Delegation with strategic complements and substitutes*

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Abstract

We examine strategic delegation in a two-stage game. Principals first set the incentives for their respective agents, and subsequently the agents choose the strategies in the underlying game. Equilibrium predicts that principals set cooperative incentives if the game is characterized by strategic complements and competitive incentives if the game is characterized by strategic substitutes. We set up a lab experiment to test these predictions. Results show that, as predicted, principals choose competitive incentives for their agents with strategic substitutes, but contrary to prediction, principals do not set cooperative incentives in the game with strategic complements. It turns out that agents behave more cooperatively with strategic complements than equilibrium would predict. This may explain why principals do not set cooperative incentives in this case.

Keywords: strategic delegation, strategic complements and substitutes, laboratory experiment
JEL Codes: C71, C92, D02, D21, D23

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1 Introduction

Thomas Schelling was the first to point out that players may have incentives to use delegation as a strategic commitment device: "Just as it would be rational for a player to destroy his own rationality in certain game situations, ..., it may also be rational for a rational player to select irrational agents" (Schelling, 1960, p. 143). Other players' equilibrium strategies depend on a player's own best response function. A player can modify its best response function by delegating decisions to an agent and setting the agent's incentives. By appropriately doing so, a player can move other players' equilibrium strategies in a given direction.

This insight has been widely applied in theoretical models. A textbook example is quantity-setting oligopoly where owners have an incentive to make the managers' compensation depend, not just on profits, but also on revenues or sales (Vickers, 1985; Fershtman and Judd, 1987; Sklivas, 1987). Doing so induces the managers to compete more aggressively and set higher quantities than they would if compensation were based on profits only. Other applications of strategic delegation include R&D decisions (Kopel and Riegler, 2006), mergers (Ziss, 2001), location choice (Liang et al., 2011), corporate finance (Brander and Lewis, 1986), resource extraction (Ritz, 2008), organizational design (Vroom, 2006), political competition (Harstad, 2010), and climate policy (Habla and Winkler, 2018).[1] In all of these settings, principals have a strategic motive to provide agents with incentives that differ from the principals' own incentives.

An overarching insight emerging from this literature is that the direction in which the agents' incentives are distorted depends on the type of strategic interaction. If a game is characterized by strategic complements principals are predicted to endow their agents with more cooperative payoffs than the principals' own payoffs; in the case the game is characterized by strategic substitutes principals will give their agents more competitive payoffs.[2] Miller and Pazgal (2001) provide an illustrative example. In a quantity-setting duopoly with substitutable products (strategic substitutes) a firm-owner benefits if the other firm chooses a low quantity and this may be achieved by giving her manager aggressive incentives, inducing the manager to choose a higher quantity than the firm-owner would have incentives to do herself. Conversely, in a price-setting duopoly with substitutable products (strategic complements) the firm-owner benefits if the other firm chooses

[1] For a review of the literature on strategic delegation in industrial organization, see Kopel and Pezzino (2018); for applications in management, see Sengul et al. (2012).

[2] A closely related insight emerges from the literature on the evolution of preferences. Bester and Güth (1998) and Possajennikov (2000) show that altruistic (spiteful) preferences are evolutionary stable when the material payoff functions are characterized by strategic complements (substitutes).

a higher price and this can be achieved by giving her agent cooperative incentives, stimulating the agent to choose a higher price than the firm-owner would choose herself. Although the logic behind the predictions is compelling, it is certainly not trivial.

We explore these predictions by means of a laboratory experiment. We implement a four-player game between two principal-agent pairs. Each agent makes the decisions on behalf of his principal. Each principal determines the payoff function of her own agent by assigning a certain weight to the other principal's payoffs, as in Miller and Pazgal (2001). A positive weight implies cooperative (altruistic) incentives; a negative weight implies competitive (spiteful) incentives. We implement two treatments: one with strategic complements and one with strategic substitutes. This allows us to examine whether the principals distort the agents' payoffs away from the principals' own payoffs and whether, as predicted, the direction depends on the nature of the strategic interaction.

Empirical studies on strategic delegation are scarce. Aggarwal and Samwick (1999) find that managers' bonuses are more positively correlated with rivals' profits when the degree of competition is higher. This is consistent with the use of strategic delegation to soften competition in a price-setting oligopoly when products are closer substitutes. Kedia (2006) classifies industries into complement or substitute industries depending on whether firms' marginal profits are decreasing or increasing in rival firms' sales levels. She finds that executive compensation is less closely related to profits and more to sales in substitute than in complement industries. This is consistent with the prediction that executive delegation leads to more aggressive competition with substitutes than with complements. Bloomfield (2018) uses data on the executive compensation contracts and finds that the prevalence of revenue-based incentives increases with industry concentration in Cournot industries. This effect arises only after the introduction of an executive compensation disclosure mandate and does not occur in Bertrand industries, which is consistent with the gist of the theoretical literature about strategic delegation. However, studies based on field data often face issues caused by the difficulty to measure the shape of the compensation contracts and the type of strategic interaction. There is no widely accepted method. Kedia (2006) measures strategic interaction using data on the change in profits and sales in relation to rival firms' profits and sales. Bloomfield (2018) uses four different measures. Moreover, empirical measures of strategic interaction and compensation are prone to potential endogeneity issues: executive compensation may be affected by the type of market interaction, but in turn may also shape this interaction.

An important advantage of experiments is that the nature of the interaction can be varied exogenously. Another advantage is that incentive contracts can be observed without noise. Huck et al. (2004) were the first to study strategic delegation in the laboratory. They implement quantity-setting duopoly experiments and find that owner-principals typically align the payoffs of the manager-agents with the principals' own payoffs; that is, principals do not choose more competitive (aggressive) incentives for their agents, as would be predicted by the models of Vickers (1985), Fershtman and Judd (1987), and Sklivas (1987). On the other hand, evidence supporting these theoretical predictions is reported in the experimental study by Barreda-Tarrazona et al. (2016) who find that principals induce more aggressive behavior by inversely relating their agents' compensation to competitors' profits. A major difference between our study and Huck et al. (2004) and Barreda-Tarrazona et al. (2016) is that we do not only implement a setting with strategic substitutes but also one with strategic complements.[3]

Our results indicate that in a majority of the cases principals distort their agents' incentives, both with strategic complements and with strategic substitutes. As predicted, distortions in the direction of competitiveness are more frequent with strategic substitutes (73.6%) than with strategic complements (59.4%). Contrary to the prediction, however, with strategic complements principals also set competitive incentives more frequently than cooperative incentives. Upon closer inspection we find that this may be explained by the behavior of the agents which is broadly in line with subgame-perfect equilibrium predictions in the Substitutes treatment but more cooperative than predicted in the Complements treatment. Given that agents behave cooperatively with complements the principals have no incentive to induce the agents to behave cooperatively. Principals even have an incentive to set slightly competitive incentives since the strategic effect of the incentives is weaker than predicted. Taken together, our results support the relevance of strategic delegation models, but also indicate that this support is more compelling for strategic substitutes than for strategic complements.

The rest of the paper is organized as follows. In Section 2 we introduce the theoretical model on which our experiment is based. Section 3 describes the experimental design. Section 4 presents the results. Section 5 discuss these results. Section 6 concludes the paper.

