Rel(a)ying on your team-mates is not enough: On sequential contributions to team production under competition

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Abstract

Many tasks require the input by more than one person very often with members of the team contributing sequentially. However, team production is plagued by disincentive problems. In this paper we investigate individual incentives to team production with sequential contributions and competing teams. We show that earlier contributors free-ride on team members contributing later on, with later contributors also providing suboptimal effort. We test our predictions on sports data using an athlete's performance in the individual race as a natural control for his relay performance. Our empirical findings strongly support the theoretical claims.

Keywords: team production, contest, intergroup competition, sequential contribution, free-riding
JEL-Classification: C70, D20, D70, H40

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1 Introduction

It is widely acknowledged that team production is plagued by disincentive problems because individuals free-ride on the contributions of other team members (Alchian and Demsetz, 1972; Holmstrom, 1982). Yet, little seems to be known on the structure of such disincentives when there is between-team competition and individuals' contributions build on previous work done by the other team members. In this paper we provide both a theoretical and an empirical investigation of the issue.

Sequential contributions to a team are indeed quite common in real-world production processes. For instance, in the era of globalization work is done around the clock, with computer programmers, planners and other workers producing output that can easily be sent electronically around the globe; at the end of the day they hand over their work to colleagues located in a country where the sun is about to rise. The problems involved are the same that occur when drafting a document: a bad draft requires more effort by the people working on it at later stages in order to achieve a certain level of quality. Another example is the training of students at universities. Colleagues who do a proper job teaching first year courses prepare students well for courses to be taught by other faculty in the second year. One may also think of mail delivery. In many countries, parcels or registered letters have to be delivered personally by the postman. It is a common perception that postmen sometimes do not even bother to ring the bell and just leave a notice on the door saying that the mail can be retrieved at some mail delivery center. Thus, they save on their time while increasing the workload at the center. Finally, in production processes organized along assembly lines a poor job by some worker at an early stage can increase the workload of subsequent workers in order to achieve the target quality. In all these examples it may be difficult or very expensive to track the responsibility for a poor final outcome down to the contributions of all the team members involved.

It is most natural to identify a team with an individual firm. In this interpretation, competition comes directly from market forces. However, having multiple teams performing the same task in a competitive environment might also be a strategy of internal organization within the firm, specifically targeted at reducing free-riding of employees. Whatever the interpretation, it is interesting to know *a priori* whether and to what extent there are incentives to free ride in a competitive environment, and whether such incentives change along the production process.

To this aim we develop a model where members of competing teams contribute sequentially to win a commonly shared price. The main findings are that free-riding remains pervasive, with earlier contributors exploiting team members contributing later on, and later contributors also providing suboptimal effort.

For testing our predictions we turn to swimming data. This has several advantages. Typically, it is difficult to measure the performance of workers and their individual contribution to a team in standard work situations. Moreover, from a researcher's perspective it is usually infeasible to construct a convincing counterfactual that would allow to draw causal inference from the observations in an environment of an operating firm. In order to overcome these problems economists have increasingly turned to sports data recognizing that these markets provide a number of natural experiments which allow for the testing of the effects of incentives on labour market behavior (Ehrenberg and Bognanno, 1990; Kahn, 2000; Szymanski, 2003). Our comprehensive data-set covers swimming competitions from all over the world during the years 1972 to 2009 with a total of more than 300,000 observations. It seems to be particularly suited for our purposes as it allows us to construct a counterfactual for each individual's performance by comparing times swam in individual races with the same swimmer's performance in a relay at the same event typically taking place within a time period smaller than 2 days. This solves a major identification problem, that arises because the team members starting order in a relay depends on individual ability, with better swimmers generally placed first or last. Moreover, the richness of the data allows us to exclude a series of other potentially confounding factors. The evidence supports the prediction that even competitive environments are characterized by substantial free-riding, with a marked first-mover advantage.

We proceed in the following way. After reporting on the related literature in the next section, in section 3 we set-up the theoretical model. In section 4 we present our empirical testing strategy, also providing some background on the rules and main characteristics of swimming competitions and describing the data we use, while in section 5 we present and discuss our empirical results. Section 6 offers our conclusions.

2 Related literature

Our paper builds a bridge between two separate strands of the literature. The first one looks at contributions to public goods.Varian (1994) argued that with sequential choice the free-riding problem is exacerbated with respect to the simultaneous contributions mechanism, and that there exists a first mover advantage with early contributors contributing less. While this contribution is akin to ours in the sense that agents make sequential choices, there is no competition between teams with a prize to be won.

Experimental evidence by Andreoni et al. (2002) specifically tailored to test the predictions of Varian (1994) confirms the first mover behavior but also shows that the difference between simultaneous and sequential play vanishes to the end of the experiment. More recent experiments by Gaechter et al. (2009) support the prediction that the overall contribution is lower in sequential contributions but do not find evidence for the predicted first mover advantage. In another, earlier experimental study Erev and Rapoport (1990) compared sequential and simultaneous contributions to public goods and showed, contrary to Varian, that simultaneous choice is significantly less effective in solving the dilemma. However, we are not aware of an empirical assessment of free-riding with sequential contributions in natural work environments. Moreover, none of the studies reviewed above considers the effect of competition between groups on within-group performance.

This is the focus of the second strand we are relating to. Models of between-group competitions have been developed in the vast literature on contests, which goes back to the seminal contribution of Tullock (1980).[1] Tullock assumed simultaneous contributions and employed a contest success function (CSF) where the probability of winning the competition is equal to the ratio of own effort to global effort, the sum of efforts of all contenders.[2]

Again, empirical analyses of between-group competition have mainly involved

[1] See for instance Katz et al. (1990), Ursprung (1990), and Gradstein (1993). Two recent surveys are Corchòn (2007) and Konrad (2009).

