Online appendix for
Carbon is Forever: A climate change experiment on cooperation

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A Proofs

We first briefly discuss the social optimum. At any round t, let E be any initial value of emission and $V(E)$ the associated value function, i.e. the solution of the dynamic programming problem (Hamilton Jacobi Bellman equation):

$$V(E) = \max_{e_r, e_p} \left\{ \frac{N}{2}\gamma \left[ln(a_r e_r) + ln(a_p e_p)\right] - c \times \left(E + \frac{N}{2}e_r + \frac{N}{2}e_p\right) + \delta V\left(E + \frac{N}{2}e_r + \frac{N}{2}e_p\right)\right\},$$

where for a simpler notation E is the stock of pollution inherited from the past. Let $e_p(E), e_r(E)$ be solutions to the previous maximization. Plugging these into the previous equation we obtain a functional equation in $V(E)$. We guess that $V(E)$ takes the following form:

$$V(E) = \frac{N}{2}\left(w_p + w_r\right) - \frac{N}{2}(k_p + k_r)E.$$

We now have to verify if these four parameters w_i and k_r exist that satisfy the HJB equation and to identify them. From the HJB equation, applying our guess for the value function we obtain

$$\begin{aligned}\frac{N}{2}\left(w_p + w_r\right) - \frac{N}{2}(k_p + k_r)E \quad &= \quad \max_{e_r, e_p} \left\{ \frac{N}{2}\gamma \left[ln(a_r e_r) + ln(a_p e_p)\right] - c \times \left(E + \frac{N}{2}e_r + \frac{N}{2}e_p\right) + \right.\\ &\left. +\delta\left[\frac{N}{2}\left(w_p + w_r\right) - \frac{N}{2}(k_p + k_r)\sigma\left(E + \frac{N}{2}e_r + \frac{N}{2}e_p\right)\right]\right\}\end{aligned}$$

The necessary conditions on e_r, e_p are

$$\frac{\gamma}{e_i} = c + \delta\sigma(k_p + k_r)\frac{N}{2}$$

or

$$\bar{e}_i = \frac{\gamma}{c + \sigma\delta(k_p + k_r)\frac{N}{2}}$$

which is independent of E. Plugging into the HJB Equation, we have

$$\begin{aligned}\frac{N}{2}\left(w_p+w_r\right)-\frac{N}{2}(k_p+k_r)E &= \frac{N}{2}\gamma\left[ln(a_r\bar{e}_r)+ln(a_p\bar{e}_p)\right]-c\times\left(E+\frac{N}{2}\bar{e}_r+\frac{N}{2}\bar{e}_p\right)+\\ &\quad +\delta\left[\frac{N}{2}\left(w_p+w_r\right)-\frac{N}{2}(k_p+k_r)\sigma\left(E+\frac{N}{2}\bar{e}_r+\frac{N}{2}\bar{e}_p\right)\right]\end{aligned}$$

Solving for w_p+w_r

$$\begin{aligned}(w_p+w_r) &= \frac{1}{1-\delta}\left\{(k_p+k_r)E+\gamma\left[ln(a_r\bar{e}_r)+ln(a_p\bar{e}_p)\right]-c\times\left(E\frac{2}{N}+\bar{e}_r+\bar{e}_p\right)+\right.\\ &\quad \left.+\delta\left[-(k_p+k_r)\sigma\left(E+\frac{N}{2}\bar{e}_r+\frac{N}{2}\bar{e}_p\right)\right]\right\}\end{aligned}$$

and in order for w_p+w_r to be independent of E it must be

$$(k_p+k_r)-c\frac{2}{N}-\delta(k_p+k_r)\sigma=0$$

that is

$$k_p+k_r=\frac{2c}{N(1-\delta\sigma)}$$

which shows $\bar{e}_i=e^*$. Substituting, the optimality condition corresponds to equating the marginal benefit from the individual emission to the marginal present-valued *group*'s damage,

$$N\times\frac{c}{N}\left[1+\delta\frac{\sigma}{(1-\delta\sigma)}\right]=\frac{c}{1-\delta\sigma}\ .$$

Finally, we also notice that

$$V(E)=\frac{1}{1-\delta}\left[\frac{N}{2}\gamma\left[ln(a_re^*)+ln(a_pe^*)\right]-\frac{c}{1-\sigma\delta}Ne^*\right]-\frac{c}{1-\sigma\delta}E.$$

Proof of Proposition 1 (Constant-actions Markov perfect equilibrium). We show that if all decision-makers $j\neq i$ play the constant action e^F then the best response for decision-maker i is $e_i=e^F$ which leads to a value function of the type

$$V_i(E)=w-kE.$$

With this guess on the value function we can write

$$w-kE=\max_{e_i}\left\{\gamma ln(a_ie_i)-\frac{c}{N}\times\left(E+e_i+(N-1)e^F\right)+\delta\left[w-k\sigma(E+e_i+(N-1)e^F)\right]\right\}$$

where for a simpler notation E is the stock of pollution inherited from the past. The maximizer must satisfy

$$\frac{\gamma}{e_i} = \frac{c}{N} + \delta\sigma k \Longleftrightarrow e_i = \frac{N\gamma}{c + N\delta\sigma k}$$

Subsisting, the previous HJB equation does not depend on E iff,

$$-k = -\frac{c}{N} - \delta\sigma k.$$

or, equivalently

$$k = \frac{c}{N\left(1-\delta\sigma\right)}.$$

It then follows that the best response is indeed

$$e_i = \frac{N\gamma}{c + N\delta\sigma k} = \frac{N\gamma}{c + \delta\sigma\frac{c}{(1-\delta\sigma)}} = \frac{N\gamma\left(1-\delta\sigma\right)}{c} = e^F.$$

It is also useful to notice that with this result we can write

$$w = \frac{1}{1-\delta}\left[\gamma ln(a_i e^F) - c\frac{1}{1-\delta\sigma}e^F\right]$$

so that

$$V_i(E) = \frac{1}{1-\delta}\left[\gamma ln(a_i e^F) - c\frac{1}{1-\delta\sigma}e^F\right] - \frac{c}{N\left(1-\delta\sigma\right)}E.$$

For future reference the value functions can be written as

$$V_i^F(E_0) = U_i^F - \frac{c\sigma}{N(1-\delta\sigma)}E_0,$$

where

$$U_i^F = \frac{1}{1-\delta}\left[\gamma ln(a_i\ e^F) - \frac{c}{1-\delta\sigma}e^F\right].$$