[3]There also exists a small strand of experimental literature on delegation in allocation games. Fershtman and Gneezy (2001) study strategic delegation in an ultimatum game and find that both the proposer and the responder can benefit from using a delegate. Studies on delegated dictator games (Hamman et al., 2010; Coffman, 2011; Bartling and Fischbacher, 2011; Choy et al., 2016; Gawn and Innes, 2019) show that principals may use a delegate to make unfair decisions on their behalf without feeling morally responsible for such unfairness. Responsibility for making unfair offers can be effectively shifted to a delegate, allowing punishment to be avoided.

2 The Model

The model on which our experiments is based follows the basic set-up of Miller and Pazgal (2002) and Eaton (2004). We consider a two-stage game with four players: two principals (principal i and j) and two agents (agent i and j).[4] The principal i's payoff function takes the following form:

$$\pi_i = ax_i - bx_i^2 + cx_ix_j \tag{1}$$

with $x_i, x_j \geq 0$, $i, j = 1, 2$, and $i \neq j$. We impose the following restrictions: $\frac{\partial \pi_i}{\partial x_i} = a - 2bx_i + cx_j > 0$ for all x_i, x_j, $\frac{\partial^2 \pi_i}{\partial x_i^2} = -2b < 0$, $a > 0$, and $b > |c|$. The strategic environment of the game is represented by the sign of c. In case $c > 0$, we have $\frac{\partial^2 \pi_i}{\partial x_i \partial x_j} > 0$, indicating that x_i and x_j are strategic complements. In case $c < 0$, we have $\frac{\partial^2 \pi_i}{\partial x_i \partial x_j} < 0$, indicating that x_i and x_j are strategic substitutes.

Principals delegate the choice of x_i to their respective agents. Each agent's payoff is a weighted sum of the payoff of his own principal and the payoff of the other principal:

$$G_i = \lambda_i \pi_i + (1 - \lambda_i)\pi_j \tag{2}$$

The specification of the agent's payoff function follows Miller and Pazgal (2002). This captures the idea that the agent takes into consideration of the payoff of both the own principal and the rival principal.[5] The weight λ_i is set by principal i. It is essentially a decision to select an agent with specific (social) preferences over the payoffs of the two principals. If a principal sets $\lambda_i = 1$, she selects an agent whose payoff is perfectly aligned with her own payoff. With $\lambda_i > 1$, a principal selects an agent who places a high weight on her own payoff and a negative weight on the other principal's payoff. We call such preferences "competitive". If the principal sets $\lambda_i < 1$, she selects an agent who places a positive weight on both her own payoffs and the other principal's payoff. We call such preferences "cooperative". As in Huck et al. (2004), we assume $\lambda \in [0, 2]$. Following previous theoretical literature on strategic delegation (Vickers, 1985; Fershtman and Judd, 1987; Sklivas, 1987; Miller and Pazgal, 2002), the agent's payoff is assumed not to be paid out of the principal's payoff, in order to focus on principal's incentive-setting motivations without possible cost considerations.

The game consists of two stages. In the first stage, the principals, simultaneously and independently, set λ_i and λ_j. In the second stage, being informed about

[4] For ease of distinction, we will use feminine pronouns for the principals, and masculine pronouns for the agents.

[5] Although we don't expect to observe managerial compensation contracts that literally correspond to (2), there is some evidence that firms in imperfectly competitive markets get close to them. See Aggarwal and Samwick (1999).

λ_i and λ_j, the agents set x_i and x_j, simultaneously and independently. We use backward induction to solve for the subgame perfect equilibrium. In the second stage, given λ_i and λ_j, each agent i chooses x_i to maximize his payoff G_i. It is straightforward to show that this yields the following equilibrium:

$$x_i^*(\lambda_i, \lambda_j) = \frac{ac\lambda_j + 2ab\lambda_i\lambda_j}{4b^2\lambda_i\lambda_j - c^2}, \tag{3}$$

with $i, j = 1, 2$, $i \neq j$, and $4b^2\lambda_i\lambda_j - c^2 \neq 0$.

Substituting the equilibrium values for x_i and x_j, into the principals' payoff functions, yields the following unique subgame perfect equilibrium:[6]

$$\lambda_i^* = \lambda_j^* = 1 - \frac{c}{2b}. \tag{4}$$

Detailed derivations are provided in Appendix A.1.

In case $c > 0$ (x_i and x_j are strategic complements), we have $\lambda^* < 1$; principals set cooperative incentives for their agents, assigning positive weight to the payoff of the other principal. In case $c < 0$ (x_i and x_j are strategic substitutes), we find $\lambda^* > 1$; principals set competitive incentives for their agents, assigning negative weight to the payoff of the other principal. It is these basic predictions that we aim to test in our experiment

The parameters we used for the experiment are: $a_{comp} = 8, b_{comp} = 1, c_{comp} = 0.8$ for the Complements treatment, and $a_{subs} = 40, b_{subs} = \frac{25}{9}, c_{subs} = -\frac{20}{9}$ for the Substitutes treatment.[7] These parameters satisfy a number of conditions which we deem desirable for a balanced comparison between the two treatments:

1. The equilibrium weights in the two treatments are equidistant from the neutral (no-delegation) case: $|\lambda^*_{comp} - 1| = |\lambda^*_{subs} - 1|$. Specifically, with our parameters we have $\lambda^*_{comp} = 0.6$ and $\lambda^*_{subs} = 1.4$.
2. The equilibrium payoffs for the principals are the same in the two treatments. With our parameters we have $\pi^*_{comp} = 67.2 = \pi^*_{subs}$.
3. The equilibrium payoffs for the agents are the same in the two treatments. With our parameters we have $G^*_{comp} = G^*_{subs} = 67.2$.[8]

[6] $4b^2\lambda_i\lambda_j - c^2 \neq 0$, $b \neq 0$, $2b \neq c$ need to be satisfied for the existence of a unique pure strategy SPE.

[7] With these parameters, the restrictions specified in Footnote 5 are satisfied for $\lambda \in [0, 1]$ in the Complements treatment and $\lambda \in [1, 2]$ in the Substitutes treatment.

[8] Our set of parameters is not unique in satisfying these four conditions. To reduce arbitrariness we used the following procedure by Pazgal and Miller (2001) to relate the two treatments. Given a linear demand function (we use $q_i = 8 - p_i + 0.8p_j$) a game with strategic complements arises by taking prices as strategic variables (i.e., $x_i = p_i$, i = 1,2) and an equivalent game with strategic substitutes arises by taking quantities as strategic variables (i.e., $x_i = q_i$, i = 1,2).

3 Experimental design

The experiment was conducted in February and March 2017 at CentERlab, Tilburg University. We held five sessions with strategic complements (the Complements treatment) and five sessions with strategic substitutes (the Substitutes treatment). The number of participants in each session ranged between 12 to 24. The total number of subjects was 180. Each session lasted around 150 min. The average payment for each subject was 18.62 Euro in the Complements treatment and 19.75 Euro in the Substitutes treatment, including a 3-Euro show-up fee. The experiment was programmed using zTree (Fischbacher, 2007).