[2] Tullock's idea was to compare rent seeking activity –group contribution in our setting– to the purchase of lottery tickets: the higher the number of tickets, the more likely to win the lottery. Skaperdas (1996) provided an axiomatic foundation for the Tullock CSF, while more recently Jia (2008) offered a distribution based justification for its ratio form.

laborary experiments. For instance, Bornstein et al. (1990) compared the performance of groups in a social dilemma situation under two conditions: one in which groups were not facing competition and another in which groups were competing for an additional reward. They found that between-group competition significantly increased the contributions of the simultaneously acting team members, a finding that was replicated by Erev et al. (1993) in a different work environment where subjects picked oranges, as well as by Gunnthorsdottir and Rapoport (2006). However, all these experiments involved simultaneous contributions. In summary, surprisingly, little seems to be known on whether competition between teams eliminates free-riding as team members contribute sequentially.

Our contribution aims at filling this gap. In our theoretical model we follow the approach developed by Tullock, and extend it to the case when team members contribute sequentially. We are then able to test our implications in a setting where one would *a priori* expect very little free-riding. The fact that swimmers in the first legs of a relay slow down with respect to their potential performance strongly suggests that they free-ride on swimmers in subsequent legs. That this happens to be true even in the Olympic finals speaks of the ubiquity of free-riding.

We are not the first to look at swimming competitions as a testbed. Existing studies mostly involve experimental work stemming from the area of social psychology with one of the earliest contributions by Sorrentino and Sheppard (1978), followed by Williams et al. (1989), Everett et al. (1992) or Miles and Greenberg (1993). Contrary to these contributions, we draw inference from swimmers who performed in a natural setting.

3 A model of inter-group competition with sequential intra-group choices

We model competition between groups along the lines of a Tullock-contest (Tullock, 1980). Tullock employed a contest success function (CSF) where the probability of winning the competition is equal to the ratio of own effort to global effort, the sum of efforts of all contenders.

There are two teams A and B competing for a prize S. Each team has two players, denoted with 1 and 2. Inputs of players are substitutes.[3]All players are of homogeneous ability. The prize S has equal value to each of the team members.

Team members exert effort e at cost $c(e)$. We employ a quadratic cost function $c(e) = e^2$. As in Gunnthorsdottir and Rapoport (2006) the contributions of team members to the overall team output enter additively. In order to reflect the sequential nature of the game, however, first members of teams A and B choose their effort level first. Second players make their choice on the basis of first players' outcome. Thus, members 1 are Stackelberg leaders *vis-á-vis* members 2 in their teams. We denote with e_{A1} effort spent by the team member moving first in team A, and e_{A2} as effort spent by the team member who moves second in team A. Notation for team B is accordingly.

The fact that effort is not deterministically transformed into performance, and that there are stochastic elements in the competition is taken into consideration by CSFs. In our setting, however, uncertainty is partly resolved after the first players finish their task. Hence, second players face a different informational content.

[3]When individual contributions are perfect complements no free-riding can occur, by definition.

We model this by introducing an additional random term ε with support $[0, 1]$. Realization of this random variable takes place before second players choose their effort, and is thus considered as given for second players, as is first players' effort. This amounts to say that second players observe first players' performance.

The winning probability of team A is then

$$p_A = \begin{cases} \alpha \frac{e_{A1}+e_{A2}}{e_{A1}+e_{A2}+e_{B1}+e_{B2}} + (1-\alpha)\varepsilon & \text{if } e_{A1}+e_{A2}+e_{B1}+e_{B2} > 0 \\ \frac{1}{2} & \text{otherwise,} \end{cases} \tag{1}$$

with $0 < \alpha < 1$ being a relative weighting factor of the random component on individual performance. The probability of winning for the other team B is $p_B = 1 - p_A$.

Expected payoffs are

$$V_{it} = p_i S - e_{it}^2 \quad i = \{A, B\},\ t = \{1, 2\}. \tag{2}$$

The game is solved by backward induction. Second players take the effort level of first players as given, know the realization of ε, and choose their own effort simultaneously. First players make their choices taking into account the later realization of ε, and the reaction of the second players in teams A and B, respectively.

As players are homogeneous, everybody expects that simultaneous players will put the same effort. Imposing $e_{A1}^* = e_{B1}^*$ and $e_{A2}^* = e_{B2}^*$, as we will do in the following, greatly simplifies the derivation of the proofs.[4]

[4]The same results can be obtained without imposing symmetry. The proofs are available upon request.

For second players, effort choices follow from the first order conditions

$$H \equiv \frac{\mathrm{d}\,V_{A2}}{\mathrm{d}\,e_{A2}} = \alpha \frac{e_{B1} + e_{B2}}{D^2} S - 2e_{A2} = 0 \tag{3}$$

$$F \equiv \frac{\mathrm{d}\,V_{B2}}{\mathrm{d}\,e_{B2}} = \alpha \frac{e_{A1} + e_{A2}}{D^2} S - 2e_{B2} = 0 \tag{4}$$

with $D = e_{A1} + e_{A2} + e_{B1} + e_{B2}$. Expected marginal gains have to equal the marginal costs. Solving these first order conditions for the optimal choices e^*_{A2} and e^*_{B2}, ruling out negative effort, yields

$$e^*_{A2} = -\frac{e_{A1}}{2} + \sqrt{\frac{e^2_{A1}}{4} + \alpha \frac{S}{8}} \tag{5}$$

$$e^*_{B2} = -\frac{e_{B1}}{2} + \sqrt{\frac{e^2_{B1}}{4} + \alpha \frac{S}{8}}. \tag{6}$$

With second order conditions being fulfilled, e^*_{A2} and e^*_{B2} constitute the best choice of the team members moving second.[5] Efforts decrease when α decreases. The intuition is that if the gap arising from the competition of first players increases, the incentive to put extra effort diminishes. But due to the symmetry of leads and lags, this is true for all players and both the leader and the laggard slow down. Therefore, if first players put the same effort, second players also exercise the same effort.

