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Incentives in Supervised Teams
An experimental and computational approach

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Abstract
A carefully designed experimental procedure may be an invaluable source for gathering empirical data and a key to grasp the heterogeneity of human behavior, which is of the utmost importance when modeling artificial agents. We consider a model of organization where heterogeneous agents interact in a supervised team. After providing a theoretical analysis of the agents' interaction, we describe the experimental setting we used to observe human subject interactions in a similar situation. Finally, we consider an agent-based simulation where the agents exhibit some of the behavioral components emerged in human subject experiment. The results we obtain allow to emphasize the importance of incorporating experimental data when modeling artificial agents in order to shed light on the complexity of human interactions.
Keywords: agent behavior, experiments, bounded rationality, incentives, grounded theory

1. Introduction

The Moral Hazard literature approaches multi-agent relationships in different ways. For example, the *joint production models* provide interesting insights in terms of income distribution among the agents. Another relevant aspect is the comparison between centralized and decentralized structures as far as contracting goes. For example, the literature provides conditions under which the delegation of the supervisory task, i.e. decentralizing, is beneficial; to get a first analysis of the advantages and disadvantages of delegation the reader may refer to Macho-Stadler & Pérez-Castrillo (1997).

Following the joint production approach, we consider a modular model of hierarchical organization. Specifically, we concentrate mainly on pyramidal structures. This particular structure is widespread and, consequently, both the economic (see Beckmann, 1988, for a formal analysis) and simulative literature (for instance, see Glance and Huberman, 1994) find interest (for an analysis of the different approaches to pyramidal structures see Merlone, 2003). In our model, the organization consists of heterogeneous agents interacting in a supervised team with a Cobb-Douglas production function. We provide a theoretical analysis of the agents interaction and study the impact agents' heterogeneity, and incentive schemes in the team when all the agents are fully rational. While there exist infinite solutions to the optimal effort allocation problem, we can identify a natural solution.

Since the assumption of fully rational individuals is quite extreme (see for instance Simon, 1982) and evidence against it are common in the experimental economics literature (see Kagel & Roth, 1995), we introduce some behaviors that are not fully rational.

The importance of individual behavior at work is well known in the literature. For example, in Thompson (2003) the Author devotes a whole chapter to the human variable and states "The human actor is a multidimensional phenomenon subject to the influences of a great many variables. ... Neither we nor organizations have the data or the calculus to understand organization members in their full complexity, and the requirements of complicated technologies in complicated task environments cannot be met if the full range of human variations comes into play within the organization". The approach we use in modeling consists in building some classes of behaviors by the observation of human subjects when interacting in a task which is similar to the one we consider (see Dal Forno & Merlone, 2004).

When introducing several bounded rationality behaviors in this simple model of supervised team, the complex dynamics between the agents call for the simulation approach. The Agent-Based simulation model we consider allows the extension of the results obtained in the theoretical analysis of the supervised team. First, using the simulation platform we have developed, it is possible to consider complex dynamics where agents adapt their efforts to different incentive schemes and to the observable variables. In particular, some of the behavioral components emerged in human subjects experiment we ran have been coded. Second, it is possible to compare the different performances when the team composition varies in terms of agents' behavior.

Our results shed light on some aspects of interaction between individuals in complex environment and economic performance and give insights in terms of observation of the performance measures in the organization. Furthermore, we can observe how the different outcomes in terms of performance are the result of the team composition. In particular, it is interesting to observe the optimal incentive scheme effect when operatives are bounded rationality agents.

In Section 2 we present the theoretical model separating the analysis from the subordinate's and the supervisor's point of view respectively. Section 3 describes the design of the experiment we ran and presents the behavior categories that emerged. Results are presented and discussed in Section 4, while Section 5 is devoted to conclusions and further research.

2. The Model

We consider a model of supervised team in which a supervisor and two subordinates cooperate (see Fig. 1).

In this model the supervisor acts as a principal while the two subordinates act as agents.[1] Agent i has a capacity c_i to be allocated between effort l_i, provided with his partner, and effort u_i, provided with his supervisor. The joint production function for agents 1 and 2 is $(u_1+u_2)^{\alpha}(l_1+l_2)^{\beta}$, where $0<\alpha<1$ and $0<\beta<1$ are, respectively, the output elasticity with respect to the joint effort with the supervisor and with the partner. Fig. 2 illustrates the allocation of the efforts exerted by the two considered agents.

We assume that each agent's capacity is private information. Furthermore, each agent can observe the level effort his partners provides, but cannot observe the effort his partner provides with the boss. Conversely, the supervisor can observe the joint output and the effort each agent provides with her. The agent's retribution is given by a fixed wage plus a linear incentive proportional to the joint output of the team and a linear incentive on the effort each agent exerts with the supervisor. Finally, the supervisor's profit is the output of the supervised team.