QED

Proof of Proposition 2 (Constant Trigger Equilibrium). For any E, the incentive compatibility constraint for any decision-maker i with a (candidate) constant equilibrium with actions $\hat{e}_i$ is

$$\begin{aligned}
&\gamma ln(a_i\ \hat{e}_i) - \frac{c}{N}\times\left(E + \frac{N}{2}\hat{e}_r + \frac{N}{2}\hat{e}_p\right) + \delta\left\{\hat{U}_i - \frac{c}{N(1-\delta\sigma)}\sigma\left(E + \frac{N}{2}\hat{e}_r + \frac{N}{2}\hat{e}_p\right)\right\}\\
\geq\ &\gamma ln(a_i\ \tilde{e}_i) - \frac{c}{N}\times\left(E + \tilde{e}_i + \frac{N-1}{2}\hat{e}_{i'} + \frac{N}{2}\hat{e}_j\right) + \delta\left\{U_i^F - \frac{c}{N(1-\delta\sigma)}\sigma\left(E + \tilde{e}_i + \frac{N-1}{2}\hat{e}_{i'} + \frac{N}{2}\hat{e}_j\right)\right\}
\end{aligned}$$

Clearly, an optimal deviation requires $\tilde{e}_i = e^F$ and the constraint becomes

$$\begin{aligned} &\gamma ln(a_i\ \hat{e}_i) - \frac{c}{N} \times \hat{e}_i + \delta \left\{ \hat{U}_i - \frac{c}{N(1-\delta\sigma)} \sigma \hat{e}_i \right\} \\ \geq\ &\gamma ln(a_i\ e^F) - \frac{c}{N} \times e^F + \delta \left\{ U_i^F - \frac{c}{N(1-\delta\sigma)} \sigma e^F \right\} \end{aligned}$$

Using the definition of

$$\hat{U}_i = \frac{1}{1-\delta} \left[\gamma ln(a_i\ \hat{e}_i) - \frac{c}{N(1-\delta\sigma)} \left(\frac{N}{2}\hat{e}_r + \frac{N}{2}\hat{e}_p \right) \right]$$

and of

$$U_i^F = \frac{1}{1-\delta} \left[\gamma ln(a_i\ e^F) - \frac{c}{1-\delta\sigma} e^F \right]$$

(the w in the proof of Proposition 1) the constraint can be finally rewritten as (using $\hat{e}_i = \hat{e}_r = \hat{e}_p$)

$$\begin{aligned} &\gamma ln(a_i\ \hat{e}_i) - \frac{c}{N} \times \hat{e}_i + \delta \left\{ \frac{1}{1-\delta} \left[\gamma ln(a_i\ \hat{e}_i) - \frac{c}{1-\delta\sigma} \hat{e}_i \right] - \frac{c}{N(1-\delta\sigma)} \sigma \hat{e}_i \right\} \\ \geq\ &\gamma ln(a_i\ e^F) - \frac{c}{N} \times e^F + \delta \left\{ \frac{1}{1-\delta} \left[\gamma ln(a_i\ e^F) - \frac{c}{1-\delta\sigma} e^F \right] - \frac{c}{N(1-\delta\sigma)} \sigma e^F \right\} \end{aligned}$$

which becomes

$$c\left(e^F - \hat{e}_i\right) \left[\frac{1}{N} + \delta \frac{N + \sigma(1-\delta)}{(1-\delta)N(1-\delta\sigma)} \right] \geq \frac{1}{1-\delta} \gamma \left[ln(a_i\ e^F) - ln(a_i\ \hat{e}_i) \right].$$

Substituting $\hat{e}_i = \frac{\gamma(1-\delta\sigma)}{c}$ and $e^F = N\frac{\gamma(1-\delta\sigma)}{c}$ this becomes,

$$c\left(N\frac{\gamma(1-\delta\sigma)}{c} - \frac{\gamma(1-\delta\sigma)}{c} \right) \frac{(1-\delta)(1-\delta\sigma) + \delta\left[N + \sigma(1-\delta)\right]}{N(1-\delta\sigma)} \geq \gamma \left[ln\left(N\frac{\gamma(1-\delta\sigma)}{c} \right) - ln\left(\frac{\gamma(1-\delta\sigma)}{c} \right) \right]$$

from which finally

$$\delta \geq \frac{1}{N-1} \left[ln(N)\frac{N}{N-1} - 1 \right].$$

QED

Referring to the case $N = 4$ as in our experiments, the constraint becomes

$$\delta \geq \frac{1}{3} \left[ln(4)\frac{4}{3} - 1 \right] = \frac{1}{9} \left[8ln(2) - 3 \right] \simeq 0.28.$$

Proof of Proposition 3 (Non-constant Markov equilibria). The proof is based on the arguments of the proof of Theorem 8 of Dutta and Radner (2009) and only sketched here.

We show that: (a) when the stock is above the "target" stock level $E(t, \tilde{e})$ so that all other decision-makers are expected to set an emission equal to e^F, then it is optimal for any decision maker to do so, (b) when instead the stock is at (or below) the level $E(t, \tilde{e})$ then, given that all other players are setting the optimal level of emission $\tilde{e}$ then the best response is indeed $\tilde{e}$. Consider the case for $\tilde{e} = e^*$, but the reasoning clearly applies for other $\tilde{e}$.

Case (a). Notice that if e^F is sufficiently large, then even if the decision-maker sets $e = 0$ then the stock remains above E^* and all other players will continue to set emissions e^F. In this case, e^F is a best-response. The condition that guarantees e^F is sufficiently large is,

$$E(t, \tilde{e}) + \epsilon + (N-1)e^F \geq E(t, \tilde{e}) + Ne^F$$

for any ϵ. Considering the more demanding case to violate the constraint (i.e. $\epsilon = 0$), the condition is implied by $N \geq \frac{e^F}{e^F - e^*}$ (which is satisfied in our experimental set-up where $N = 4$, $e^F = 12$ and $e^* = 3$).

Case (b). Consider the situation in which the current stock is actually at E^* (the case $E(t) < E^*$ requires a more elaborate discussion with explicit specification of the players' strategies for $E(t) < E^*$, but is based on similar arguments), and all players are expected to set emissions at e^*. Using the one-deviation principle, the decision-maker has then the choice either to set e^* which would perpetuate the socially optimal equilibrium and associated payoff, or deviate with a higher e (other deviations are dominated). In the latter case, it is simple to see that the optimal deviation is exactly e^F in which case he would obtain an immediate gain but the stock would then evolve to the C-MPE stock E^F. As usual and as in our previous proofs, this type of deviation is dominated if δ is sufficiently large (the condition being precisely that of Proposition 2 in this case).