Equations (5) and (6) are the reaction functions which the first players in the team are facing with respect to the effort choices of their teammates who follow. Both reaction functions are downward sloping. An increase of effort of the first player leads to a decrease in the teammate's effort. Thus, effort choices within

[5] Corner solutions with zero effort are ruled out as $H(0) > 0$ and $F(0) > 0$.

teams are substitutes, and it is this property which will essentially drive our result that second players exert more effort as we compare optimal choices within teams for first and second players.

First players of teams A and B also decide on their effort simultaneously taking into account that their choice will have an effect on the choices of the subsequent swimmers, and not knowing the realization of ε. The first order conditions for these players after taking expectations over ε are

$$\frac{\mathrm{d}\, V_{A1}}{\mathrm{d}\, e_{A1}} = \alpha \frac{(e_{B1} + e_{B2})(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} - \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}})}{D^2} S - 2e_{A1} = 0 \tag{7}$$

$$\frac{\mathrm{d}\, V_{B1}}{\mathrm{d}\, e_{B1}} = \alpha \frac{(e_{A1} + e_{A2})(1 + \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{B1}} - \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{B1}})}{D^2} S - 2e_{B1} = 0 \tag{8}$$

using $e^*_{A1} + e^*_{A2} = e^*_{B1} + e^*_{B2}$. Eqs. (7) and (8) determine the effort choices of first players. Again, expected marginal benefits have to equal the marginal costs which are a function of the effort of the first players. Compared to the first order conditions of the second players, the marginal benefits of the first players take account of the effect of the effort choice of the first player on the teammates choice coming after, and the second player's effort choice of the competing team.

Proposition 1 *In equilibrium, the optimal effort level provided by first players is lower than the effort level provided by second players.*

Proof See Appendix A.

This result stems from the substitutability of within team members efforts, $-1 < \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} < 0$, and $\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} = 0$ which implies that the choices of the first players do not have an impact on the other team's second player behavior. The team member moving first knows that an increase in his effort is leading to a decrease in the effort of the team member moving second. Thus higher effort on his side is not fully reflected in a larger chance of winning the competition but he would still have to burden the higher costs of effort.

So far we have highlighted that first players free-ride with respect to second players, *i.e.* they exert a lower effort. Now, we show that also the effort of second players is too low with respect to the one that would be optimal for the team as a whole.

Proposition 2 *In equilibrium, the effort level provided by second players is lower than the cooperative social optimum for the team.*

Proof See Appendix A.

Intuitively, the cooperative solution takes into consideration that the prize S is non-rival and that effort exerted by any individual player has a positive externality on the other team member. As marginal costs are increasing, it is advisable from a social point of view to share the burden equally among team members. Hence, $e^*_{A1} = e^*_{A2}$ (and $e^*_{B1} = e^*_{B2}$) for the cooperative solution.

We can also show that second players choose an effort level which is lower than what a player chooses for an individual production. Moreover, effort choice for individual production is equal to the effort choice in a cooperative social optimum.

Proposition 3 *In equilibrium, the optimal level of effort for an individual production is the same as the cooperative socially optimal level of effort for a team production.*

Proof See Appendix A.

This result stems directly from the assumption that the prize S gives the same individual utility in both cases.

4 Data and testing strategy

4.1 Empirical strategy

Now, we turn to swimming data to test the most important implications of our model. Relays come very close to the situation described by our model. In a relay, there is sequential contribution to a team with one swimmer performing after the other, and teams competing against each other. The task is simple, and the rules are clear to everybody.

Our theory predicts that earlier swimmers slack off more than later swimmers which should be reflected in a sequence of decreasing swimming times of relay swimmers. However, taking this result straightforwardly to the data is not feasible. First swimmers in a relay competition start upon hearing the starting signal while the following swimmers start after the previous swimmer touched the wall of the pool. This implies that there is a reaction time advantage for all relay swimmers coming after the first ones, who can see their preceding team-mate approaching and fine-tune their start. Would we observe faster second swimmers than first swimmers, we were not able to disentangle the reaction time effect from a potentially slacking off of second swimmers. However, as there is no reaction time issue involved for all swimmers following the first one, we may employ those swimmers to test free-riding on later contributors to the team. But again, one has to be cautious to straightforwardly go for such a test. If swimmers are not allocated randomly to slots, say faster swimmers are systematically swimming at later positions in the relay, we would not be able to infer from faster swimming times for later swimmers in a relay that there is free-riding. In order to overcome this problem, we use information on each relay swimmers' performance in the individual competition to control for his/her ability: our dependent variable is, therefore, the *relative difference in swimming time between the relay and the individual competition*. In other words, each swimmer acts as his/her own control.

Our first target for empirical testing is Proposition 1, which suggests that the relative difference in swimming times decreases. Given that subsequent swimmers enjoy a reaction time advantage compared to first swimmers, this test involves looking only at swimmers other than the first.

Note that Proposition 1 –hence, its empirical test– does not require the assumption of an equal valuation of the prize S. If we are willing to assume such an equal valuation, we can go even further and quantify the amount of free-riding. With equal valuation of the prize S , by Proposition 3 one can interpret the swimming time in the individual competition as a proxy for the socially optimal effort. Looking at how big the difference between the relay and the individual competition times is would then provide a measure of the amount of free-riding. However, we can directly compare the times swam in the individual and the relay races only for first swimmers, as subsequent swimmers, as already pointed out, enjoy an advantage in reaction time. Our measure of free-riding in teams will then be interpreted as an upper limit –Proposition 2, however, suggests that free-riding remains positive also for subsequent players.

To recapitulate, in order to get rid of composition issues we look at the relative difference between the relay and the individual competition. We interpret a *diminishing* difference as we move from the second to subsequent swimmers as evidence in favour of Proposition 1, which states that early swimmers enjoy a first-mover advantage. The swimming time in the individual competition is used only as a control here.

Moreover, we interpret a *positive* difference for first swimmers as an upper measure of free-riding in our context, conditional on an equal valuation of the prizes in the relay and in the individual competition. The swimming time in the individual competition is used as a proxy for the socially optimal effort here, along Proposition 3.