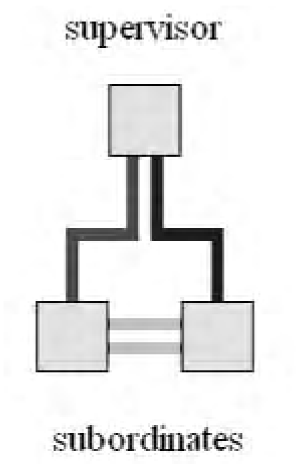

Figure 1 Model of a supervised team

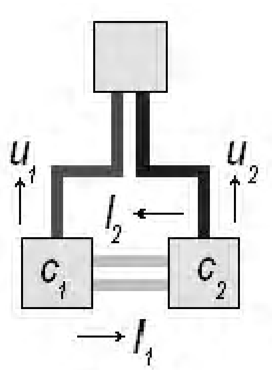

Figure 2 Agents' effort allocation

[1] For a first survey of the principal-agent literature when several agents are considered, the reader can refer to Macho-Stadler & Pérez-Castrillo (1997).

2.1 The Agents' Problem

Assuming coordination and commitment between agents, the following problem must be solved

$$\max_{u_1,u_2,l_1,l_2} \quad (u_1+u_2)^{\alpha}(l_1+l_2)^{\beta}$$
$$\text{sub} \quad u_i+l_i \le c_i, \quad i=1,2.$$

By first order conditions it is easy to obtain

$$\begin{cases} u_1+u_2=\dfrac{\alpha}{\alpha+\beta}(c_1+c_2) \\ l_1+l_2=\dfrac{\beta}{\alpha+\beta}(c_1+c_2). \end{cases}$$

There are infinite solution to the considered problem, nevertheless, a rather natural effort allocation is

$$\begin{cases} u_1=\dfrac{\alpha}{\alpha+\beta}c_1 \\ l_1=\dfrac{\beta}{\alpha+\beta}c_1 \end{cases} \quad \begin{cases} u_2=\dfrac{\alpha}{\alpha+\beta}c_2 \\ l_2=\dfrac{\beta}{\alpha+\beta}c_2. \end{cases}$$

This allocation may be interpreted as focal in the sense of Schelling (1960).

The process the agents use to reach this effort allocation is the following:

$$\begin{cases} \left(u_1^{t+1},l_1^{t+1}\right)=BR\left(u_2^{t},l_2^{t}\right) \\ \left(u_2^{t+1},l_2^{t+1}\right)=BR\left(u_1^{t},l_1^{t}\right). \end{cases}$$

With any initial condition such that

$$\left(u_1^0,l_1^0\right)=\left(k_1\frac{\alpha}{\alpha+\beta}c_1,k_1\frac{\alpha}{\alpha+\beta}c_1\right), \quad \left(u_2^0,l_2^0\right)=\left(k_2\frac{\alpha}{\alpha+\beta}c_2,k_2\frac{\alpha}{\alpha+\beta}c_2\right) \quad k_1,k_2\in[0,1] \ ,$$

the system converges to the natural effort allocation in one single step. From any other initial conditions the system oscillates in period-2 cycles. We are interested in conditions under which the system converges to the optimal allocation. To this purpose we consider different incentive schemes and individual diversity.

2.2 The Supervisor's Problem

The supervisor's problem is to design a linear compensation scheme for the subordinates that induces them to use their capacity to maximize the team output. The supervisor can observe the efforts the subordinates exert with her (u_i, $i=1,2$) and the team output. Each subordinate's compensation is $w_i=s+b_iu_i+b_t(u_1+u_2)^{\alpha}(l_1+l_2)^{\beta}$, $i=1,2$, where s is a base salary sufficient to meet the participation constraint of the agents, b_i, $i=1,2$ are the incentives given to subordinates for their individual effort with supervisor, and b_t is the incentive given to them for the team output. We assume that the supervisor declares the incentives and that the subordinates decide their efforts in order to maximize their wage.

Theoretically, the supervisor has to solve the following problem

$$\max_{b_1,b_2,b_t} \left(u_1^* + u_2^*\right)^{\alpha} \left(l_1^* + l_2^*\right)^{\beta} \left(1 - 2b_t\right) - b_1 u_1 - b_2 u_2$$

$$\text{sub} \quad \begin{array}{l} 0 \le b_i \le 1, \quad i = 1,2 \\ 0 \le b_t \le 1 \\ \left(u_1^*, u_2^*\right) \text{and} \left(l_1^*, l_2^*\right) \text{are optimal.} \end{array}$$

When considering fully rational agents the solution is obvious. Since any individual incentive given to agents gives a suboptimal effort allocation, and null team output incentive makes for subordinates any allocation optimal, the optimal solution is

$$\begin{cases} b_1 = 0 \\ b_2 = 0 \\ b_t = \varepsilon > 0. \end{cases} \tag{1}$$

3. The Experimental Design

Here we present the experiment we ran in the classroom. The purpose of the experiment is to observe the behavior of human subjects in the situation considered in our model. In particular, we are interested in observing a situation where the operatives are different in term of capacity. For this reason we considered three roles:

- supervisor
- hi-capacity subordinate
- low-capacity subordinate.