At the beginning of each session, instructions (see Appendix A.3) were given to the subjects. The game was presented in a neutral frame. The λ choice of the principal was labeled as a "weight", and the x choice of the agent was called an "input"; the payoff to the principal was labeled as "earnings" and the payoff to the agent was labeled as "compensation". Subjects were randomly assigned to the roles of principals and agents after reading the instructions. The roles were fixed for the entire session.

Participants were informed about the payoffs in three different ways. They were informed about the payoff function, they were provided with a payoff matrix, and they were given access to a payoff calculator in which they could input possible values for the weights (λ_i, λ_j) and the inputs (x_i, x_j) and see the corresponding payoffs ("earnings" and "compensation"). The payoff matrix exhibited six possible values for the inputs. These six values corresponded to six benchmark outcomes of the two treatments.[9]

The matching protocol was aimed at retaining the one-shot character of the game, while at the same time giving the subjects the possibility to learn. At the beginning of a session, each principal was randomly matched with an agent. A principal-agent pair remained together for three rounds. At the beginning of the three rounds, a principal chose λ from the interval $[0, 2]$. This λ was kept fixed for three rounds. This allowed the agent to gain some experience with a specific value of λ. After three rounds, a principal was re-matched with another agent, but such that a principal was not matched with the same agent more than once.[10]

In each round, a principal-agent pair was randomly matched with another

[9]Let $x_i(\lambda_i, \lambda_j)$ denote the equilibrium value of x_i in the subgame with (λ_i, λ_j). The six benchmarks can then be defined as (1) $x_i(\lambda^*, \lambda^*)$, (2) $x_i(1, 1)$, (3) $x_i(\lambda^*, 1)$, (4) $x_i(1, \lambda^*)$, (5) $x_i(2 - \lambda^*, \lambda^*)$, and (6) $x_i(\lambda^*, 2 - \lambda^*)$. The latter two benchmarks refer to cases in which one of the principals set a value of λ that fits the other treatment. The actual values used in the matrix were slightly adjusted to retain similar distance between each other and were rounded to one decimal place.

[10]One session in the Substitutes treatment had only 12 participants, and a principal was matched with two agents twice.

principal-agent pair (with replacement). All four players were informed of the λ-pair set by the two principals. In a round, an agent then chose a value for x_i from $[0, 15]$ in the Complements treatment, and from $[0, 10]$ in the Substitutes treatment. Specifically, for each treatment we wanted the equilibrium values of x that correspond to the no-delegation benchmark ($\lambda = 1$) to be roughly in the middle of the strategy space.

At the end of each round, all four decision variables (weights and inputs) and each player's own corresponding payoff (earning or compensation) were revealed to the each player. In addition, subjects had access to a history table with the same information from previous rounds. A session consisted of 24 rounds, where the first three rounds were trial rounds which did not count for the final earnings. After all 24 rounds were completed, subjects were asked to fill in a survey which collected demographic information: age, gender, country of residence, education level, number of courses in economics, and whether they have some knowledge of game theory.

At the end of the session one round was randomly selected for payment. The conversion rate of "points" into money earnings was 3 : 1 in the Complements treatment, and 4 : 1 in the Substitutes treatment. This was to done to make average earnings (at the theoretical predictions) similar across the two treatments.[11] Subjects also received a show-up fee of 3 Euro.

4 Results

4.1 Principal's choice of λ

Our main hypothesis is that principals set cooperate incentives with strategic complements and competitive incentives with strategic substitutes. Table 1 presents basic statistics about the weights set by the principals. Table 2 presents p-values of sign tests comparing the weights set by the principals to the SPE benchmark and the no-delegation equivalent benchmark.[12] The results in the Complements treatment do not support the theoretical prediction. The principals on average set a λ of 1.186, much higher than the predicted value of 0.6. A sign test rejects the hypothesis that the value of λ is equally likely to be above than below 1 in favor of the alternative hypothesis that principals are more likely to choose competitive incentives ($\lambda > 1$). In fact, in each of the five sessions, the

[11] Even though payoffs are the same in the subgame perfect equilibria of the two treatments, they are different in the no-delegation benchmark ($\lambda = 1$) which, based on the results of Huck et al. (2004), we anticipated to be reached often as well.

[12] For all tests we treat each session as one observation, implying that we have 5 independent observations in each treatment.

average value of λ was above 1.

Table 1: Principals' choice of λ

Treatment	SPE predicted λ^*	Average λ
Complements	0.6	1.186 (0.078)
Substitutes	1.4	1.382 (0.147)

Notes: The unit of observation is one independent session. Standard deviations are shown in brackets.

In the Substitutes treatment (second row), we observe an average value for λ of 1.382, which is close to the theoretically predicted value of 1.4. A sign test cannot reject the hypothesis that the median of λ is 1.4. At the same time a sign test rejects the hypothesis that the median value of λ is 1. These findings support the hypothesis that principals set competitive incentives with strategic substitutes.

Table 2: p-values from tests of λ

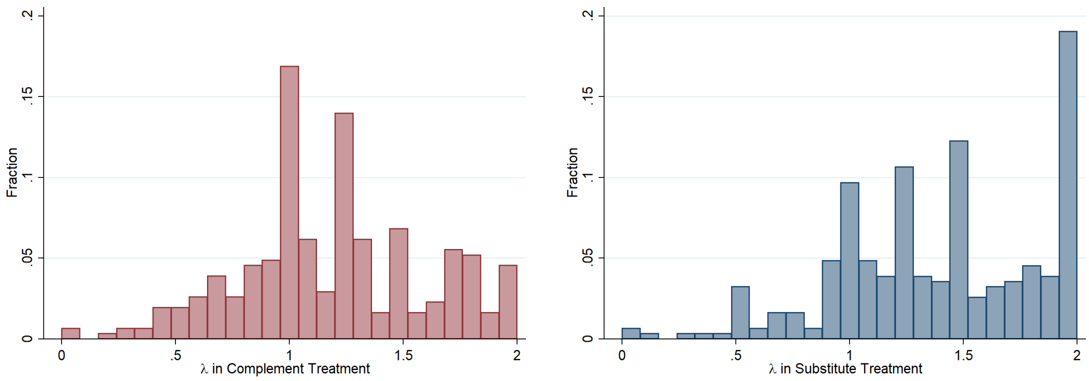
Treatment	Sign test $H_1 : \lambda \neq \lambda^*$	Sign test $H_1 : \lambda > 1$	Mann-Whitney u test $H_1 : \lambda_{\text{Comp}} < \lambda_{\text{Subs}}$
Complements	0.063*	0.031**	0.024**
Substitutes	1.000	0.031**	

Notes: The unit of observation is one independent session. Number of independent observations is 5 per treatment. Stars represent the level of significance, with *** p<0.01, ** p<0.05, and * p<0.1.

Comparing the two treatments, we find that principals on average set less competitive incentives in the Complements treatment ($\lambda = 1.186$) than in the Substitutes treatment ($\lambda = 1.382$). A one-sided Mann-Whitney u test reveals that this difference is significant. The direction of this difference is in line with the main theoretical prediction.