4.2 Data description

Our data-set was kindly provided by GeoLogix AG, a Suisse company which gets the data directly from the European Swimming Federation (LEN) and other participating federations. In total we have 311,784 observations of performances of individual swimmers at more than 7,000 events which took place worldwide between 1972 and 2009. Due to our identification of individual ability by comparing a swimmer's performance in a relay with his performance in an individual competition, the data comprises athletes who took part in the same event and for the same style, both in the individual competition and in the relay.

The events included in our sample are major events such as the Olympic Games, World Championships, European Championships, Pan Pacific Games, the Commonwealth Games or Universiades, and other events, like national championships (see table 1).

As for the *personal characteristics* of the swimmers, we have information on age, gender, nationality, and FINA points. Age is between 6 and 109 years with a median of 16. Gender composition of the sample is more or less equally split. The FINA Point Scoring assigns point values to swimming performances. Points are assigned at every competition, by comparing a swimmer's performance with a base time that is recalculated every year, taking the average of the top ten of the All Time World Rankings. More points go along with better performance. In the sample, FINA points are related to the individual competitions and vary between 5 and 1,181 with a median of 504. Michael Phelps had 1,063 in the year of the Olympic Games in Beijing.

Next we have information on the *event* (event name, location and beginning and ending day), the *competition* (style, distance, date of attendance and round – heats, preliminary, semifinals, or finals) with the day of the competition allowing to some extent to control for the sequence of the individual and the relay race, and finally *performances*, which include the time in the individual and the relay competition, the total relay time, as well as the starting order in the relay and the final placement both for the relay and the individual competition.

4.3 Swimming competitions

Swimming competitions entail four competitive styles –backstroke, breaststroke, butterfly and freestyle– at varying distances (e.g. 100 meters, 200 meters, etc.) typically in 25 or 50 meter pools.[6]

Relays are a group of swimmers who either all swim freestyle or each swim

[6]Rules for these swimming competitions, may they be national or international, are set by the Federation Internationale de Natation (FINA) (`www.fina.org`).

one different style in the order of backstroke, breaststroke, butterfly and freestyle (medley relay). Except for some specific (usually minor) events, relay teams, according to FINA rules, consist of four swimmers. Unless specified by the Promoter's conditions the nomination of team members and the relay swimming order must be made before the competition. Any relay team member may compete in a race only once.

Various rules guarantee accurate measurement of swimmers' performances. Time keeping is under the supervision of appointed officials and is either made by automatic equipment or manually. If manually registered there are three timekeepers and watches must be certified by the governing body. If two of three watches record the same time, the two identical times are the official time. If all three watches show different times the intermediate time is taken, and if only two of the three watches work the average time is calculated. In any case times are recorded to $1/100$ of a second.

As already pointed out, individual and relay times are immediately comparable for first swimmers only, as there is an advantage for all following swimmers in a relay in terms of reaction time. However, that first swimmers in a relay can be compared to their individual performance in a single race is reflected in the fact that if a first swimmer in a relay competition swims a record time it gets approved.

5 Empirical evidence

5.1 Descriptive evidence

We now report descriptive statistics on our dependent variable. Table 2 shows the relative difference in swimming time between the relay and the individual competition for different starting orders in the relay. First swimmers are, on average, slower in relays, with respect to their performance in the individual competition. In the whole sample (66,561 observations, with an average swimming time in the individual competition of 56.84 seconds), this difference amounts to .22%, that is 12/100 of a seconds in absolute terms.

Testing the relative difference for the first swimmers against the null of there being no difference in performance yields a highly significant p-value. This result is robust against splitting the sample along gender or age. It is furthermore valid for swimmers with higher or lower FINA points than the median swimmer. It also holds over all styles if we focus on the sign of the difference in swimming times and in 6 out of 7 subgroups for the various styles in terms of significance.

There are no indications that training or the use of illegal substances targeted to a specific competition (individual or relay) might disturb our results. In 87% of the observations individual and relay competitions are within 1 day of separation which implies that training efforts influence individual and relay competitions equally. With illegal substances targeting longer term goals such as the building up of red blood cells basically the same logic applies as with legal training methods.

One might also be concerned that fatigue decreases performance in later events. However, the distribution of days of separation between individual and relay competitions is quite symmetric. In any case, we also split the sample along the timing of competitions to check whether it makes a difference if the individual race took place before or after the relay at the particular swimming event for which we compare the swimming times. It is still true that relay performances are weaker than individual performances.

Finally our result is also valid if we look into major events only.

As we have already noted, direct comparison between the relay and the individual competition is possibly only for first swimmers, as subsequent swimmers enjoy an advantage in terms of reaction time, given that they can see the previous swimmer approaching the end of his/her leg. This explains why the time difference turns negative for the second to the fourth swimmers in the relay. More importantly, however, last swimmers in relays seem to slack off less (with respect to their own individual performance) than swimmers starting 2nd or 3rd. Again, this is what we would have expected from our theory.

Summarizing these findings, faster swimming times for later swimmers in the relays provide evidence in support of our Proposition 1. Furthermore, if one is willing to accept the hypothesis of equally valuable prizes in the individual and the relay competition, the evidence presented for first swimmers is consistent with the overall implications of Propositions 1 and 3 of our theoretical model. In order to further elaborate on these findings we turn to a multivariate analysis which allows us to increase the number of controls.

5.2 Regression analysis

The dependent variable that we use in the multivariate analysis is still the relative difference between relay and individual swimming times. We introduce indicator variables for the starting order in the relay competition. Other controls are gender, age[7], style, type of the competition (major vs. non-major) and schedule (whether the individual competition is on a day before the relay, on the same day, or on a day after).

We expect the coefficient of the indicator variable for the first swimmer in the relay to be positive. Furthermore, we expect the coefficients for the indicator variables for subsequent swimmers to be negative because of the advantage in the reaction time for every swimmer following the first one. As later swimmers should on average exert more effort we also expect that the indicator variables change in size with higher orders becoming more negative.