When decision-makers coordinate on $\tilde{e} > e^*$ and a target stock $E(t, \tilde{e}) > E(t, e^*)$, case (a) clearly requires a different condition for e^F sufficiently large, but the steps of the reasoning are unchanged. Finally, as for case (b), let the current stock be at $E(t, \tilde{e})$ (as before, for $E(t) < E(t, \tilde{e})$). Since all other decision-makers are emitting $\tilde{e}$, any emission $e_i > \tilde{e}$ induces a future payoff associated with a stock $E(t, e^F)$ that is dominated by that with $E(t, \tilde{e})$ if δ is sufficiently high.

QED

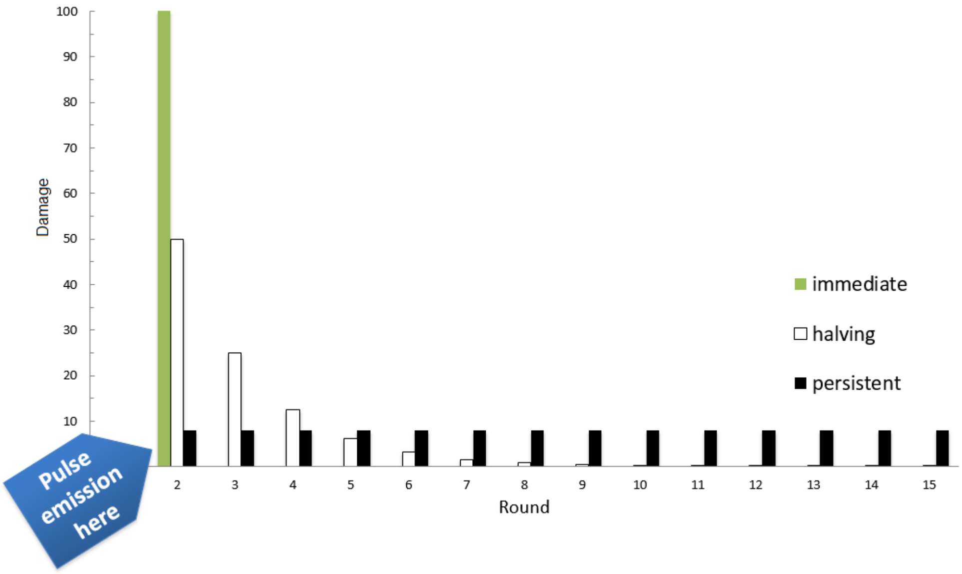
References

Dutta, P. K. and R. Radner (2009). A strategic analysis of global warming: Theory and some numbers. *Journal of Economic Behavior & Organization 71*(2), 187–209.

B Additional information about experimental procedures

Figure B.1 shows the damage profiles across the treatments of our experiment.

Figure B.1: Illustration of damage profiles across treatments.



Note: Damage suffered in each round because of an occasional emission in round 2 (=pulse) and zero emission in all other rounds. The emission as well as the present value of the generated damage are identical in all treatments, but the distribution of the damage over time differs.

Below we report additional details on the measures we adopted to ensure that participants had a good understating of the climate game.

- Out of 25 participants that took part in a session, only the 20 with the highest score in an understanding quiz on the instructions participated in the climate game. There was no monetary compensation for correct answers in quiz. Whenever a participant selected a wrong answer, the software pointed out the correct one. Participants had 50 seconds per question, and missing answers counted as mistakes.

- In every round participants could use a simulator to forecast the future impact of emissions. Up to four simulations per round were allowed. In Immediate and Persistent, participants used on average 5% of the total simulations available. In Halving, they simulated slightly more (9%). Some participants never used the simulator (17 in Immediate, 18 in Halving, and 14 in Persistent).

- Before the incentivized sequences, all participants took part in a practice sequence of 15 rounds interacting with robots. Robots were programmed to choose different levels of emission in every round. Robots' decisions were the same for all participants and for all sessions in every treatment. The practice sequence had no consequences on earnings.

- At the end of every round participants were asked to write down on paper each group member's emission choice. We used these record sheets simply to help participants to keep track of the history of the game. While past emissions are irrelevant for decisions according to the C-MPE, they can be relevant for the C-TE (Proposition 2).

- Participants were explicitly told that the socially optimal emission was equal to 3. Similarly, climate negotiators are aware of the optimal long-term emissions targets.

C Additional figures and tables

Table C.1: Tests on treatment differences in all rounds emissions.

	Average emission	p-value	Observations
Jonckheere-Terpstra test			
Immediate > Halving > Persistent	8.2, 7.4, 7.3	0.134	15, 15, 15
Wilcoxon-Mann-Whitney tests			
Immediate vs. Persistent	8.2, 7.3	0.494	15, 15
Immediate vs. Halving	8.2, 7.4	0.455	15, 15
Halving vs. Persistent	7.4, 7.3	0.430	15, 15

Note: All rounds of sequence 1 only. The unit of observation is a group. The null hypothesis in JT and WMW tests is that the samples come from the same population. In JT, the alternative hypothesis is that the medians are ordered by persistence as shown in the table.

Table C.2: Tests on treatment differences in rich and poor emissions.

	Avg. rich emission	Avg. poor emission	p-value	Observations
A. Round 1				
Immediate	7	6.9	0.838	30, 30
Halving	5.8	6.7	0.079	30, 30
Persistent	4.8	6.6	0.052	30, 30
B. All rounds				
Immediate	7.7	8.7	0.296	15
Halving	6.9	7.8	0.107	15
Persistent	7.1	7.5	0.389	15

Note: Sequence 1 only. The unit of observation is a participant emission in panel A.; the unit of observation is the average emission of the rich and poor types in a group in panel B. In panel A. are Wilcoxon-Mann-Whitney exact tests; in panel B. are Wilcoxon signed-rank tests.

Table C.3: Tobit regressions of individual emission with player type specific trend.

Dependent variable:	Immediate	Halving		Persistent	
Individual emission in a round	(1)	(2)	(3)	(4)	(5)
Rich type	-0.032	-1.068*	-1.123**	-1.026	-1.285
	(0.901)	(0.628)	(0.471)	(0.995)	(0.961)
Round number within	-0.029	0.192**	-0.070*	0.648***	-0.381*
a sequence	(0.023)	(0.075)	(0.042)	(0.025)	(0.203)
Trend within a	0.083***	0.091***	0.015	0.050	0.057
sequence for rich type (Round × Rich type)	(0.029)	(0.028)	(0.017)	(0.125)	(0.132)
Stock of pollution			0.106***		0.024***
at the beginning of a round			(0.012)		(0.005)
Sequence number	0.183	1.151***	0.979**	0.501*	0.311***
	(0.333)	(0.364)	(0.411)	(0.266)	(0.101)
Length of past	-0.015	-0.148***	-0.005	-0.004	-0.002
sequence	(0.101)	(0.039)	(0.043)	(0.081)	(0.029)
Mistakes in the quiz	0.243***	0.606***	0.486***	0.449	0.200
	(0.080)	(0.175)	(0.064)	(0.344)	(0.196)
Limited liability	4.665***	1.447***	-1.298***		
	(0.366)	(0.348)	(0.352)		
Constant	9.973***	6.796***	2.373***	4.440**	7.251***
	(1.470)	(0.504)	(0.639)	(1.778)	(1.157)
Observations	2380	2000	2000	2120	2120
Pseudo R^2	0.010	0.042	0.084	0.048	0.069

Note: See notes to Table III.