Figure 1 displays the distribution of the values of λ for each of the two treatments. In the Complements treatment, the modal value of λ is 1, the "no-delegation"-equivalent. Other frequently selected values are 1.25 and 1.5. In 59.6% of the cases a value $\lambda > 1$ is chosen. The overall distribution is also skewed to the right, but less so than in the Substitutes treatment. In the Substitutes treatment, the distribution of λ is skewed to the right, where most of the λ choices are higher than 1. The modal value of λ is 2, the competitive extreme, where the principal induces the agent to care only about the difference in payoffs of the two principals. Other frequently chosen values are 1, 1.25 and 1.5. Overall, a value $\lambda > 1$ is chosen in 73.6% of the cases.

Figure 2 presents the development of λ over time. It turns out that the average in the Substitutes treatment is always above the average in the Complements treatment. Moreover, the average values are rather stable in both treatments.



(a) Complements (b) Substitutes

Figure 1: Histogram of λ in both treatments
Notes: The histograms are based in all decisions by all principals over the 21 rounds. The horizontal axis uses a bin width of 0.08.

Most importantly, there is no evidence that the value of λ in the Complements treatment displays a downward trend and tends toward the equilibrium value over time.[13]

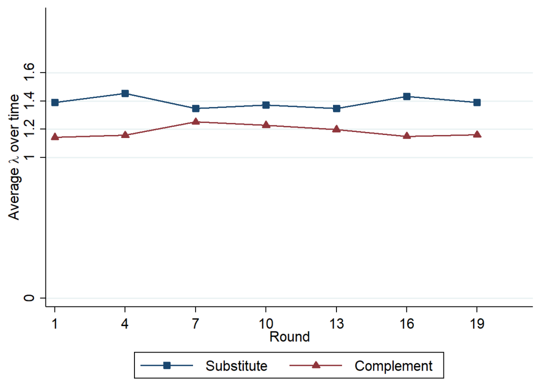


Figure 2: Average λ over time

4.2 Agents' choice of x

Descriptive statistics of the agents' choice of x are presented in Table 3. To evaluate the agents' choice of x, we use two benchmark values: the predicted equilibrium value ($x_i(\lambda^*, \lambda^*)$) assuming that the principals choose the equilibrium values for λ, and the predicted equilibrium value of the inputs ($x_i(\lambda_i, \lambda_j)$) in the subgame corresponding to the values for λ_i and λ_j that the principals actually choose in the round (see equation 3). The latter benchmark varies from one round

[13]Similar patterns are discovered at the session level. See Appendix for details.

to the next. The third column in Table 3 is based on the average value across all rounds within each session.

Table 3: Agent's choice of x

Treatment	Prediction		Average x
	$x(\lambda^*, \lambda^*)$	Average $x(\lambda_i, \lambda_j)$	
Complements	12	6.573 (0.290)	7.329 (0.429)
Substitutes	5.6	5.410 (0.182)	5.566 (0.152)

Notes: The unit of observation is one independent session. Standard deviations are shown in brackets.

We observe that in the Complements treatment agents set a much lower average value x (7.329) than would be predicted by SPE (12). Much of this difference can be explained by the earlier observation that the principals on average set a more competitive (i.e., higher) λ than predicted by SPE. Taken this into account, when investigating agents' responses, the SPE predicted x is a less relevant benchmark than the NE predictions with the specific (λ_i, λ_j) pair each agent faces in each subgame. We observe that the average value of x (7.329) is actually higher than the average equilibrium value of the inputs (6.573) in the corresponding subgames $(x_i(\lambda_i, \lambda_j))$. In this sense, the behavior of the agents in the Complements treatment is more cooperative than the incentives by the principals would induce them to be.[14]

For the Substitutes treatment, the results are quite different. The average value of x (5.566) is very close to the value (5.6) predicted by SPE. Statistically, the two values are indistinguishable ($p = 1$ with a sign test). As was seen in the previous subsection, the average values for λ set by the principals are also close to the SPE prediction. So, unlike the Complements treatment, the incentives set by the principals provide no reason for the inputs chosen by the agents to deviate from SPE. Still, taking the actual values of the λ's into account, the average equilibrium inputs (5.410) are somewhat lower than the average observed inputs (5.566), and the difference is significant with a sign test. This implies that agents behave more competitively than the incentives give them reason to. However, the difference is small in magnitude, and it is fair to say that the behavior of the agents accords quite well with SPE.[15]

[14]Recall that due to the difference in the strategic nature of the interaction, the value of x has a different interpretation in the two treatments. In the Complements treatment a higher x indicates more cooperative behavior, whereas in the Substitutes treatment a higher x indicates more competitive behavior.

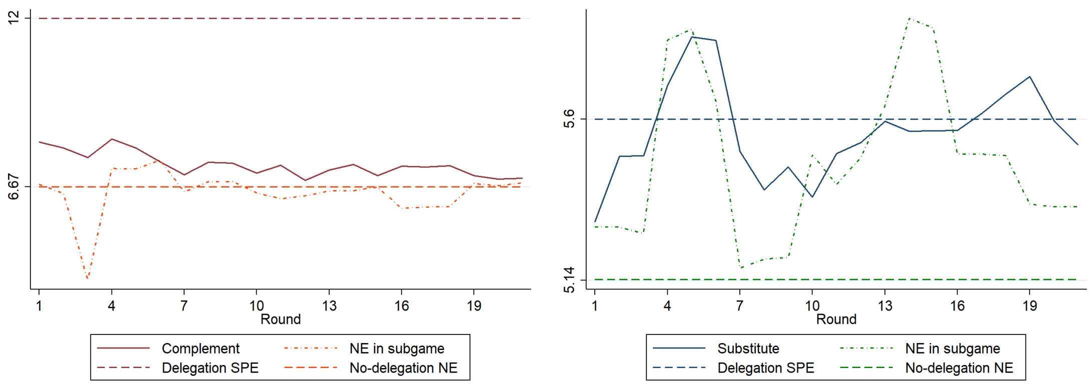
[15]We also looked at the observations when both principals set $\lambda = 1$, which can be regarded as equivalent to the case without delegation, as the payoff function of the agents are the same as the payoff function of their respective principals. There were altogether 40 (28) observations in 3 (1) sessions of the Complements (Substitutes) treatment. In the Complements treatment, the average value of x in these no-delegation equivalent cases (7.778) is also more cooperative

Table 4: p-values from tests of x

Treatment	$H_1 : x \neq x(\lambda^*, \lambda^*)$		$H_1 : x \neq x(\lambda_i, \lambda_j)$	
	Sign test	Signed rank test	Sign test	Signed rank test
Complements	0.063*	0.043**	0.063*	0.043**
Substitutes	1.000	0.893	0.063*	0.043**

Notes: The unit of observation is one independent session. Number of independent observations is 5 per treatment. Stars represent the level of significance, with *** p<0.01, ** p<0.05, and * p<0.1.

The dynamics of the average x are depicted in Figure 3. The two static benchmarks in the figure are the inputs that correspond to the delegation subgame perfect equilibrium ($x(\lambda^*, \lambda^*)$ and the no-delegation equilibrium ($x(\lambda = 1, \lambda = 1)$), respectively. The dynamic benchmark ($x(\lambda_i, \lambda_j)$) is based on the equilibrium inputs corresponding to the actual weights chosen by the principals.