The experiment was run in nine weekly sessions where two different groups interacted separately; each subject was allowed to participate only to one single session. One week before the first session, subjects were given the instructions for the experiment (Fig. 3) and a short explanatory discussion took place.

For each session we asked the subjects to volunteer one week in advance. The day the experiment took place, roles were randomly attributed and, while subjects were aware of their own role, they were not aware of the others' one. Furthermore, no communication was allowed during the experiment in order to avoid cheap talk issues. In particular, capacity and effort allocation remained private.

Furthermore, in each session of the experiment each participant was given further instructions adapted for the role he/she was playing. These instructions are not reported for brevity's sake.

INSTRUCTIONS – Supervised team

A 2-agent team is supervised by a manager. Agents' wage consists of a (fixed) base salary s plus an incentive given by the manager. Each agent has a fixed effort capacity c_i that can be distributed between an effort u_i, exerted with the manager, and an effort l_i, exerted with the team-mate. Agents can choose of not using the whole capacity or even not exerting it at all; the base salary will be given in any case.

Each agent's capacity is private information: his/her team-mate observes just the effort l_i he/she exerts with him/her. The manager can observe both the exerted efforts u_i with him/her and the team total production O. The manager might want to pay each agent both an individual incentive λ_i – proportional to u_i – and a production incentive λ_O – proportional to the team production.

The production function is $O = (u_1 + u_2)^{\alpha}(l_1 + l_2)^{\beta}$ where:

u_i : effort exerted by agent i with the manager
l_i : effort exerted by agent i with the team-mate
α : production elasticity w.r.t. the aggregate effort exerted with the manager
β : production elasticity w.r.t. the aggregate effort exerted between team-mates.

Retribution of agent i is $r_i = s + \lambda_i u_i + \lambda_O O$ where:

s : base salary
λ_i : individual incentive given to agent i
λ_O : production incentive.

The manager receives the net production after incentives are paid:

$$n = 5.59181589 \cdot (1 - 2 \cdot 0.01) - 0.03 \cdot 3 - 0.02 \cdot 4 = 5.66979577286 .$$

EXAMPLE

Let $\alpha = 0.7$, $\beta = 0.3$, c_1 = 5, c_2 = 7 and let the base salary be s = 2. In the first period the manager decides and passes on the following linear incentives:

individual incentive to agent 1: λ_1 = 3%
individual incentive to agent 2: λ_2 = 2%
collective incentive: λ_O = 1%.

Agents allocate efforts respectively as $(u_1 = 3, l_1 = 2), (u_2 = 4, l_2 = 2)$; the total production is therefore $O = (3+4)^{0.7}(2+2)^{0.3} = 5.59181589.$. Agents' wages are respectively:

$$r_1 = 2 + 0.03 \cdot 5.59181589 = 2.14918158952$$
$$r_2 = 2 + 0.02 \cdot 5.59181589 = 2.09918158952$$

while the manager's net result is:

$$n = 5.59181589 \cdot (1 - 2 \cdot 0.01) - 0.03 \cdot 3 - 0.02 \cdot 4 = 5.66979577286 .$$

Figure 3 Instructions for the supervised team

Since motivating subjects in experiments is a well-known problem, we encouraged our students in the following way. Subjects would receive up to 1 mark in addition to whatever their grade would be in the final exam of the Math class (the maximum available grade is 30/30 and pass grade is 18/30). Furthermore, only written motivations made them eligible for the additional mark. Subjects were also told that the actual incentive depended on their performance (incentive = ranked performance[2] normalized in the range [0,1]).

We collected the data from undergraduates at the University of Biella (Torino), who were in the Math class. Subjects were told that the experiment would last about an hour and that some extra time would be required for writing a report explaining their choices. The experiment we ran consisted of 18 sessions, one team each. At the beginning of each session the 3-person group

[2] The ranking of performance may have consequences on strategies. This may be relevant (see Dal Forno & Merlone, 2001), even though subjects did not seem aware of this.

SUPERVISOR:
GROUP ___________
SURNAME ___________
α = ...
β = ...
base salary s = ...