This is what we find (as shown in table 3, Model 1): the estimated parameters for first to fourth swimmers are .08, -.59, -.61 and -.87, respectively. All indicator variables are highly significant with p-values smaller than .001. The Wald tests reject equality of the coefficients of the order two, three and four indicators at a high level of significance. As for the other controls, we find that female swimmers and young and old age groups perform relatively worse in relays, while the gap in relative performance is reduced, as expected, in major events.

[7] We use three age groups rather than a continuous age variable, in order for the coefficients of the starting order indicators to show the effects for the reference group (swimmers aged 15-30), rather than for swimmers of a specific age; the consequential reduction in explanatory power –as measured by R^2– is very small.

5.3 Addressing confounding factors

We have already dealt with the most important composition issue that more able swimmers might be placed in a later slot –which could have been an alternative explanation for our finding that later swimmers slack off less: we control for individual ability by relating the relay performance of a swimmer to the performance of the same swimmer, in the same event and for the same style, in the individual competition. But there may still be other confounding factors which we address now.

One might be concerned that some swimmers are more motivated than others in swimming a relay. If this was the case and team managers put more motivated athletes as last swimmers in the relay, first swimmers would be less motivated. This could explain slower relative performance even after controlling for individual ability.

We cannot do anything for the case when motivation is event-specific: the team manager knows that a particular swimmer is very motivated in swimming the relay on that particular occasion, hence assigns him or her to the final leg. But if motivation is event-driven one would expect it to show up also in the individual competition –hence relative performance should not be affected. Finally, if motivation for doing particularly well in relays has to do with some pro-social attitude, it should be time-invariant.

In order to control for time-invariant motivation and other unobservable individual-specific characteristics we introduce individual fixed effects (Model 2). Thus, we compare the difference in performance of one specific athlete between relay and individual time when starting the relay at a different leg (at different events).

Given that the outcome variable is already a (relative) difference, our fixed-effect strategy is a diff-in-diff estimator. For example, a swimmer might have participated at the Olympic Games and the World Championships for 100 m freestyle and the 4×100 meters freestyle as third and forth swimmer, respectively. If our results did not hold, we should observe no increase in the relative performance with respect to the individual race when he swam forth, even if outcome is driven by unobservable characteristics. If, however, we still observe faster relative swimming times for later swimmers after canceling out unobservable individual characteristics, our results would be strengthened.

Running a fixed effects model yields a coefficient for the first swimmer indicator variable of .51.[8] The coefficients for the other indicator variables become -.21, -.27 and -.53, respectively. Hence, the fixed effect model confirms our previous findings (and our theoretical model). Note that the number of observations drops to 107,808 as all records pertaining to swimmers for which there is no variation in the independent variables have to be dropped.

That free-riding is still prevalent as we use each swimmer's time in the individual competition as a control for individual ability and as we additionally run a fixed effect model may also be interpreted as supporting evidence for our modeling choice in the first part of the paper. We assumed that all swimmers have the same ability when deriving our propositions. If heterogenous ability mattered, then we should find that free-riding vanishes as we run fixed effects models on top of controlling for individual ability with swimming times of individual competitions. As it did not, we feel quite confident with the (simplifying) mod-

[8]This value cannot be fully compared with the corresponding value of Model 1, as the age group variable is not included (in a fixed effect model, it would be estimated only on ages around the age group thresholds).

eling choices made. Although heterogeneous ability is certainly given among the swimmers of the teams, it seems that team managers cannot solve the free-riding problem by allocating swimmers to particular slots.

One could also object that free-riding depends on the competitive pressure, and that our results are driven by competitions that are either not so close, or of minor importance. Therefore, we estimate our fixed effect model on finals only, both for the relay and the individual competition (Model 3), on the assumption that finals are more competitive. The coefficient for the first swimmer indicator variable is still positive (.81), while the coefficients for the second, third and fourth swimmer indicator variables are decreasing and significantly different from each other: .06, -.03, -.43 respectively. Due to the additional restriction, the number of observations drops to 25,138. The results still go through if we further restrict to swimmers ending up in the first four positions both in the relay and in the individual competition (the coefficients for the indicator variables are, respectively, 1.25, .31, .17, -.27, with 8,728 observations). In order to reduce a further cause of unobserved heterogeneity, we estimated our fixed effect model on freestyle swimmers only. The results still go through (the coefficients for the indicator variables are, respectively, .61, -.22, -.28, -.54, with 85,625 observations). As a final robustness check, we look at 100m freestyle finals at Olympic events. The same pattern for the coefficients of the indicator variables shows up (.49 for the first swimmer, -.67 for the second swimmer, -1.46 for the fourth swimmer, with 48 observations[9]).

[9] The only third swimmer we have in this selected sample swam no other Olympic 100m freestyle final, so the observation was dropped in the fixed effect procedure.

5.4 Size of the effects

For establishing a benchmark against which to evaluate the size for free-riding, we calculate the average lag in swimming time between individuals belonging to teams that finished in nth place in relays and individuals belonging to teams that finished in $n - 1$th place, for $n > 1$. On average this lag is .23% for major events and 1.35% for non-major events among the first 10 positions in the final ranking. These numbers may now be compared to the size of free-riding as shown in tables 2 and 3. In table 2 we calculated for first swimmers at a major event a relative time difference between relay and individual competition of 0.03%, whereas the relative time difference for all other events amounts to 0.22%. In table 3 (Model 2) we get an effect that is even more relevant: first swimmers in our reference category (100m male freestyle, non-major events, swimmer aged 15-30) are on average .51 percentage points slower in relays than in individual competitions compared to an average lag to an immediately preceding team of .78 percentage points for this group.

Assessing the relevance of the finding that effort decreases as team members get involved in earlier stages of the production process, involves looking at the difference between the coefficients of second, third and fourth indicator variables in table 3. Comparing the estimated effect of the forth swimmers with the third swimmers yields a change in free-riding of -.53+.27=-.26 percentage points. This value must again be compared with an average lag over the preceding team of .78 percentage points, and accounts for one third of this lag. The detected effect between third and second swimmers is smaller (-.27+.21≈-.07), but still sizeable.[10]

[10] Results do not line up due to rounding.