(a) Complements (b) Substitutes

Figure 3: Agents' x decisions over time

In the Complements treatment, the average x starts at a relatively high level and approaches the no-delegation equilibrium towards the last round. In the Substitutes treatment, the average x starts at a relatively low level and approaches the SPE towards the last round. This implies that in both treatments the values of x start at a relatively cooperative level, and that cooperation decreases over time (i.e., x increases over time in Substitutes and decreases over time in Complements).

We also see that in the Substitutes treatment the average input traces the dynamic benchmark (equilibrium in the subgame) quite well. The two move up and down more or less in parallel, indicating that the agents are responsive to

than the no-delegation NE (6.67). In the Substitutes treatment, the average value of x in the no-delegation equivalent cases (4.786) is also slightly more cooperative than the no-delegation NE (5.14). Due to the small number of observations, we are unable to statistically test the differences.

the incentives set by the principals. In the Complements treatment, the inputs display a downward trend over time, but are above the theoretical benchmark in almost all rounds. As we already noted, agents' choices in this treatment are more cooperative than their incentives would predict. The last three rounds exhibit a narrowing of the gap between agents' choice of inputs and the dynamic benchmark. However, there is no clear trend indicating whether sufficiently long play would result in the convergence to the dynamic benchmark.

To further examine how agents respond to the incentives set by the principals, we estimate the following relationship between agents' input choices in a round (x_{it}) and the weights set by the own principal (λ_{it}) and the other principal (λ_{jt}):

$$x_{it} = \alpha_0 + \alpha_1 \lambda_{it} + \alpha_2 \lambda_{jt} + \epsilon_{it} \tag{5}$$

Table 5: Agents' inputs in response to principals' weights

Variables	Complements	Substitutes
λ_{it}	-2.543***	1.404***
	(0.195)	(0.196)
λ_{jt}	-0.479**	-0.107***
	(0.157)	(0.00843)
Constant	10.95***	3.750***
	(0.559)	(0.261)
Observations	924	930
Number of subjects	46	44

Notes: A Prais-Winsten panel regression model with AR(1) disturbance is estimated. Standard errors are clustered at Session level and shown in parentheses. Stars represent the level of significance, with *** p<0.01, ** p<0.05, and * p<0.1.

This equation can be interpreted as an empirical first-order Taylor approximation of the non-linear equilibrium equation (3). The equation is estimated using a random effect panel regression with AR(1).[16] The estimated coefficients are presented in Table 5. We observe that the agents' input choices are significantly affected by the principals' weights. Moreover, for each treatment the signs of the effects of both the own and the other principals' weight are in line with the equi-

[16] A Hausman test ($\chi^2 = 0.01$ for Complements and $\chi^2 = 5.32$ for Substitutes) cannot reject the null hypothesis that the difference in coefficients is not systematic. The hypothesis of no serial correlation (F=5.17 for the Complements treatment and F=35.71 for the Substitutes treatment) is rejected for both treatments. Since subjects are randomly re-matched within the same session, we cannot rule out the fact that standard errors may be correlated within session. Therefore, a Prais and Winstein panel regression with AR(1) disturbance and session-level clustered standard errors is estimated.

librium predictions that follow from equation (3).[17] This indicates that the agents respond to the incentives set by the principals in the direction predicted by the equilibria of the corresponding subgames. We calculate the theoretically predicted coefficients α_1 and α_2 of Equation 5 around each observed (λ_i, λ_j) pairs. In the Complements treatment, the average predicted α_1 is -19.778 and the average predicted α_2 is -10.322, while the estimated α_1 and α_2 in the regression as reported in Table 5 are -2.543 and -0.479 respectively. In the Substitutes treatment, the average predicted α_1 and α_2 are 7.028 and -1.781 respectively, while the estimated coefficients are 1.404 and -0.107. The average theoretically predicted coefficients are higher than the estimated ones in absolute values. Even though the agents' responses to the incentives in the subgames are in the predicted directions, the agents largely underreact to the incentives set by their own principal and the other principal.

4.3 Payoffs

In the game with strategic complements, the model predicts that both principals set cooperative incentives, resulting in both principals and agents being better off than in the case without delegation. With our parameterization, the delegation SPE yields a payoff of 67.2 for both principals and agents, while the Nash equilibrium payoff is 44.4 without delegation for both roles. In the game with strategic substitutes, the model predicts that principals set competitive incentives to induce their agents to act more competitively, resulting in both principals and agents being worse off than without delegation. With our parameterization, the payoff for both principals and agents is 67.2 in the SPE, which is lower than the equilibrium payoff of 73.5 without delegation (or, equivalently, with $\lambda_i = \lambda_j = 1$) for both roles.

Table 6: Average payoffs for principals and agents by treatment

Treatment	Delegation SPE	No-delegation NE	Principals' payoff	Agents' payoff
Complements	67.2	44.4	44.592	47.828
			(2.110)	(2.755)
Substitutes	67.2	73.5	64.540	68.191
			(0.848)	(2.565)

Notes: The unit of observation is one independent session. Standard deviations are shown in brackets. The payoffs of the principals and the agents are the same in the delegation SPE, as well as in the no-delegation NE.

[17]Specifically, we have $\frac{\partial x_i}{\partial \lambda_i} = -\frac{2abc\lambda_j(2b\lambda_j+c)}{(4b^2\lambda_i\lambda_j-c^2)^2}$ and $\frac{\partial x_i}{\partial \lambda_j} = -\frac{ac^2(2b\lambda_i+c)}{(4b^2\lambda_i\lambda_j-c^2)^2}$. With our parameterization, this gives $\frac{\partial x_i}{\partial \lambda_i} < 0$, $\frac{\partial x_i}{\partial \lambda_j} < 0$ for Complements, and $\frac{\partial x_i}{\partial \lambda_i} > 0$, $\frac{\partial x_i}{\partial \lambda_j} < 0$ for Substitutes.

The average payoffs of the principals and agents in each treatment are shown in Table 6. In the Complements treatment, both principals and agents are worse off than the SPE prediction. Their realized payoffs are much closer to the no-delegation prediction, which is consistent with the fact that principals set more competitive incentives than those in the SPE. As was seen in the previous section, agents' actions in the Complements treatment are more cooperative than predicted. As a result, even though the principals' average incentives are slightly more competitive than the no-delegation equivalent level, both principals and agents are slightly better off than in the no-delegation equilibrium. In the Substitutes treatment, the average payoffs for both the principals and the agents are similar to the SPE prediction. This result, of course, is consistent, with the fact that both the principals' and the agents' decisions are close to the SPE prediction.

5 Discussion

The behaviors of both the principals and the agents in the Substitutes treatment in our experiment accord well with the theoretical predictions. Principals set competitive incentives, which are responded to with competitive actions by the agents, although agents are less reactive to incentives than theoretically predicted. The results of the Complements treatment, however, differ substantially from the theoretical predictions. Principals set competitive incentives whereas they are predicted to set cooperative incentives, and agents act more cooperatively than predicted given these incentives. How can we explain this?

First, we should note that the finding that agents in our Complements treatment act more cooperatively than predicted is in line with the results in various experimental studies of oligopoly without delegation (Engel, 2007; Suetens and Potters, 2007; Potters and Suetens, 2009; Barreda-Tarrazona et al., 2016). They report significantly more cooperation when actions are strategic complements than in the case of strategic substitutes. In price-setting oligopoly experiments it is often found that outcomes are more collusive than predicted by equilibrium, whereas in quantity-setting experiments they are typically more competitive.

