a tendency, those distributions which favor stability imply low gains from cooperation and vice versa. This has some resemblance with the paradox of cooperation, which has been first established by Barrett (1994), and has been reiterated later several times in the context of public goods with a summation technology. Nevertheless, self-enforcing treaties under the weakest-link technology can make a difference to no cooperation.
5) *Will the qualitative conclusion also hold if players fail to perfectly coordinate on the Pareto-optimal Nash equilibrium in such a treaty game?* Again, the answer in Caparrós and Finus (2019) is affirmative, treaties can make a difference, though less than perfect coordination will entail a welfare loss.

[10] Similar notions of this transfer scheme have been developed by Eyckmans et al, (2012), Fuentes-Albero and Rubio (2010) and Weikard (2009).

In our less than perfect world, with large differences between countries, coordination is unlikely to be the sole answer and cooperation will be needed. Although a numerical analysis of whether or not the world is in a situation that favors the success of a treaty on cooperation in the Corona-weakest-link game is beyond the scope of this paper, we will informally discuss the likelihood of its success. What is needed for a successful self-enforcing treaty is basically a positively skewed distribution of autarky provision levels. This means a small group of strong countries, which are clearly stronger than the rest, and a large group of relatively weak countries (in this context, 'strong' means to be interested in a high level of provision in autarky, i.e., without external support). Within the EU, this might not be the case. Hard hit countries include relatively poorer countries (in the European context) such as Spain and Italy, but also relatively well-off countries such as France, Belgium and the UK. Furthermore, even relatively poor countries in Europe have excellent medical systems and would aim at a high level of provision even in autarky. Hence, cooperation on this topic might prove to be more complicated than one would hope.[11] However, at a global level, the perspective for effective and self-enforcing cooperative efforts might be more positive. Differences in the medical systems between developed and developing countries are stark, and this would probably imply large differences in protective measures (and vaccination efforts) between developed and developing countries in autarky. Furthermore, the number of developed (strong) countries is considerable smaller than the number of developing countries (weak) countries. This is especially true concerning measures to conduct mass vaccination. The number of countries able to provide the technology and the means to vaccinate at a massive scale is most likely small. Self-enforcing cooperation can be successful in this context, including transfers, as strong players have an interest in halting outbreaks in weak countries as they will ultimately reach their shores due to migration and tourism. This is true for COVID-19 but also for future pandemics. Hence, the world should work on establishing strong international institutions that facilitate cooperation on pandemic control.[12] This is both necessary and likely to succeed, given the prevailing incentive structure.

3.2 Experimental Evidence and Behavioral Cooperative Theory with Mistakes

In Caparrós et al (2020) the possibility of joining a treaty is called team formation. Eight cohorts (with 8 subjects in each cohort) with treatments based on Table 1 are considered in the experiment. In order to analyze the difference in average and minimum numbers also within the same subject pool, each cohort played 10 rounds without and then 10 rounds with the possibility of forming a team. The setting is close to that in the cartel game, but with some modifications. In fact, the degree of consensus in stage 1 and 2 is much higher than in the standard cartel formation game, as all decision have to be taken by unanimity, which strengthens the ability of teams to reduce their risk. In stage 1, players can announce whether to join team S. This decision is disclosed to all players and those who have announced to join the team are asked to confirm their membership. If and only if all team members confirm their membership will the team form (otherwise it dissolves). In the second stage, provided a team has formed in the first stage, all members can propose a number of which the minimum number will automatically be selected. Single players choose their own number in this final stage.

Clearly, in this setting, if the grand coalition forms, subjects face no risk by announcing the Pareto-optimal number 7. The risk of receiving a low payoff because an outsider chose a lower

[11] This would be different if the impacts on the economy turn out to be very unequal across Europe, impacting relatively poorer countries much more. Hence, asymmetry could be an asset for the prospects of cooperation.