Table C.4: Tobit regressions of individual emission without choices under limited liability.

Dependent variable:	Immediate	Halving		Persistent	
Individual emission in a round	(1)	(2)	(3)	(4)	(5)
Rich type	1.142	-0.276	-0.926***	-0.676	-0.892
	(0.874)	(0.417)	(0.319)	(1.582)	(1.507)
Round number within a sequence	0.015	0.273***	-0.078**	0.673***	-0.352
	(0.042)	(0.093)	(0.036)	(0.067)	(0.272)
Stock of pollution at the beginning of a round			0.105***		0.024***
			(0.013)		(0.005)
Sequence number	0.196	1.115***	0.956***	0.501*	0.312***
	(0.342)	(0.247)	(0.320)	(0.266)	(0.102)
Length of past sequence	-0.015	-0.168***	-0.026	-0.004	-0.002
	(0.102)	(0.039)	(0.016)	(0.082)	(0.029)
Mistakes in the quiz	0.254**	0.733*	0.558**	0.450	0.202
	(0.107)	(0.440)	(0.251)	(0.346)	(0.200)
Constant	9.368***	6.037***	2.439***	4.264**	7.051***
	(1.629)	(0.872)	(0.927)	(2.107)	(1.564)
Observations	2145	1658	1658	2120	2120
Pseudo R^2	0.003	0.042	0.088	0.048	0.069

Note: See notes to Table III.

Table C.5: Tobit regressions of differences in emissions' trends at sub-sequence level.

Dependent variable: Individual emission in a round	(1) Rounds 1 to end	(2) Rounds 1 to 20	(3) Rounds 1 to 10	(4) Rounds 11 to 20	(5) Rounds 11 to end
Halving dummy	-2.127	-1.463	-2.188*	-6.221**	-3.836**
	(1.492)	(1.411)	(1.205)	(2.659)	(1.891)
Persistent dummy	-4.758***	-3.418***	-3.169***	-10.870***	-9.266***
	(1.252)	(1.296)	(0.863)	(3.170)	(2.618)
Round number within a sequence	0.013	0.224***	0.292***	-0.163	-0.073***
	(0.031)	(0.086)	(0.042)	(0.117)	(0.011)
Halving dummy × Round number within a sequence	0.246***	0.144	0.365**	0.434**	0.261***
	(0.067)	(0.090)	(0.175)	(0.188)	(0.073)
Persistent dummy × Round number within a sequence	0.649***	0.434***	0.407***	0.992***	0.882***
	(0.066)	(0.105)	(0.094)	(0.192)	(0.141)
Rich type	0.075	-0.345	-0.537	0.382	1.321
	(0.625)	(0.559)	(0.498)	(0.881)	(0.847)
Sequence number	0.528**	0.523**	0.512***	1.402*	1.442**
	(0.254)	(0.232)	(0.188)	(0.723)	(0.641)
Length of past sequence	-0.065	-0.073	-0.081**	0.079	0.107
	(0.042)	(0.048)	(0.037)	(0.145)	(0.099)
Limited liability	2.304***	1.817***	2.453***	1.769	2.816**
	(0.879)	(0.601)	(0.744)	(1.188)	(1.184)
Mistakes in the quiz	0.477***	0.451***	0.470***	0.473***	0.470***
	(0.104)	(0.124)	(0.141)	(0.171)	(0.129)
Constant	9.194***	8.201***	7.987***	10.220***	8.081***
	(1.192)	(1.286)	(0.909)	(3.222)	(2.342)
Wald test p -value: Having vs. Persistent dummy	0.043	0.088	0.377	0.135	0.085
Wald test p -value: Having vs. Persistent trend	0.000	0.000	0.833	0.007	0.000
Observations	6500	5380	3980	1400	2520
Pseudo R^2	0.032	0.031	0.021	0.016	0.022

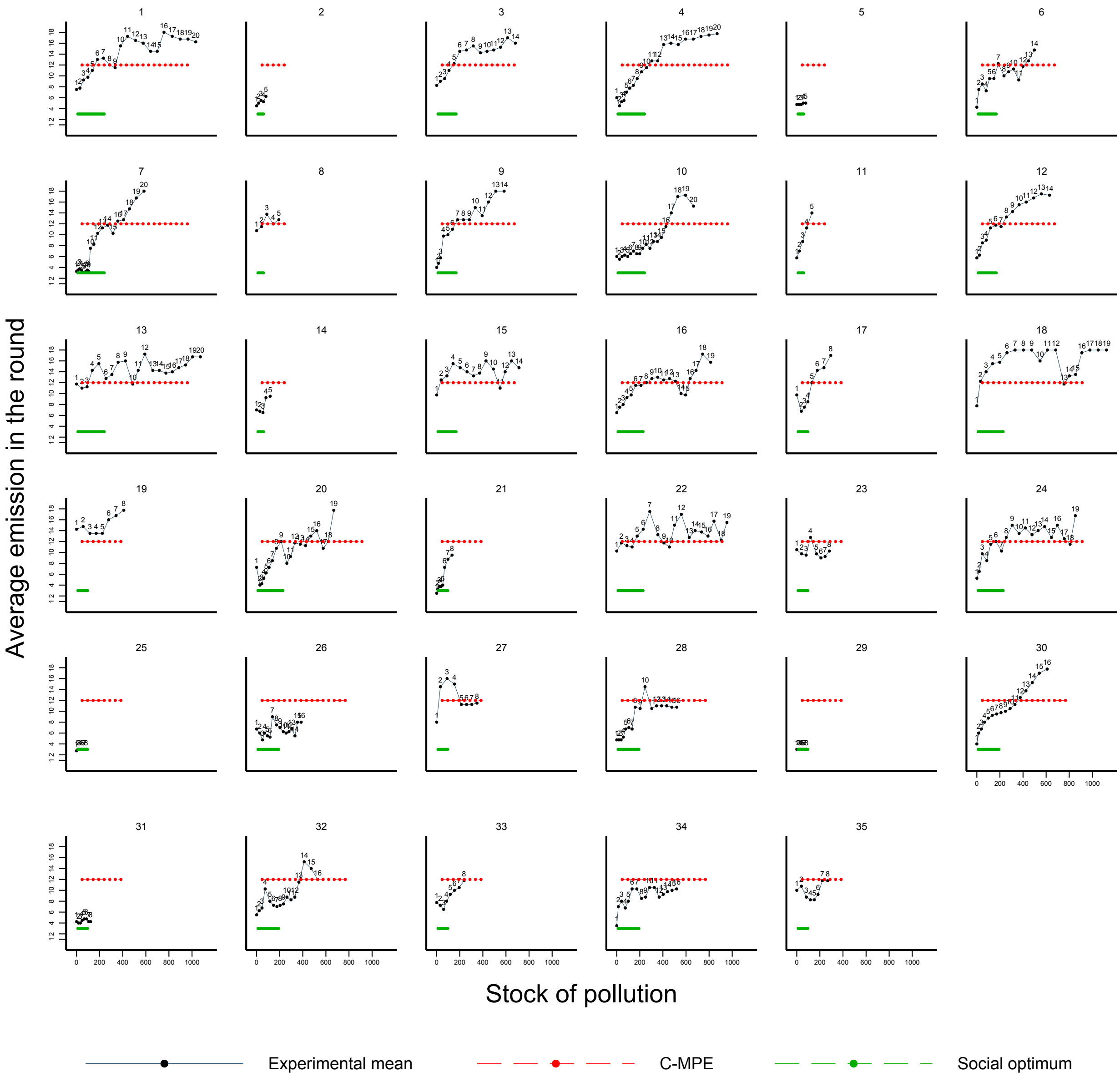
Note: Tobit regressions with observations censored at 1 and 18. The unit of observation is a participant in a round. Every regression includes data from all three treatments. All sequences are included. On top of each column are the rounds considered in the estimation, where "end" denotes the final round of a sequence. Standard errors are clustered at the session level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table C.6: Treatment differences in the adoption of trigger strategies.