It is possible that the principals in the Complements treatment set more competitive incentives than predicted *because* the agents behave more cooperatively than predicted. The delegation SPE predicts that principals set cooperative incentives for their agents in order to induce them to behave more cooperatively than they are predicted to do without such incentives. But if the agents already behave cooperatively without explicitly being induced to do so, and if the principals anticipate or learn this, then the principals may have an incentive to set less cooperative incentives in the first place.

To further explore this possibility we examine how the principals' incentives change if they anticipate that the agents will respond in accordance with equation (5). It is straightforward to show that the equilibrium weights would then become:

$$\tilde{\lambda}_i = \tilde{\lambda}_j = \tilde{\lambda} = \frac{a\alpha_1 + (c - 2b)\alpha_0\alpha_1 + c\alpha_0\alpha_2}{(\alpha_1 + \alpha_2)(2b\alpha_1 - c(\alpha_1 + \alpha_2))} \tag{6}$$

If we insert the values for the parameters (a, b, c) of our experiment and the estimated coefficient (α_0, α_1, α_2) from Table 5, the predicted equilibrium weights are $\tilde{\lambda} = 1.100$ in the Complements treatment, and $\tilde{\lambda} = 1.162$ in the Substitutes treatment.

The principals now have an incentive to set competitive incentives also in the Complements treatment. The reason is that agents act more cooperatively than equilibrium predicts. To compensate for this the principals may want to stimulate the agents to act more competitively. This may explain why the predicted value of $\tilde{\lambda} = 1.100$ is much closer to the average value of $\lambda = 1.186$ in the experiment than the SPE prediction of $\lambda^* = 0.6$. In the Substitutes treatment, the value $\tilde{\lambda} = 1.162$ is lower than the SPE prediction of $\lambda^* = 1.4$ and also lower than the average observed value of $\lambda = 1.382$. The reason is that, as we have seen in Section 4.2, the agents are more competitive than the equilibrium in the subgame predicts. This gives principals an incentive to set less competitive incentives than in the SPE. Still, the size of this adjustment is smaller than in the Complements treatment.

Our finding that principals in the Substitutes treatment set competitive incentives is different from the results in Huck et al. (2004), who find strong evidence for principals choosing neutral (non-distorted) incentives in an oligopoly setting with strategic substitutes.[18] The main reason for their result is the agents' behavior in asymmetric subgames where one principal sets competitive incentives and the other sets neutral incentives. In their experiment, the agents with "neutral" incentives find themselves in strategically weaker positions and punish the agents with competitive incentives. This destroys the strategic advantage of setting competitive incentives, making it dominated by setting neutral incentives. We also observe similar patterns in our Substitutes treatment. In our Substitutes treatment, agents with strategically weaker positions in asymmetric subgames punish their counterpart agents by acting more competitively than predicted. However, the agents do not punish enough to make it a clearly dominated strategy for principals to set competitive incentives. This may explain why we still observe principals setting competitive incentives in our Substitutes treatment.

[18] In Huck et al. (2004), principals only choose between two incentive schemes: a competitive incentive which is the delegation SPE prediction and a neutral incentive which is equivalent to not delegating.

6 Conclusion

In this paper we provide experimental evidence on strategic delegation. We find that principals tend to endow their agents with payoffs which differ from their own payoffs. In line with prediction, we find that on average the principals set competitive incentives for their agents in case the underlying game is characterized by strategic substitutes. Contrary to prediction, however, the principals also set competitive incentives for their agents in case the game is characterized by strategic complements, even though less so than with strategic substitutes.

Our paper underscores the relevance of the literature, inspired by Schelling (1960), suggesting that players may use delegation for strategic reasons. Principals distort their agents' payoffs. Moreover, the degree to which they do so, if not the direction, depends on the nature of strategic interaction. Theoretically, delegation is predicted to lead to more competitive outcomes in games with strategic substitutes and to more cooperative outcomes in games with strategic complements. The former prediction is borne out by our experimental results, whereas the latter is not. In this sense the results point toward an important asymmetry. The competition-enhancing effect of delegation under strategic substitutes seems to be more compelling behaviorally than the cooperation-enhancing effect under strategic complements. A possible explanation is that strategic complementarity by itself already embodies a cooperation-enhancing effect without delegation (Bester and Güth, 1998; Potters and Suetens, 2009). Given that agents' behavior is more cooperative than predicted, principals' incentive to further encourage cooperation are weakened if not reversed.

Interestingly, our finding that principals set more competitive incentives for their agents with substitutes than with complements is broadly consistent with the empirical literature that relates executive compensation to strategic interaction (Kedia, 2006; Bloomfield, 2018). In fact, this literature reveals little evidence that executives are endowed with cooperative incentives in the case of complement industries. For instance, Bloomfield (2018) indicates that he does not have reliable data to test the prediction that executive compensation in Bertrand industries encourages collusive behavior. So, while the empirical evidence for Cournot industries is in line with strategic delegation, for Bertrand industries the evidence is less convincing.

Our experiment invites several paths for further inquiry. One is the question whether the distortion of incentives relies on the observability of the incentives that the principals set for the agents. The essence of strategic delegation is to change one's own best response function and to induce the other player to respond to this change in the desired direction. It would be interesting to examine to what extent the observability of the agents' contracts is key here. Another important question relates to the cost of delegation. In our current setup the agent's incentives bear no direct cost to the principal. It would be interesting to examine whether different incentives would be set in case the principal would have to pay for the agents' payoffs. We leave these issues for future studies.

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A Appendix

A.1 Mathematical derivation of the model

Using backwards induction, in the second stage of the game, agent i maximizes his payoff $G_i = \lambda_i \pi_i + (1-\lambda_i)\pi_j$, knowing that the principal's payoff is $\pi_i = ax_i - bx_i^2 + cx_i x_j$. Agent i selects x_i to maximize G_i

$$G_i = -\lambda_i b x_i^2 + (\lambda_i a + c x_j)x_i + (1-\lambda_i)(ax_j - bx_j^2) \tag{7}$$

The F.O.C of Equation (7) yields:

$$x_i = \frac{\lambda_i a + c x_j}{2\lambda_i b} \tag{8}$$

$$x_j = \frac{\lambda_j a + c x_i}{2\lambda_i b} \tag{9}$$

Solving the equation system gives agents' best response function to (λ_i, λ_i):

$$x_i^*(\lambda_i, \lambda_j) = \frac{ac\lambda_j + 2ab\lambda_i\lambda_j}{4b^2\lambda_i\lambda_j - c^2} \tag{10}$$

with $4b^2\lambda_i\lambda_j - c^2 \neq 0$.