Period 1
Team incentive λ_O = ...
Individual incentive for agent 1 λ_1 = ...
Individual incentive for agent 2 λ_2 = ...
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Agent 1's effort with the manager u_1 = …
Agent 2's effort with the manager u_2 = …
Gross production result O = …
Net result n = …

Period 2
Team incentive λ_O = ...
Individual incentive for agent 1 λ_1 = ...
Individual incentive for agent 2 λ_2 = ...
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Agent 1's effort with the manager u_1 = …
Agent 2's effort with the manager u_2 = …
Gross production result O = …
Net result n = …

Period 3
Team incentive λ_O = ...
Individual incentive for agent 1 λ_1 = ...
Individual incentive for agent 2 λ_2 = ...
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Agent 1's effort with the manager u_1 = …
Agent 2's effort with the manager u_2 = …
Gross production result O = …
Net result n = …

Period 4
Team incentive λ_O = ...
Individual incentive for agent 1 λ_1 = ...
Individual incentive for agent 2 λ_2 = ...
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Agent 1's effort with the manager u_1 = …
Agent 2's effort with the manager u_2 = …
Gross production result O = …
Net result n = …

Period 5
Team incentive λ_O = ...
Individual incentive for agent 1 λ_1 = ...
Individual incentive for agent 2 λ_2 = ...
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Agent 1's effort with the manager u_1 = …
Agent 2's effort with the manager u_2 = …
Gross production result O = …
Net result n = …

Figure 4 Manager's form

AGENT:
GROUP ___________
SURNAME ___________
Capacity c_i = …
α = ...
β = ...
base salary s = ...

Period 1
Team incentive λ_O = ...
Individual incentive λ_i = ...
Effort with the manager u_i = …
Effort with the manager l_i = …
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Gross production result O = …
Payment r_i = …
Team-mate's effort l_i = …

Period 2
Team incentive λ_O = ...
Individual incentive λ_i = ...
Effort with the manager u_i = …
Effort with the manager l_i = …
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Gross production result O = …
Payment r_i = …
Team-mate's effort l_i = …

Period 3
Team incentive λ_O = ...
Individual incentive λ_i = ...
Effort with the manager u_i = …
Effort with the manager l_i = …
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Gross production result O = …
Payment r_i = …
Team-mate's effort l_i = …

Period 4
Team incentive λ_O = ...
Individual incentive λ_i = ...
Effort with the manager u_i = …
Effort with the manager l_i = …
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Gross production result O = …
Payment r_i = …
Team-mate's effort l_i = …

Period 5
Team incentive λ_O = ...
Individual incentive λ_i = ...
Effort with the manager u_i = …
Effort with the manager l_i = …
Motivation
… … … … … … … … … … … … … … … … …
… … … … … … … … … … … … … … … … …
Gross production result O = …
Payment r_i = …
Team-mate's effort l_i = …

Figure 5 Agents' form

was arranged, with two operatives and one supervisor. Each role within the team was assigned randomly. All the operatives were provided with an individual capacity, one high (c_1= 10) and one low (c_2 = 2), as private information. All the members were given the two elasticities $(\alpha = 0.7, \beta = 0.3)$ and the base salary[3] (s = 2), as common knowledge. Both private and common values were the same across all the sessions.

Each session consisted of five periods in which actions took place. Each period was divided into three steps, where the experimenter was in charge of transmitting all the relevant information to the subjects:

1. incentives - manager plans the individual incentives λ_1 and λ_2 (privately communicated to each agent) and publicly communicate the collective incentive λ_0;
2. efforts - once both personal and collective incentives have been learnt, subordinates allocate their capacity between the effort u_i (privately communicated to the manager) and l_i (privately communicated to the team-mate);
3. production and payoffs - the experimenter calculates and publicly communicates the total production O and, accordingly to the incentives, payments r_i (privately communicated to the agents) and net result n (privately communicated to the manager).

In each step, for each of the five periods of the session, written motivations of subjects' decision were required. Team members received a form to be filled during the experiment. The forms were specific to the role the subject played and are shown in Fig. 4 and 5.

The motivations provided by subjects gave us different kinds of information that enabled to complement the simple observation of their behavior in terms of given incentives and provided efforts. In particular, the motivations our subjects provided allow the *grounded*[4] modeling of artificial agents. In fact, the approach we used in categorizing and labeling the different behaviors is related to some of the methods that are used in qualitative research (for further details the reader may consult Glaser & Strauss, 1999, and Strauss & Corbin, 1998).

Some of the difficulties we found in analyzing the data we gathered lie in the fact that both managers and their operatives were interacting and adjusting each other. As a matter of facts all subjects strategies seemed to be the result of both their initial assumptions on the game and the other partecipants' actions. A different approach would have been studying just one role at the time, for example having one human subject interacting with artificial coworkers. This way, while it would have been easier to understand a single role, we would have lost the joint construction of mutual interaction between human subjects.

Analyzing the data we could categorize several components of behavior both for operatives and managers. In particular, as it concerns the operative role, the behaviors we could identify are reported in Table 1 where $c_i^\tau \le c_i$ is the capacity agent *i* devolves to efforts at time τ, while u_i^τ, and l_i^τ are respectively agent *i*'s effort with boss and effort with partner at time . Function r is any convenient behavioral rule used to determine the effort to be exerted.