	Dep. var.: Trigger strategy = 1
x‘x‘x	(1)
Treatment dummies	
Halving	-0.099
	(0.070)
Persistent	0.055
	(0.052)
Rich type	0.017
	(0.029)
Sequence number	-0.006
	(0.031)
Length of current sequence	0.011**
	(0.004)
Length of past sequence	-0.005
	(0.005)
Wald test p-value: Having vs. Persistent	0.007
Observations	700

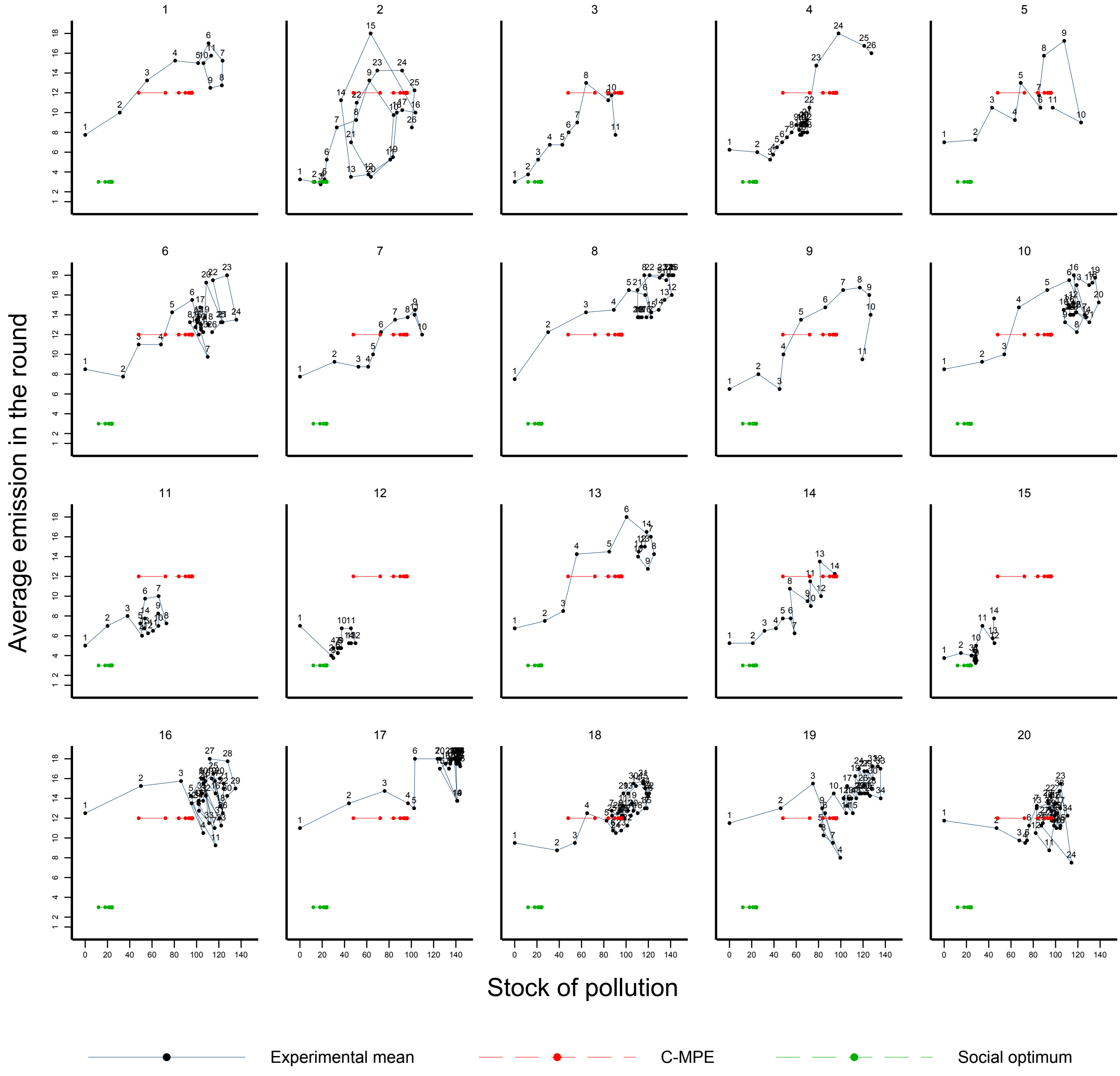
Note: Marginal effects from a Probit regression are reported. The unit of observation is a participant in a sequence. Only sequences that lasted three or more rounds are included. Standard errors are clustered at the session level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Figure C.1: Current emission over current emissions' stock across groups in Persistent.



Note: One observation is a group in a sequence. Only groups which interacted for at least 5 rounds are reported.