Anticipating that agents' best response to the λ pairs in the second stage takes the above form, principal i selects λ_i in the first stage to maximize:

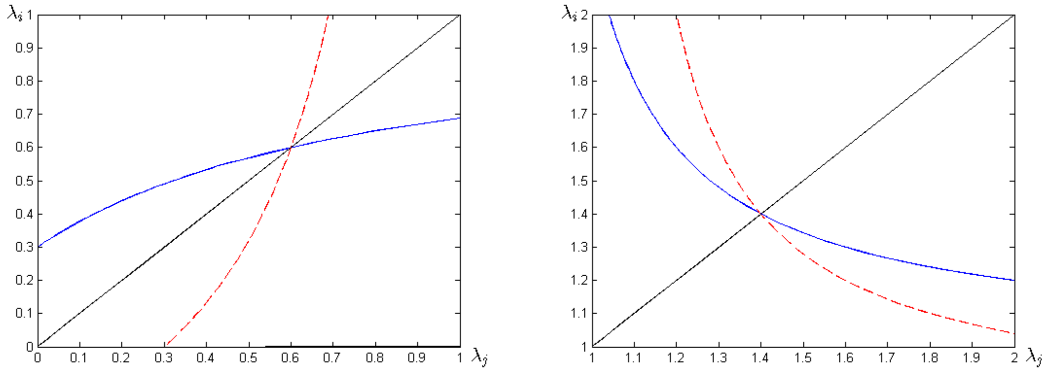
$$\pi_i\big(x_i^*(\lambda_i, \lambda_j), x_j^*(\lambda_j, \lambda_i)\big) \tag{11}$$

Derivation of the F.O.C gives us a system of best response functions $\lambda_i = f(\lambda_j), \lambda_j = f(\lambda_i)$ showing how principal i set λ_i in response to λ_j set by the other principal. Solving the system of equations, we have the subgame perfect equilibrium:

$$\lambda_i^* = \lambda_j^* = 1 - \frac{c}{2b}. \tag{12}$$

with $4b^2\lambda_i\lambda_j - c^2 \neq 0$, $b \neq 0$, and $2b \neq c$.

With the parameters we used in our experiment ($a_{comp} = 8, b_{comp} = 1, c_{comp} = 0.8$ for the Complements treatment, and $a_{subs} = 40, b_{subs} = \frac{25}{9}, c_{subs} = -\frac{20}{9}$ in the substitute treatment), the best response functions $\lambda_i = f(\lambda_j), \lambda_j = f(\lambda_i)$ and the SPE λ^* in each treatment can be plotted as in Figure A1



(a) Strategic complement (b) Strategic substitute

Figure A1: Best-response functions of λ in two treatments

A.2 Additional Tables

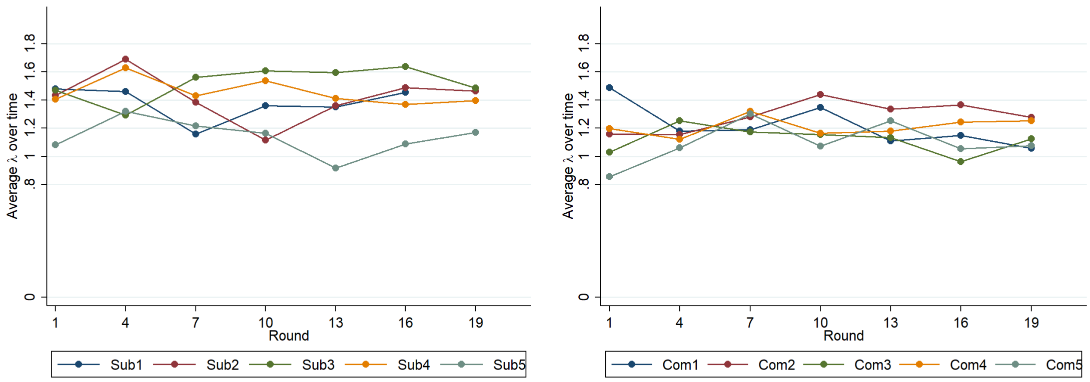
A.2.1 Principals' choice of λ

Table A1: Principals' choice of λ in each session

Treatment	Subjects	Average λ	$\lambda > 1$	$\lambda = 1$
Complements				
Com1	16	1.217 (0.435)	68.07%	5.36%
Com2	16	1.287 (0.400)	69.64%	3.57%
Com3	20	1.119 (0.400)	51.43%	22.86%
Com4	20	1.211 (0.426)	67.14%	12.86%
Com5	16	1.096 (0.378)	44.64%	21.43%
Substitutes				
Sub1	24	1.378 (0.501)	66.66%	22.22%
Sub2	16	1.419 (0.556)	71.43%	7.14%
Sub3	24	1.521 (0.424)	84.52%	3.57%
Sub4	12	1.454 (0.236)	97.62%	0%
Sub5	16	1.137 (0.337)	64.29%	5.36%

Notes: Standard deviations are shown in brackets.

A.2.2 Development of λ over time in each session



(a) Strategic substitute

(b) Strategic complement

Figure A2: Average λ over decision intervals in two treatments

A.3 Instructions

A.3.1 Instructions in the Complements treatment

Welcome to the experiment. We will first go over the instructions together. After that, you will be given some time to read the instructions at your own pace and ask questions. Please do not write on the instructions. If you need to take notes, you can use the extra blank paper.

During the experiment, you will interact with other participants in this room and make some decisions. The earnings that you make during the experiment are denoted in points. The number of points you earn depends on your decisions, the decisions of other participants, and chance. At the end of the experiment, we will exchange your points into Euro according to a conversion rate of **3 points = 1 Euro**. In addition, you will receive a participation fee of **3 Euro**. The payment shall be transferred to your bank account within one working day.

Please be quiet during the experiment and do not talk with any other participants. If you have a question, please raise your hand and an experimenter will come to you.

The task

There will be two roles: **Principal** (denoted by **P**), and **Agent** (denoted by **A**). You will either be a principal or an agent. A principal is matched with one other principal, let's call them Principal 1 (P1) and Principal 2 (P2). Each principal has to select an input level, $Input_1$ for P1 and $Input_2$ for P2. These input levels determine the earning of each principal. Specifically, the earnings of P1 are given by the following equation:

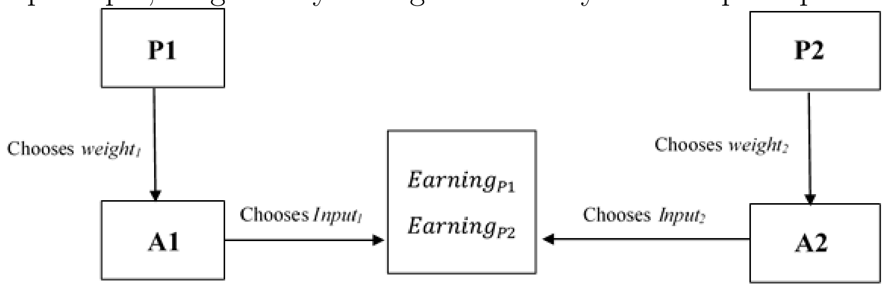
$$Earning_{P1} = 8 \times Input_1 - {Input_1}^2 + 0.8 \times Input_1 \times Input_2$$

The earning of P2 is determined in a similar way.

However, the input decisions will not be made by the principals themselves. Every principal is matched with an agent. The input decision is made by the agent to whom the principal is matched. That is, Agent 1 (A1) chooses the input level ($Input_1$) for P1, and Agent 2 (A2) chooses the input level ($Input_2$) for P2. The only decision a principal makes is how her agent is compensated. The compensation of A1 depends on the earning of P1 and the earning of P2, with a weight set by P1. That is, the compensation of A1 is given by the following equation:

$$Compensation_{A1} = weight_1 \times Earning_{P1} + (1 - weight_1) \times Earning_{P2}$$

where $weight_1$ is selected by P1. Similarly, the compensation of A2 is determined by the weight ($weight_2$) chosen by P2. In other words, the compensation of each agent is determined by the earning of his own principal and the earning of the other principal, weighted by a weight chosen by his own principal.