By comparing the value of the fourth leg indicator with that of the second leg indicator we get a reduction in free-riding of approximately .32 percentage points, which should be regarded as a lower bound in the overall reduction of free-riding (since it is not possible to assess the reduction between first and second swimmers, due to the presence of a reaction time advantage for first swimmers).

6 Summary and conclusions

In this paper we developed a simple model of sequential contributions to a team when teams compete against each other. We find that team members contributing earlier to a team's common task contribute less than the team members contributing later. The mechanism underlying the free-riding in teams is substitutability of inputs between team members to a Tullock contest. At the margin a team member contributing earlier refrains to increase costly efforts as he can foresee that the following team members will reduce their input. In a cooperative solution it would be optimal to share the burden equally among team members, but this does not happen even under between-team competition.

Our theoretical claims find considerable empirical support. Drawing on a unique data set of more than 300,000 observation from swimming competitions from all over the world during the last four decades we find evidence for free-riding and the pattern of efforts over the course of sequential contributions to a team as suggested by our model.

The basic idea employed for empirical testing was to compare for a given event the swimming performance of the same individual athletes for individual and relay competitions. By definition no free-riding occurs in an individual competition which is why swimmers should exert full effort at these occasions. Taking their performance in the individual race as a control we find that on average first swimmers swim slower in relays. Moreover, controlling for reaction times and confounding factors including individual effects we find that free-riding diminishes as we move from the second, to the third and finally the fourth swimmer in the relays. These estimated time differences occur to be of meaningful size.

Our attribution of the lower performances in relay with respect to individual competitions to free-riding depends on the assumption that the prize S is equally valuable in relays and individual competitions. This assumption might be questioned: even with equal monetary prize, obtaining it in an individual competition might be more valuable as the honors do not have to be shared.[11] If this was the case, it could be socially optimal to individually provide less effort in relays, and our empirical analysis of Propositions 2 and 3 would not allow us to detect any inefficiency. There are three responses to this concern. First, and most importantly, our result that there is free-riding *within* teams, and that this free-riding is stronger for early contributors (Proposition 1), remains unaffected from a potentially different valuation of prizes won in relays and individual competitions. Secondly, one could argue that for a vast majority of athletes what matters in winning a gold medal in their career is that they are gold medalist. The difference in utility from winning it in the individual competition rather than in the relay are, if any, of minor importance. Finally, for some athletes winning a medal in the relay might be the only possibility to become a medalist at all. For them, we would expect to particularly show effort in the relays. That we, nevertheless, find free-riding speaks for the strength and ubiquity of our findings.

[11]The other side of 'two in distress make sorrow less'.

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Appendix A

Proposition 1

Proof The proof is in two parts. In part (I) we show that the f.o.c. define the optimal effort level for players 1 as the s.o.c. are also satisfied. In part (II) we show that the optimal effort level for players 1 is lower than the optimal effort level for players 2.

Part I:

Expected payoffs for the first player of team A (analogously for team B) are:

$$V_{A1} = p_A S - e_{A1}^2 \tag{9}$$

with the f.o.c. as shown in the main text being

$$\frac{\mathrm{d}\, V_{A1}}{\mathrm{d}\, e_{A1}} = \alpha \frac{(e_{B1} + e_{B2})(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} - \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}})}{D^2} S - 2e_{A1} = 0. \tag{10}$$

The solution to this equation is the optimal choice of effort for player 1, given that the s.o.c. is satisfied. To see that this is indeed the case, consider

$$\begin{aligned}\frac{\mathrm{d}^2\, V_{A1}}{\mathrm{d}\, e_{A1}^2} = {} & \alpha \frac{D^2(\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}}(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}}) + (e_{B1} + e_{B2})\frac{\mathrm{d}^2\, e_{A2}}{\mathrm{d}\, e_{A1}^2})}{D^4} S \\ & - \alpha \frac{D^2((1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}})\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} + (e_{A1} + e_{A2})\frac{\mathrm{d}^2\, e_{B2}}{\mathrm{d}\, e_{A1}^2})}{D^4} S \\ & - \alpha \frac{((e_{B1} + e_{B2})(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}}) + (e_{A1} + e_{A2})\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}})2D(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} + \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}})}{D^4} S - 2\end{aligned} \tag{11}$$

We can find expressions for $\frac{\mathrm{d}^2\, e_{A2}}{\mathrm{d}\, e_{A1}^2}$, $\frac{\mathrm{d}^2\, e_{B2}}{\mathrm{d}\, e_{A1}^2}$ and $\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}}$ by taking the total derivatives around the optimal solution for second players given by the f.o.c.:

$$\frac{\partial H}{\partial e_{A2}}\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} + \frac{\partial H}{\partial e_{B2}}\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} + \frac{\partial H}{\partial e_{A1}} = 0 \tag{12}$$

$$\frac{\partial F}{\partial e_{A2}}\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} + \frac{\partial F}{\partial e_{B2}}\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} + \frac{\partial F}{\partial e_{A1}} = 0. \tag{13}$$

Rewriting in matrix form yields

$$\begin{pmatrix} \frac{\partial H}{\partial e_{A2}} & \frac{\partial H}{\partial e_{B2}} \\ \frac{\partial F}{\partial e_{A2}} & \frac{\partial F}{\partial e_{B2}} \end{pmatrix} \begin{pmatrix} \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} \\ \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} \end{pmatrix} = \begin{pmatrix} -\frac{\partial H}{\partial e_{A1}} \\ -\frac{\partial F}{\partial e_{A1}} \end{pmatrix}. \tag{14}$$

Applying Cramer's rule we get for the effect of a change in the effort of the agent moving first in team A on the optimally chosen effort of the second team member in A

$$\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} = \frac{-uv + xw}{yv - zx} \tag{15}$$

and for the effect on the optimal effort of the second player in team B

$$\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} = \frac{-yw + zu}{yv - zx}. \tag{16}$$