While as it concerns managers the categories which emerged are reported in Table 2 where $\pi_N^\tau = \left(u_1^\tau + u_2^\tau\right)^\alpha \left(l_1^\tau + l_2^\tau\right)^\beta \left(1 - b_1^\tau - b_2^\tau - 2b_t^\tau\right)$ is the net production at time τ, and r_1, r_2, r_t are convenient behavioral rules used to assign respectively the two individual incentives and the one for the team.

By combining some of them we modeled the classes of behavior described in the following.

[3] The actual value of base salary is not important for the theoretical analysis, provided that it is positive.
[4] In the sense of Glaser & Strauss (1967).

Behavior Description	Formal Modelization
subjects using their whole capacity	$c_i^\tau = c_i$
subjects increasing over time the capacity assigned to efforts	$c_i^\tau = c_i\left(1-\frac{1}{\tau+1}\right)$
subjects partitioning their efforts according to received incentives	$\begin{cases} u_i^\tau = \frac{b_i^\tau}{b_i^\tau + b_t^\tau} c_i^\tau \\ l_i^\tau = \frac{b_t^\tau}{b_i^\tau + b_t^\tau} c_i^\tau \end{cases}$
subjects reacting to differences in received incentives, i.e., diminishing their efforts when incentives dropped	$\begin{cases} u_i^\tau < u_i^{\tau-1} & \text{if} \quad b_i^\tau < b_i^{\tau-1} \\ l_i^\tau < l_i^{\tau-1} & \text{if} \quad b_t^\tau < b_t^{\tau-1} \end{cases}$
subjects sensitive to the effort provided by their partner	$l_i^\tau = \mathrm{r}\left(l_i^{\tau-1}, l_{-i}^{\tau-1}\right)$

Table 1 Categories for operatives' behavior.

Behavior Description	Formal Modelization
subjects incentivizing mainly individual efforts	$b_t^\tau \le b_1^\tau, b_2^\tau$
subjects incentivizing mainly collective production	$b_t^\tau \ge b_1^\tau, b_2^\tau$
subjects rewarding the subordinate who provides higher effort with the manager	$b_i^\tau = \begin{cases} b_i^{\tau-1} + \delta & \text{if} \quad u_i^{\tau-1} > u_{-i}^{\tau-1} \\ b_i^{\tau-1} & \text{if} \quad u_i^{\tau-1} \le u_{-i}^{\tau-1} \end{cases}$
subjects punishing the subordinate providing lower effort with the manager	$b_i^\tau = \begin{cases} b_i^{\tau-1} & \text{if} \quad u_i^{\tau-1} \ge u_{-i}^{\tau-1} \\ b_i^{\tau-1} - \delta & \text{if} \quad u_i^{\tau-1} < u_{-i}^{\tau-1} \end{cases}$
subjects adjusting their incentives according to the trend of the net production.	$\begin{cases} b_1^\tau = \mathrm{r}_1\left(\pi_N^{\tau-1}, \pi_N^{\tau-2}\right) \\ b_2 = \mathrm{r}_2\left(\pi_N^{\tau-1}, \pi_N^{\tau-2}\right) \\ b_t = \mathrm{r}_t\left(\pi_N^{\tau-1}, \pi_N^{\tau-2}\right) \end{cases}$

Table 2 Categories for managers' behavior.

- Manager 1 (*individual punisher*): at the first turn she gives both operatives a low collective incentive and slightly higher individual incentives. At the following turns, if the net production has increased, then she increases the individual incentive of the operative who exerted the higher effort with her, otherwise (i.e., if the net production does not increase) decreases the individual incentive of the lower effort operative.
- Manager 2 (*team punisher*): at the first turn she gives both operatives a low collective incentive and slightly higher individual incentives. At the following turns, if the net production has increased, then she increases the individual incentive of the operative who exerted the

higher effort with the manager, otherwise (i.e., if the net production does not increase) decreases both individual incentives.

- Operative 1 (*partitioner*): at each turn he uses all of his capacity partitioning it proportionally to the individual and collective incentives.
- Operative 2 (*increasingly partitioner*): he increases the used capacity over time and partitions it proportionally to the individual and collective incentives.
- Operative 3 (*incentive averager*): he uses his capacity proportionally to the ratio of incentives just received with the average of the incentives so far obtained; the used capacity is partitioned proportionally to the individual and collective incentives.
- Operative 4 (*team effort limiter*): at each turn he uses all of his capacity partitioning it proportionally to the individual and collective incentives, but limiting his effort with the partner to the one he observed the previous turn.

Furthermore, in order to compare the behavior of fully rational agents we implemented also the following classes:

- *Rational operative*: given last partner effort and current incentives, this agent optimizes his effort.
- *Rational manager*: implements the optimal solution (1) where is fixed at 1%.