Figure C.2: Current emission over current emissions' stock across groups in Halving.



Note: One observation is a group in a sequence. Only groups which interacted for at least 5 rounds are reported.

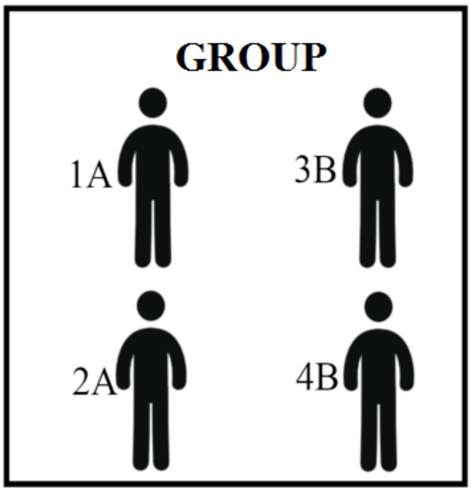
D Experimental instructions (Persistent treatment)

Welcome!

You are going to participate in a study on economic decision-making funded by the Italian Ministry of Instruction and Scientific Research.
Your earnings depend on yours and others' decisions. Payment will be made in private at the end of this study.
We ask you to follow these instructions carefully. It is not allowed to talk with other participants. Please turn off you phone. If you have questions, raise your hand at any time and an assistant will answer in private.

SEQUENCES AND GROUPS

This study consists of four independent parts - if there will be enough time - which we call "sequences". The instructions are the same for all sequences. Every sequence includes multiple rounds of interaction.



- Before every sequence, participants are matched in **groups** of 4 members, two of type **A** and two of type **B**.
- Every type has different earnings. The type is randomly assigned at the beginning of the study and remains fixed throughout the study.
- Your group is fixed for the length of a sequence.
- Your group changes in the subsequent sequences. You will never be matched with the same person in more than one sequence.

EARNINGS

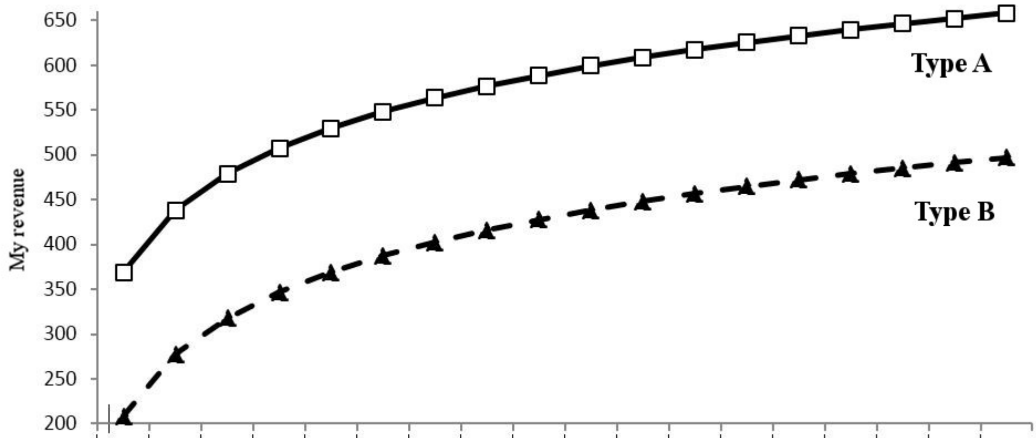
In every round, every participant chooses how much to **produce** from 1 through 18.
Your production has two effects:

1. It generates a **revenue** for you.
2. It creates a **damage** both for you and for the other members of your group.

Your earnings are determined by your revenue minus your damage and will be expressed in tokens. For every 6 tokens you will earn 1 cent (€0.01). In addition you will receive €4 for your participation. Your production in the round generates a revenue limited to the current round. However, it creates a damage both in the current round and in the subsequent rounds.
Let us look at these effects in detail.

REVENUE

The more you produce, the more your revenue increases.
For every level of your production, you can see the generated revenue below:



My production	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
My revenue if I am type A	369	438	479	508	530	548	564	577	589	599	609	618	626	633	640	646	652	658
My revenue if I am type B	208	277	318	347	369	387	403	416	428	438	448	457	465	472	479	485	491	497

As you can see from the table, for the same production, a type B participant has always a lower revenue than a type A. For example:

- A type A who produces 5 has a revenue of 530 tokens
- A type B who produces 5 has a revenue of 369 tokens

The revenue depends only on your production in the current round.
If you want to know it, the mathematical formula is the following:

Type A: My revenue = $100\times logarithm(40\times$My current production)

Type B: My revenue = $100\times logarithm(8\ \times$My current production)

Are there questions about the revenue?

DAMAGE

The more you produce, the more the damage increases.
The production affects both the revenue and the damage, but in different ways

- On the one hand, the revenue is only yours, while the created damage is **equally split among all group's members**.
- On the other hand, the revenue is immediately obtained in the round, while the damage hits immediately **but persists also in all the subsequent rounds**.

Let us see the first feature of the damage. Every unit you produce in a round generates a damage that reduces your earnings of 0.67 tokens. Moreover, it reduces in the same way also the earnings of every member of the group and hence it generates a damage in the round to the group equal to 2.68 tokens (=0.67×4).

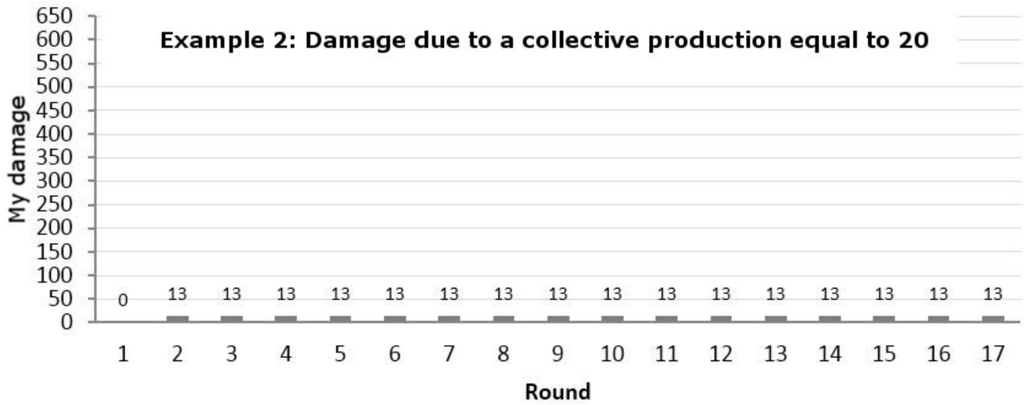
Thus, to compute your damage from production, it is not enough that you only look at what you produce. Instead, you have also to consider the sum of the productions of all the members of your group in the round, namely the current "collective production":

$$\text{My damage from the current production} = 0.67 \times \text{Current collective production}$$

<u>Example 1:</u> We are in round 2 and everyone produces 3. The collective production of the group is hence equal to 12 and creates a damage to you of 8 tokens in the current round (=0.67×12). Moreover, it creates a damage of 8 tokens in the current round to every member of the group. How much is your damage if instead you produce 1 and everyone else produces 5? The collective production will be 16 and it will create a damage to you of 11 tokens in the current round (=0.67×16).