Furthermore we have

$$\frac{\mathrm{d}^2\, e_{A2}}{\mathrm{d}\, e_{A1}^2} = \frac{u'(u - v)}{v^2} \tag{17}$$

$$\frac{\mathrm{d}^2\, e_{B2}}{\mathrm{d}\, e_{A1}^2} = \frac{v'(v - u)}{v^2} \tag{18}$$

with

$$u \equiv \frac{\partial H}{\partial e_{A1}} = \alpha \frac{-(e_{B1}+e_{B2})2D}{D^4} S < 0 \tag{19}$$

$$v \equiv \frac{\partial F}{\partial e_{B2}} = \alpha \frac{-(e_{A1}+e_{A2})2D}{D^4} S - 2 < 0 \tag{20}$$

$$w \equiv \frac{\partial F}{\partial e_{A1}} = \alpha \frac{D^2-(e_{A1}+e_{A2})2D}{D^4} S = \alpha \frac{1-\frac{2(e_{A1}+e_{A2})}{D}}{D^2} S = 0 \tag{21}$$

$$x \equiv \frac{\partial H}{\partial e_{B2}} = \alpha \frac{D^2-(e_{B1}+e_{B2})2D}{D^4} S = \alpha \frac{1-\frac{2(e_{B1}+e_{B2})}{D}}{D^2} S = 0 \tag{22}$$

$$y \equiv \frac{\partial H}{\partial e_{A2}} = \alpha \frac{-(e_{B1}+e_{B2})2D}{D^4} S - 2 < 0 \tag{23}$$

$$z \equiv \frac{\partial F}{\partial e_{A2}} = \alpha \frac{D^2-(e_{A1}+e_{A2})2D}{D^4} S = \alpha \frac{1-\frac{2(e_{A1}+e_{A2})}{D}}{D^2} S = 0 \tag{24}$$

$$u' \equiv \frac{\partial^2 H}{\partial e_{A1}^2} = \alpha \frac{3S}{D^3} > 0 \tag{25}$$

$$v' \equiv \frac{\partial^2 F}{\partial e_{A1}\partial e_{B2}} = \alpha \frac{S}{D^3} > 0 \tag{26}$$

$$w' \equiv \frac{\partial^2 F}{\partial e_{A1}^2} = -\alpha \frac{S}{D^3} < 0 \tag{27}$$

$$x' \equiv \frac{\partial^2 F}{\partial e_{A1}\partial e_{B1}} = \alpha \frac{S}{D^3} > 0 \tag{28}$$

$$y' \equiv \frac{\partial^2 H}{\partial e_{A1}\partial e_{A2}} = \alpha \frac{3S}{D^3} > 0 \tag{29}$$

$$z' \equiv \frac{\partial^2 F}{\partial e_{A1}\partial e_{A2}} = -\alpha \frac{S}{D^3} \tag{30}$$

Note that $u' = y'$, $v' = x' = -w' = -z'$. Because of symmetry we have $e_{B1} + e_{B2} = e_{A1} + e_{A2}$ so that in equilibrium by inserting terms into eq. (15) we get

$$\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} = 0. \tag{31}$$

Hence the s.o.c. simplifies to

$$\frac{\mathrm{d}^2 V_{A1}}{\mathrm{d}\, e_{A1}^2} = \alpha(e_{B1} + e_{B2}) \frac{D(\frac{\mathrm{d}^2 e_{A2}}{\mathrm{d}\, e_{A1}^2} - \frac{\mathrm{d}^2 e_{B2}}{\mathrm{d}\, e_{A1}^2}) - 2(1 + \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}})^2}{D^3} S - 2. \tag{32}$$

Inserting $\frac{\mathrm{d}^2 e_{A2}}{\mathrm{d}\, e_{A1}^2}$, $\frac{\mathrm{d}^2 e_{B2}}{\mathrm{d}\, e_{A1}^2}$ and $\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}}$ in equation (32) and further rearranging yields

$$\frac{\mathrm{d}^2 V_{A1}}{\mathrm{d}\, e_{A1}^2} = \alpha \frac{2S}{D^2}(\alpha \frac{S}{D^2} - 6) - 8 \tag{33}$$

which is negative if

$$\alpha \frac{S}{(2e_{A1} + 2e_{A2})^2} < 6. \tag{34}$$

Using equation (5) one can show that the l.h.s. is never larger than 2 which finally proves that the s.o.c. is fulfilled.

Part II:

Now, in order to have an interior solution and to show that the second player exerts more effort it must hold that:

$$-1 < \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} - \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} < 0 \tag{35}$$

which follows from the comparison of the f.o.c. of the first and second players. We already know that $\frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} = 0$, see eq. (31), and $\frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} = -\frac{u}{y} = -\frac{u}{v}$. As $|u| < |v|$ it holds that $-1 < \frac{\mathrm{d}\, e_{A2}}{\mathrm{d}\, e_{A1}} - \frac{\mathrm{d}\, e_{B2}}{\mathrm{d}\, e_{A1}} < 0$ which proves our Proposition.

Proposition 2

Proof Due to symmetry, the choices of competing swimmers of the same order must be identical. From the f.o.c. of second players given in (3) and (4), by substituting $e_{B1} = e_{A1}$ and $e_{B2} = e_{A2}$, we find that the optimal effort level of second swimmers is implicitly given by:

$$c'(e_{A2}) = 2e_{A2} = \alpha \frac{S}{4(e_{A1} + e_{A2})} \tag{36}$$

or, equivalently, by $c'(e_{B2}) = 2e_{B2} = \alpha \frac{S}{4(e_{B1}+e_{B2})}$.