4. Some Simulation Results

As it is evident in the Organizational Behavior literature, individual diversity plays a key role in real organizations (for a first introduction the reader may refer to Steers & Black, 1994). We do not limit agents diversity to different roles and personal capacities, but are also interested in different patterns of behavior. Consequently, besides the rational behavior we are interested in considering also bounded rationality for the agents in our model of team. Specifically, we are particularly interested in studying the team performance when considering the grounded behavior we modeled by analyzing the subjects in the experiments.

To this purpose, we developed a software platform in order to study the outcome of interaction when the modeled classes of behavior were considered. Among input variables there are the elasticity values a and b, the agents' capacity c_1 and c_2, and the behavioral classes of each member of the team.

The organization performance is defined as the team net production. The theoretical performance of the organization and its inefficiencies may be monitored in real time considering the following output variables:

1. *first best* - it is the output when each agent allocates optimally his capacity and no incentive is paid;
2. *second best* - it is the output when each agent allocates optimally his capacity and all the incentives are paid; this is the result obtainable in a team where both agents are rational and the manager implements the optimal incentives scheme (1);

3. *third best* - it is the net total output with actual effort allocation and all the incentives are paid.

In order to compare the production outcome when different team compositions are considered, we fixed the same parameter values both for the human subjects experiment and the computer simulations. Specifically, we assumed elasticity values α = 0.75 and β = 0.25, high capacity c_1 = 10, and low capacity c_2 = 2.

Since we assume the agents' capacities fixed throughout all the simulations, both first and second best values represent important parameters for comparing performances under different team compositions. While the first one allows for measuring the agents' effort allocation, the second one is useful for assessing the appropriateness of the adopted incentive scheme. In fact, consider the first and second best values obtainable with fully rational agents when the optimal incentive scheme (1) is adopted. Then, considering a generic team composition, the closer the gross production is to the first best value the better is the agent effort allocation; in addition, the closer is the net production to the second best value the closer the incentive scheme is to the one proposed in (1).

With the considered capacities and assuming that efforts are optimally allocated with no need to pay incentives, the gross team production, i.e., the first best value, is about 6.8385; by contrast, when agents and manager are fully rational and the optimal incentive scheme is implemented, the net production, i.e. the second best value, is about 6.7018. These yardstick values can be found in the low-right corner of Table 3, where the performance of the rational supervised team is reported.

In the following we report the results of our simulations, making a distinction between teams where the operatives belong to the same class of behavior, forming a homogeneous team, and teams where the operatives belong to different classes, which we refer as heterogeneous teams.

When we compare results in a homogeneous team of operatives (Table 3) it is immediate to see that an *individual punisher* manager, when matched with either *increasingly partitioner* or *incentive averager* operatives, consumes all her wealth by providing the incentives.

Milgrom and Roberts (1982) define the *ratchet effect* as "the tendency for performance standards to increase after a period of good performance". Obviously, whenever the workers foresee the way future standard may depend on current performance, they may refuse to

	Partitioner	Increasingly partitioner	Incentive averager	Team effort limiter	Rational operative
Individual punisher	(6.2347; **6.7871**)	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(0.0000; **0.0000**)	(6.0537; **6.6874**)
Team punisher	(0.0000; **0.0000**)	{(5.9890; **6.8368**), (6.0817; **6.8307**)}	(0.0000; **0.0000**)	(0.0000; **0.0000**)	{(6.2537; **6.6874**), (6.3537; **6.6874**)}
Rational manager	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(6.7018; **6.8385**)

Table 3 Net (normal) and gross (bold) production level in homogeneous teams. *rows* - managers; *columns* - operatives. When two couples of values are given, production oscillates between the written values in a 2-period cycle.

improve their productivity. The strategy the *increasingly partitioner* operatives adopt can, under some circumstances, anticipate the ratchet effect and, when the manager belongs to the *individual punisher* class, ends up in consuming all the gross team production in incentives. For this reason we name this result *reverse ratcheting*.

Yet, on the other hand, this manager can also get higher net productivity with *partitioner* operatives ((6.2347; **6.7871**)) than with *rational* ones ((6.0537; **6.6874**)). The reason may be that even if the given incentives are the same, when considering *partitioner* operatives the higher capacity agent reacts better, in terms of effort allocation to the suboptimal incentives.