It does not matter whether you are type A or type B: the damage is equally split among all.
Let us now look at the second feature of the damage: the persistence. Every unit you produce causes a damage in the current round, in the next one and all the subsequent rounds until the end of the sequence. Earnings will reduce of 0.67 tokens for you and the other members of your group **in every round**.

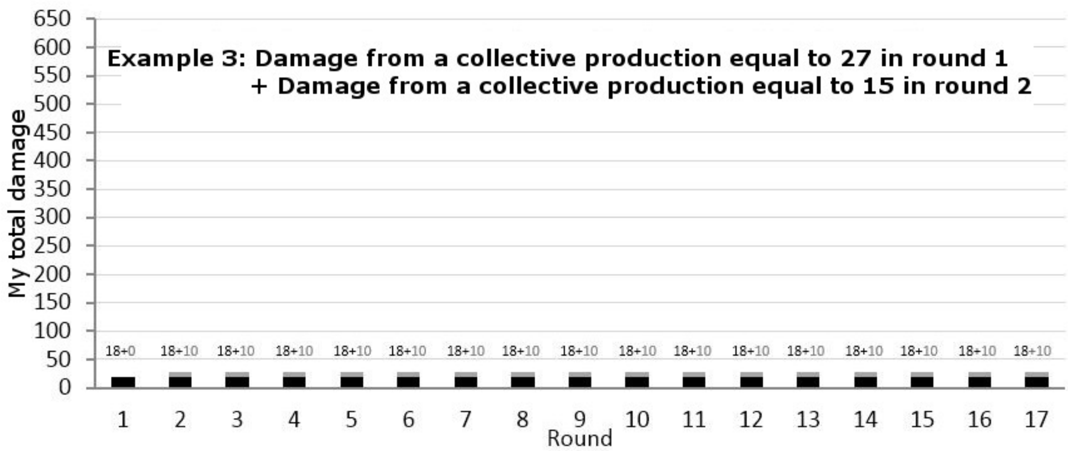
Example 2: We are in round 2 and the current collective production is equal to 20. Look the graph below: your damage is 13 tokens in round 2 (=0.67×20), 13 tokens in round 3, and so on in every subsequent round.



An important consequence of the persistence is that your total damage in a round depends both on the current production and the **past production**.
My total damage in the round=
= My damage inherited from past production + My damage from current production
=(0.67×Sum of all past collective productions)+(0.67×Collective current production)

Example 3: In round 1, the collective production was equal to 27. We are in round 2 and the collective production is 15. How much is your total damage in round 2? We must sum the damage inherited from round 1 to the damage from the collective production in round 2. The total damage is 28 tokens, 18 ow which inherited (=0.67×27) and 10 created by the current production (=0.67×15). We can see this from the computation and the graph below.

$$\begin{aligned}\text{My total damage in round 2} &= \text{Inherited damage} + \text{Damage from production in round 2}\\ &= (0.67\times27) + (0.67\times15) = 18+10=28\end{aligned}$$



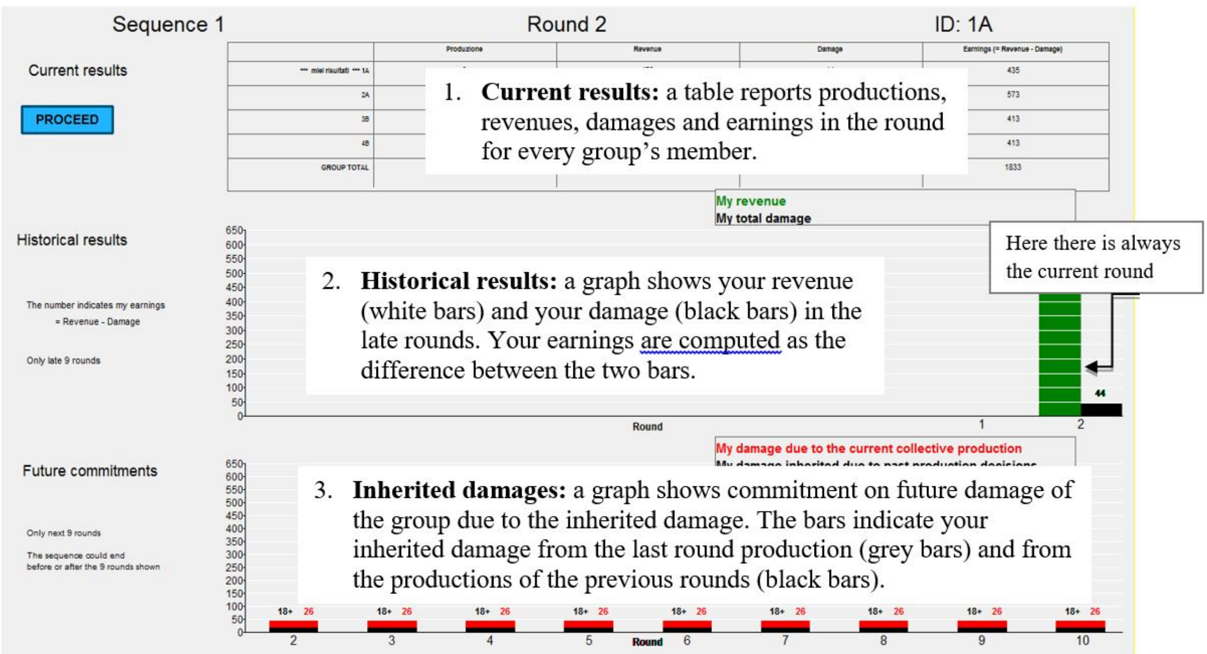
Because of the damage, your earnings in the round could be negative. In this case, the loss in the round will be subtracted from the tokens accumulated in the previous rounds.
Every sequence is independent from the previous one: you will start every sequence without any commitment on future damage due to the heritage of the past.
Are there questions about the calculation of the damage?