>From a cooperative perspective, given that the prize is non-rival within the team, the optimal level of effort maximizes:

$$V_A = 2p_A S - e_{A1}^2 - e_{A2}^2. \tag{37}$$

The f.o.c. with respect to the effort choices $e_{A1}$and e_{A2} for team A (analogously for team B) are:

$$\alpha \frac{2(e_{B1} + e_{B2})}{D^2} S - 2e_{A2} = 0 \tag{38}$$

$$\alpha \frac{2(e_{B1} + e_{B2})}{D^2} S - 2e_{A1} = 0. \tag{39}$$

Symmetry then implies

$$2e_{A1} = 2e_{A2} = \alpha \frac{S}{2(e_{A1} + e_{A2})} = \alpha \frac{S}{4e_{A2}} \tag{40}$$

which is higher than the effort exerted by the second player in the non-cooperative solution given by (36).

Proposition 3

Proof From equation (36), absent player 1, player 2's optimal effort would be determined by:

$$c'(e_{A2}) = 2e_{A2} = \alpha \frac{S}{4e_{A2}} \tag{41}$$

which is the same as the socially optimal effort in team production.

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Table 1: Descriptive statistics

Variable		
Number of events	7,081	
Overall no. of observations	311,784	
(of which at major events):	(3,835)	
Olympic games	660	
World championships	1,531	
European championships	766	
Pan Pacific games	390	
Commonwealth games	184	
Universiades	304	
	Major	Non-major
Style		
50m Breaststroke	-	20,092
50m Fly	-	17,619
50m Freestyle	7	103,079
100m Breaststroke	704	28,015
100m Fly	734	24,450
100m Freestyle	1,528	94,506
200m Freestyle	862	20,188
Schedule		
individual first$^{(a)}$	2,629	78,196
relay first$^{(b)}$	935	82,357
same day	271	147,396
Round (individual competition)		
timed finals (default)	21	144,415
finals	902	74,960
semi-finals	517	2,113
preliminaries	2,390	86,206
others$^{(c)}$	5	255
Round (relay)		
timed finals (default)	342	202,042
finals	1,569	93,238
preliminaries	1,924	12,101
others$^{(c)}$	-	568
Order (relay)		
1st	659	65,892
2nd	1,172	87,421
3rd	1,086	78,918
4th	918	75,718
...		

... table 1 continued		
Gender		
male	2,096	153,245
female	1,739	154,704
Age: median [min-max]	21 [13-52]	16 [6-109]
FINA points: median [min-max]	846 [64-1093]	501 [5-1181]

(a) Day of individual competition before day of relay

(b) Day of individual competition after day of relay

(c) Swim-Off after semi-finals, Swim-Off after preliminaries

Table 2: Comparing individual and relay swimming times only

	Swimming times				
	Individual (secs.)	Relative difference b/w relay and individual (%)			
	I	$\frac{R_1-I}{I}$	$\frac{R_2-I}{I}$	$\frac{R_3-I}{I}$	$\frac{R_4-I}{I}$
Overall	56.84	.22 ***	-.33	-.34	-.75
Gender					
male	53.66	.20 ***	-.43	-.42	-.82
female	58.01	.23 ***	-.25	-.26	-.69
Age (yrs)					
< 15	54.91	.36 ***	-.03	-.02	-.47
$15 - 30$	58.47	.11 ***	-.48	-.51	-.92
> 30	38.78	.30 ***	-.58	-.51	-.95
Ability of swimmer$^{(a)}$					
$\leq$ median	52.64	.27 ***	-.19	-.17	-.59
$>$ median	59.03	.17 ***	-.48	-.53	-.92
Style					
50m Breaststroke	39.67	.44 ***	-.51	-.12	-.25
50m Fly	33.58	.62 ***	-.10	-.48	-.32
50m Freestyle	32.03	.32 ***	-.70	-.70	-1.14
100m Breaststroke	78.27	.32 ***	-.05	-.05	-.22
100m Fly	67.88	.05	-.53	-.04	-.47
100m Freestyle	63.08	.14 ***	-.30	-.31	-.45
200m Freestyle	128.53	.07 ***	-.03	-.08	-.04
Event importance					
major events$^{(b)}$	70.99	.03	-.53	-.56	-.90
others	55.66	.22 ***	-.33	-.34	-.75
Schedule of competitions					
individual first$^{(c)}$	54.81	.19 ***	-.39	-.41	-.98
relay first$^{(d)}$	59.81	.15 ***	-.49	-.49	-.77
same day	54.17	.27 ***	-.22	-.21	-.63

I - individual competition swimming time

$R_1, \cdots, R_4$ - relay swimming time, starting order $1, \cdots, 4$

(a) As measured by FINA points

(b) Olympic, Pan Pacific and Commonwealth Games, World and European Championships, Universiades

(c) Day of individual competition before day of relay

(d) Day of individual competition after day of relay

*** $p < .01$

Table 3: Regression results

	Model 1		Model 2		Model 3	
Dependent variable			$(R-I)/I$			
swimmer 1	.08	***	.51	***	.81	***
swimmer 2	-.59	***	-.21	***	.06	***
swimmer 3	-.61	***	-.27	***	-.03	***
swimmer 4	-.87	***	-.53	***	-.43	***
female	.07	***				
age <15	.52	***				
age >30	.26	***				
major	-.19	***	-.14	***	-.31	***
same day	.19	***	.10	***	.02	
relay first	-.02	**	-.04	***	.02	
50m Breastroke (5)	-.27	***	-.46	***	-.61	***
50m Fly (6)	-.22	***	-.37	***	-.42	***
50m Freestyle (7)	-.48	***	-.72	***	-.61	***
100m Breastroke (1)	.27	***	.32	***	.27	***
100m Fly (2)	.33	***	.39	***	.41	***
200m Freestyle (4)	.21	***	.31	***	.25	***
Fixed effects	No		Yes		Yes	
R-squared	0.09		.50		.56	
Wald test (F value)						
order_2=order_3	3.93	**	30.88	***	5.67	**
order_3=order_4	822.12	***	522.59	***	155.93	***
Obs.	311,784		107,808		25,138	
Notes					finals only	

*** $p < .01$, ** $p < .05$

Reference category: 100m Freestyle, age group 15-30, individual competition on a day prior to the relay, first swimmers