Team effort limiter operatives perform poorly with any manager, getting both a net and gross production equals to zero. This is because they limit each other on the effort they exert with the partner. By contrast, *partitioner* operatives give a good result if matched with an *individual punisher* manager, while *increasingly partitioner* operatives are better associated with a *team punisher* manager. This is the only way for the latter class of manager to perform well (excluding the case of *rational* operatives), in fact in all the other cases the level production is even zero. The reason is that this manager's behavior starts a decreasing sequence of incentives in order to punish operatives when net production is not satisfactory. This leads to a decreasing effort sequence played by all the operatives but the *increasingly partitioners*. In fact, since the latter class increases the used capacity over time, it does not trigger any punishment stage. When considering *team punisher* managers we can observe 2-period cycles; the reasons for these cycles are the adjusting of effort allocation when the supervisors punishes the team. Finally, it must be noted that rational operatives perform reasonably well with all of the considered managers.

When we focus on heterogeneous teams with an *individual punisher* manager (Table 4), the presence of at least one *increasingly partitioner* operative makes the net production to be zero even if the gross one is positive. This means that she gives away all her wealth to incentivate subordinates. The same can be observed when the low capacity agent is an *incentive averager*. This may be explained because, when considering these classes of agents, the gross production increases independently with respect to the incentives given to the low capacity agents, while the supervisor rewards the higher effort agent. Finally, with this class of supervisor no cycles are present.

INDIVIDUAL PUNISHER	Partitioner	Increasingly partitioner	Incentive averager	Team effort limiter	Rational Operative
Partitioner	(6.2347; **6.7871**)	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(6.0780; **6.6273**)	(5.7916; **6.8375**)
Increasingly partitioner	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(0.0000; **4.4916**)	(0.0000; **6.7318**)
Incentive averager	(6.2347; **6.7871**)	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(6.0780; **6.6273**)	(5.7916;**6.8375**)
Team effort limiter	(5.8918; **6.8385**)	(0.0000; **6.7318**)	(0.0000; **6.7318**)	(0.0000; **0.0000**)	(5.7916;**6.8375**)
Rational Operative	(6.0536, **6.6874**)	(0.0000; **6.6873**)	(0.0000; **6.6873**)	(0.0000; **2.120**)	(6.0537; **6.6874**)

Table 4 Net (normal) and gross (bold) production level in heterogeneous teams with *individual punisher* manager. *rows* – hi capacity operatives; *columns* – low capacity operatives.

TEAM PUNISHER	Partitioner	Increasingly partitioner	Incentive averager	Team effort limiter	Rational Operative
Partitioner	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	{(6.4912; **6.7597**), (6.4431; **6.8042**)}
Increasingly partitioner	{(6.0817; **6.8308**), (6.1659; **6.8166**)}	{(5.9890; **6.8368**), (6.0817; **6.8307**)}	{(6.0816; **6.8307**), (6.1658; **6.8164**)}	{(5.5426; **6.3813**), (5.5678; **6.3064**)}	{(6.1801; **6.8310**), (6.2783; **6.8315**)}
Incentive averager	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	{(5.6725; **5.9850**), (6.4912; **6.7597**)}
Team effort limiter	(0.0000; **0.0000**)	{(5.8917; **6.8385**), (5.9891; **6.8369**)}	(0.0000; **0.0000**)	(0.0000; **0.0000**)	{(6.0852; **6.8344**), (6.1836; **6.8346**)}
Rational Operative	{(6.2537; **6.6874**), (6.3537; **6.6874**)}	{(6.2537; **6.6874**), (6.3537; **6.6874**)}	{(6.2536; **6.6874**), (6.3536; **6.6874**)}	{(1.3213; **1.7561**), ~ (4.7364 ; **5.1308**)}	{(6.2537; **6.6874**), (6.3537; **6.6874**)}

Table 5 Net (normal) and gross (bold) production level in heterogeneous teams with *team punisher* manager: *rows* – hi capacity operatives; *columns* – low capacity operatives.

If the manager is a *team punisher* (Table 5), the only way to have a positive production when the high capacity operative is either a *partitioner* or an *incentive averager*, is with a *rational* low capacity agent. This situation is always guaranteed when at least one of the operatives is *rational*. With both these managers it is quite evident how capacities and operatives' behaviors are important in terms of team production. Consider, for instance, the matching of an *increasingly partitioner* operative to a *partitioner*. In fact, the high capacity *partitioner* operative leads the performance to zero levels of production, while it is satisfactory with the opposite matching. Also if the team is composed by an *increasingly partitioner* and an *incentive averager* a difference in terms of performance may be observed when matching are reversed. It is interesting to observe that in all cases, when the net production is null the gross production is null as well. These poor performances are not, as in the previous case, the result of the consuming the production in incentives; vice versa in these cases the incentives result in an effort allocation where subordinates do not use their capacity with the supervisor. Finally, it must be noted that, as in the homogeneous team, with this supervisor 2-period cycles appear, this is due again to the mutual adjusting of incentives and effort. Furthermore in one case, with the high capacity subordinate being *rational* and the low capacity being a *team effort limiter*, we can observe a cycle of period 446. The reasons for this long cycle can be found considering the fact that both the two subordinates affect each other their behavior and the manager policy is much more flexible since it does not end up spending all its capacity in incentives.