[12] Initial steps are the call by the WHO for 'Access to COVID-19 Tools (ACT-Accelerator)' see https://www.who.int/publications/m/item/access-to-covid-19-tools-(act)-accelerator, and the 'Coronavirus Global Response' promoted by the EU, see https://ec.europa.eu/commission/presscorner/detail/en/ip_20_797.

number than the coalition increases with the number of outsiders. The most important experimental results can be summarized as follows.

1) Subjects use the opportunity to form teams; they always initiate teams and confirm them in most cases (in 90% of the cases).
2) Minimum numbers are higher with team formation than without team formation and downward trends over rounds may even be reversed. However, Pareto-optimal provision levels are not obtained.

Again, one can try to rationalize these results by applying the Quantal Response Equilibrium, though in an extended version[13] to capture the first and second stage of treaty formation. Whereas without team formation, even for low values of the rationality parameter λ, it was an equilibrium strategy to choose number 1, with team formation the opposite is true. For sufficiently high values of λ, it is an equilibrium strategy to join a team, in particular the grand team and to choose minimum number 7. That is, rationality is a curse without team formation, but it is a blessing with the option to form teams. Obviously, in the experiment, subjects are not perfectly rational, which explains that the probability of joining the team is below one and minimum numbers are typically between 4 and 7, and the average minimum number is certainly below 7. Hence, team formation improves coordination but does not solve it entirely.

Tu sum up, experiments and behavioral theory, allowing for mistakes, resulted in a gloomy perspective in section 2. Fortunately, once treaties (or other forms of institutionalized cooperation) are introduced, both methods conclude that cooperative institutions might have a positive role.

4 Research Gaps and Concluding Remarks

In terms of research gaps, it is evident from sections 3 and 4 that one should extend experiments with and without team formation to asymmetric players, including the possibility of transfer payments within a team. This would add some realism.

Another item which is missing in theory and experiments is the possibility of in-kind transfers. In a theoretical setting with asymmetric players but without the possibility of signing treaties it has been shown that in-kind transfers can raise the equilibrium provision level (Vicary and Sandler, 2002). What is missing is to include in-kind transfer in the analysis of treaties. This is important because during the Corona crisis countries received not only financial support, but also masks and technical equipment like ventilators and patients were flown out to be treated in hospitals in other countries.

The results discussed above have shown that coordination tends to collapse in the lab in the weakest-link game and that theory supports this result, when possible mistakes are taken into account. This implies a somber perspective for coordination on the Corona pandemic. Furthermore, introducing asymmetries in the game, which are clearly relevant to provide any meaningful advice for the Corona pandemic, cooperation is needed in addition to coordination. Fortunately, we have shown that theory (with or without mistakes) and experiments all highlight that cooperation institutions, such as treaties, have a role to play to foster cooperation. In a perfect world, self-enforcing institutions (treaties) could bring us to the best possible outcome. In our less than perfect world, self-enforcing institutions (treaties) can improve the situation and bring us closer to first-best. Hence the world should pursue efforts to create cooperative institutions around the Corona-pandemic, to increase cooperation and to facilitate coordination on better outcomes. As discussed above, this is both necessary and likely to succeed, given the

[13] Known as Agent Quantal Response Equilibrium (McKelvey and Palfrey, 1998).

prevailing incentive structure. Furthermore, this is true for COVID-19 but also for future pandemics. Abandoning the WHO is probably not a step in the right direction, which does not exclude the possibilities for reforms.

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Table 1: Payoffs in Van Huick et al (1990)

Number you choose	Smallest number chosen by any participant in your group (including yourself) → **7**	**6**	**5**	**4**	**3**	**2**	**1**
7	130	110	90	70	50	30	10
6		120	100	80	60	40	20
5			110	90	70	50	30
4				100	80	60	40
3					90	70	50
2						80	60
1							70

Source: Van Huick et al (1990), Payoff Table A, p. 232, all entries multiplied by 100.

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