HOW MUCH TO PRODUCE

Let us see how one can think about how much to produce. **Should I increase the production of one unit?** To answer, you can compare the additional revenue from a one unit increase in production with the additional damage.
Focus for a moment **only on your earnings**. For example, if you produce 5 units instead of 4, your revenue increases of **22** tokens, as you can see from the revenues table. Moreover, producing an additional unit increases your damage of 0.67 tokens. However, it is not enough that you consider this damage in the current round only: you must weight the damages that you create to yourself in all the subsequent rounds. For example, if you expect that there are 13 rounds, producing an additional unit in the current round increases your damage of **8.71** tokens (=0.67×13).
Consider now the **effects on all the members of your group**. For example, if you produce 5 units instead of 4, your revenue increases of **22** tokens but no one else in the group benefits from it. Instead the damage that you create is of 0.67 tokens for you and every member of the group, namely it is multiplied by four (2.68 = 0.67×4). For example, when we consider damages over 13 current and future rounds, the damage to the group increases of **34.84** tokens (=2.68×13). Following this reasoning, we can compute that – **if everyone chooses the same level of production** throughout the sequence – the earnings of the group are maximized when each one produces **3 units** in every round.

RESULTS

At the end of each round, results will be displayed with a screen as the one below:



DURATION OF A SEQUENCE

The duration of a sequence varies and is ex-ante unknown. The duration is determined as follows. At the end of every round, the computer randomly draws a number from an urn which contains the integer numbers from 1 to 100. Every number has the same probability of being drawn.

- If the number is less or equal to 92, the sequence continues with a new round.
- If the number is greater or equal to 93, the sequence ends.

So: after every round, there is 92% chances that there is another round in the sequence, and 8% chances that the sequence ends. Following this procedure of random draws:

- It is never possible to know in advance which will be the last round of the sequence.
- One can calculate that a sequence will have an **average duration of 13 rounds**. However, you can expect that some sequences will last much longer than 13 rounds and other much less.

QUIZ AND PRACTICE ROUNDS

We now ask you to answer 11 questions to verify your understanding of the instructions. **Those who do not answer satisfactorily will have a different task from that described above.**
After the quiz, you will participate in a practice sequence. **Unlike the subsequent sequences**, in the practice sequence: (a) you will not be paid for your decisions; (b) the sequence will last exactly 15 rounds; (c) the other members of your group will be robots who are programmed to choose a different production level in every round.
Are there questions before proceeding?

Before starting the four sequences, let us look at two final things.

RECORD SHEET

At the end of each round, we ask you to write down on paper the results in the round. In particular,

- **Sequence** and **Round**, that you will see on top of the screen,
- **Your production** and the **production of everyone else** that you see in the final screen of the round in table (see screen at page 5). You can fill the production of everyone after having marked down the ID of the participant to which the column refers.

SIMULATION TOOL

You can use a simulator to understand how the result changes as production choices vary. You can make trials with the simulator without any consequence on your earnings. You can insert in the simulator an hypothetical production for you and an hypothetical production for the other group members. Hypothetical productions do not influence the outcome of the round.
By clicking the button "Simulate" the hypothetical results of these choices will appear with numbers and graphs. Look at the picture below.

- You can see the "Hypothetical results in this round" in the table: revenues, damages, and earnings of everyone
- You can see the "Hypothetical results in future rounds" on the graph
  - Your earnings (white bars)
  - Your damage created by the simulated collective production (gray bars)
  - Your damage inherited from past decisions (black bars)

An important note on how to read the "Hypothetical results in the future rounds". In the example screen above, your simulated production is 3 units and the simulated production of the others is 4 units. The hypothetical results illustrate the **consequences when these levels of production is maintained constant also for all the subsequent rounds**. As you can see:

- Your revenue is constant in all rounds (white bar)
- Your damage created by the simulated production (gray bar) **increases over the future rounds** because the damage is persistent and so, with a constant production, the damage cumulates.

Example 4: Let us consider again Example 3 where the collective production in round 1 was of 27 units. Now we are in round 2 and we use the simulator to compute the consequences of a collective production of 15 units:

- Your revenue is equal to 479 tokens **in every round** (as you see in the revenues table when you produce 3 units)
- The inherited damage is equal to 18 tokens **in every round**, as we have already seen in Example 3 (=0.67×27)
- Your total damage in **round 2** amounts to 28 tokens, see in "Hypothetical results in the current round": 18 are inherited and 10 are created by the production in round 2 (=0,67×15). So in round 2 you earn 479–28 = 451 tokens
- Your total damage in **round 3** amounts to 38 tokens, which corresponds to 18 inherited (black bar), plus 10 created by the production in round 2, plus 10 created by the production in round 3 (gray bar). So in round 3 you earn 479–38 = 441 tokens.
- Your total damage in **round 4** amounts to 48 tokens, which corresponds to 18 inherited (black bar), plus 10 created by the production in rounds 2, 3, and 4 (gray bar). So in round 4 you earn 479–48 = 431 tokens. And so on.

Let us perform one last practice round (round 16), in which you have 3 minutes to try the simulator.

E Quiz (Persistent treatment)

1. How many independent sequences are there in this study? 1–10

2. You are at round 1 of a certain sequence. How many rounds do you expect there will be in the sequence on average? 1–20

3. You are at round 13 of a certain sequence. With which probability do you expect that there will be an additional round in the sequence? 0–100

4. TRUE OR FALSE? In every new sequence it is possible to meet again a participant that was in my group in a previous sequence.

5. How much is the revenue of a type B who produces 4?

6. TRUE OR FALSE? For the same production level, type B participants always obtain a lower revenue than type A participants.

7. COMPLETE THE SENTENCE: The collective production is computed…

   (A) …by summing the production of the other group's members in all rounds of the sequence.

   (B) …by summing the production of all four group's members (me included) in all rounds in the sequence.

   (C) …by summing the production of all four group's members (me included) in a round.

8. COMPLETE THE SENTENCE: If I increase my production of one unit…

   (A) …I create a damage to the group of 0.67 in the current round and in all the subsequent rounds, which is equally split among the group's members.

   (B) …I create a damage to the group of 2.68 in the current round and in all the subsequent rounds, which is equally split among the group's members.

   (C) …I damage to myself of 0.67 in the current round and in all the subsequent rounds.

9. COMPLETE THE SENTENCE: The more the other group's members produce…

   (A) …the less damages I suffer.

   (B) …the more damages me and the other group's members suffer.

   (C) …the more damages the other group's members suffer.

10. TRUE OR FALSE? The damage generated by the production reduces the earnings of types A and B of different amounts.

11. COMPLETE THE SENTENCE: The damage I suffer in every round depends…

    (A) …both on the collective production in the previous rounds and on the collective production in the current round.

    (B) …only on the collective production in the previous rounds.

    (C) …only on the collective production in the current round.