Table 6 reports the simulation results of teams with a *rational* manager. It is strikingly visible that, in order to have non null net and gross production, at least one *rational* operative is needed. The performance is better when the *rational* agent has high capacity (almost always a net level production of about 6.7018) than low (the net level production is never greater than 2.9309 when the team is heterogeneous). In all the other cases the gross production is null since all agents end up exerting no effort with the supervisor. This is the result of the null incentive given by the rational manager to the effort exerted with the supervisor. The bounded rationality agents cannot anticipate that both efforts are necessary to have a positive production.

Finally, when comparing the performance of the same teams under different manager we can observe that, while some combinations of subordinates achieve null net production with all of the manager considered, for some other combinations the net production is positive

RATIONAL MANAGER	Partitioner	Increasingly partitioner	Incentive averager	Team effort limiter	Rational Operative
Partitioner	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(2.9309; **2.9907**)
Increasingly partitioner	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(2.9309; **2.9907**)
Incentive averager	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(2.9308; **2.9906**)
Team effort limiter	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(0.0000; **0.0000**)	(1.2765; **1.3026**)
Rational Operative	(6.7018; **6.8385**)	(6.7018; **6.8385**)	(6.7018; **6.8385**)	(6.3826; **6.5129**)	(6.7018; **6.8385**)

Table 6 Net (normal) and gross (bold) production level in heterogeneous teams with *rational* manager: *rows* – hi capacity operatives; *columns* – low capacity operatives.

High capacity	**Low capacity**
Partitioner	Increasingly partitioner
Partitioner	Incentive averager
Incentive averager	Increasingly partitioner
Incentive averager	Incentive averager
Team effort limiter	Incentive averager
Team effort limiter	Team effort limiter

Table 7 Operatives combinations with null net production under all the implemented supervisors.

High capacity	**Low capacity**
Rational Operative	Partitioner
Incentive averager	Rational Operative
Incentive averager	Rational Operative
Team effort limiter	Rational Operative
Rational Operative	Rational Operative

Table 8 Operatives combinations with positive net production under all the implemented supervisors.

independently of the manager. They are listed in Table 7 and 8. It is interesting to observe two aspects. First, even the *rational* manager is ineffective when supervising these null production combinations; second, in the positive production combinations at least one operative is rational. Furthermore, a *rational* manager gets positive production only if matched with at least one *rational* operative.

Finally, some further comments about managers overly increasing the incentives are in order. First, it must be noted that both classes of non rational managers decrease incentives when production drops; nevertheless, under some circumstances one of them (i.e., *individual punisher*) ends up consuming all the production in individual incentive. Second, while we are aware that this behavior is unrealistic and partially in contrast to some of the empirical evidence we observed in our subjects during the experiment, we did not refine this behavior because its consequences are not so evident per se. Furthermore, we can think of the description of her behavior as a statement or a motto the manager adopts. In this case imposing a bound to incentives when they end up to be too costly would sound a sort of renegation. Third, it is worth to observe that this behavior is counter productive only with some classes of operatives which, in some sense, exploit it.

5. Conclusion and further research

The model we provide allows to study the optimality of the incentive schemes and the optimal allocation of individual capacity in a supervised team.

Modeling some *grounded* artificial agents, we could find that the different combinations of agents' behavior in the same team may lead to a variety of outcomes in terms of production and incentive schemes. This result is particularly interesting taking into account that some of the outcomes of the artificial teams are close to the actual team performances we observed during the experiments.

Another interesting point concerns rationality; in fact, from our simulations it seems that, while at least one rational operative under most managers is sufficient for positive net production, a rational supervisor is not. The implications of this point are relevant in terms of organizational development. Assume that in a null performance team with non rational supervisor, as the result of pressures to change the manager adopts a rational incentive scheme. Then this may not be sufficient to increase production, because if both operatives are non rational the hoped change does not take place. This may be interpreted as the result of organization resistance to change.

Several points may be developed in further research. First, one promising avenue seems to be extending the analysis of the experimental behaviors. Second, it may be interesting to use the simulation platform in order to extend the results provided by theoretical analysis in at least two directions, either multilevel organizations with the same supervised team as units, or a supervised N-agent team. This approach seems promising in terms of shedding light on more complex organization where agents with different roles interact.

The agent-based model easily allows the extension of the analysis to heterogeneous agents. In particular, the platform can be used to study the impact that different individuals have depending on their role in the organizations. Then, simulations that consider different kinds of incentive in order to improve non optimal situations can also be performed. Finally, it can be analyzed the impact of many other factors in the organization, such as reneging, (mis)perception of behavior by colleagues and social norms. This line of research allows the extension of the model to N-agent simulations where agents with different behaviors interact both on the same level and on different levels.

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