The graph on the previous page can help you understand the task. Four participants will interact together: two principals and two agents. The principals P1 and P2 will select their weights simultaneously and independently. After that, the two agents, A1 and A2, will be informed about these weights, and each agent chooses an input for his principal simultaneously and independently. These inputs determine the earnings of each principal. These earnings in turn determine the compensation (earnings) of the agents.

Timing

As soon as the experiment starts, you will be randomly assigned a role of a principal or an agent. Then each principal is randomly matched with an agent to form one principal-agent pair. Each principal selects a weight **from 0 to 2** for her agent's compensation (as explained above). Every principal-agent pair remain together for three rounds, and so does the weight selected by the principal. After three rounds, each principal will be randomly matched with another agent, and must select a weight for her new agent's compensation.

At the beginning of each round, each principal-agent pair will be randomly matched with another principal-agent pair to form a four-person group. The weights selected by the two principals will be revealed to both principals and agents. After learning the weights, each agent selects an input **from 0 to 15** for his principal. At the end of every round, you will be informed of your own earning/compensation, as well as the decisions of all four participants in the same group as you. You will also see a history table of the four decisions (two weights and two inputs) and your earning/compensation of all previous rounds. After each round, each principal-agent pair will be randomly matched with another pair.

Before the experiment, there will be three trial rounds. These trial rounds are for you to get familiar with the experiment and will not be counted towards your payment. After the three trial rounds, there will be 21 rounds in total. After all the 21 rounds, you will answer a short questionnaire. At the end of the experiment, one of the 21 rounds will be randomly selected for your payment. Each round has an equal chance of being selected for payment. Please treat your decision in every round with care. Your points earned in the selected round will be exchanged into Euro according to a conversion rate of **3 points = 1 Euro**.

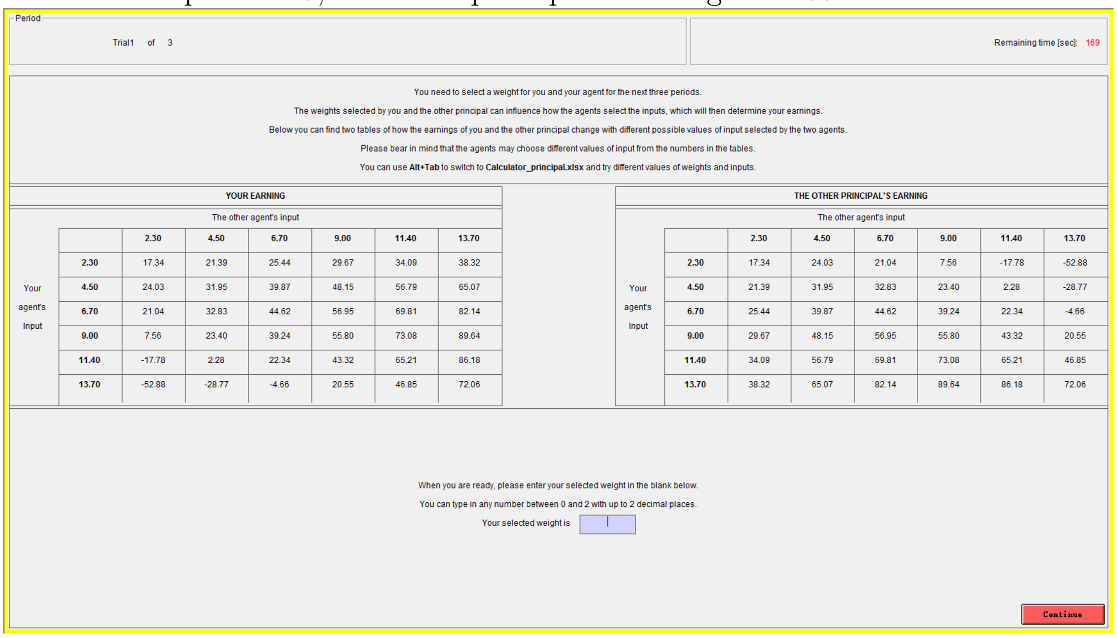
Your decisions in the three trial rounds will not be timed. In the 21 rounds that follow, you have three minutes to make up your mind for each decision. When the time is up, you will be given 10 seconds more. If still no decision is made after 10 seconds, the experiment moves on to the next stage and take your decision as the default level 0.

Information

Some information will be provided to help you understand how your earning or compensation is determined and to make better decisions.

Information for the principal

If you are a principal, when you need to choose a weight, your screen will look like the following graph. You will see two tables on the screen, the one on the left showing how your earning depends on the input choices of both agents, and the one on the right showing how the earning of the other principal depends on the input choices of both agents. In both tables, the first column includes some possible values for input from which your agent may choose, and the first row includes some possible values for input from which the other agent may choose. The numbers in other cells of the tables represent the earnings of you (left table) or the other principal (right table) for a specific combination of inputs. For example, the number 17.34 in the second row and second column of the left table indicates that your earning is 17.34 points, when both your agent and the other agent choose an input of 2.3; the number 24.03 in the second row and third column of the right table indicates that when your agent chooses an input of 2.3, and the other agent chooses an input of 4.5, the other principal's earning is 24.03.


Period

Trial1 of 3

Remaining time [sec]: 169

You need to select a weight for you and your agent for the next three periods.

The weights selected by you and the other principal can influence how the agents select the inputs, which will then determine your earnings.

Below you can find two tables of how the earnings of you and the other principal change with different possible values of input selected by the two agents.

Please bear in mind that the agents may choose different values of input from the numbers in the tables.

You can use **Alt+Tab** to switch to **Calculator_principal.xlsx** and try different values of weights and inputs.

YOUR EARNING

The other agent's input

Your agent's Input	2.30	4.50	6.70	9.00	11.40	13.70
2.30	17.34	21.39	25.44	29.67	34.09	38.32
4.50	24.03	31.95	39.87	48.15	56.79	65.07
6.70	21.04	32.83	44.62	56.95	69.81	82.14
9.00	7.56	23.40	39.24	55.80	73.08	89.64
11.40	-17.78	2.28	22.34	43.32	65.21	86.18
13.70	-52.88	-28.77	-4.66	20.55	46.85	72.06

THE OTHER PRINCIPAL'S EARNING

The other agent's input

Your agent's Input	2.30	4.50	6.70	9.00	11.40	13.70
2.30	17.34	24.03	21.04	7.56	-17.78	-52.88
4.50	21.39	31.95	32.83	23.40	2.28	-28.77
6.70	25.44	39.87	44.62	39.24	22.34	-4.66
9.00	29.67	48.15	56.95	55.80	43.32	20.55
11.40	34.09	56.79	69.81	73.08	65.21	46.85
13.70	38.32	65.07	82.14	89.64	86.18	72.06

When you are ready, please enter your selected weight in the blank below.

You can type in any number between 0 and 2 with up to 2 decimal places.

Your selected weight is

Continue

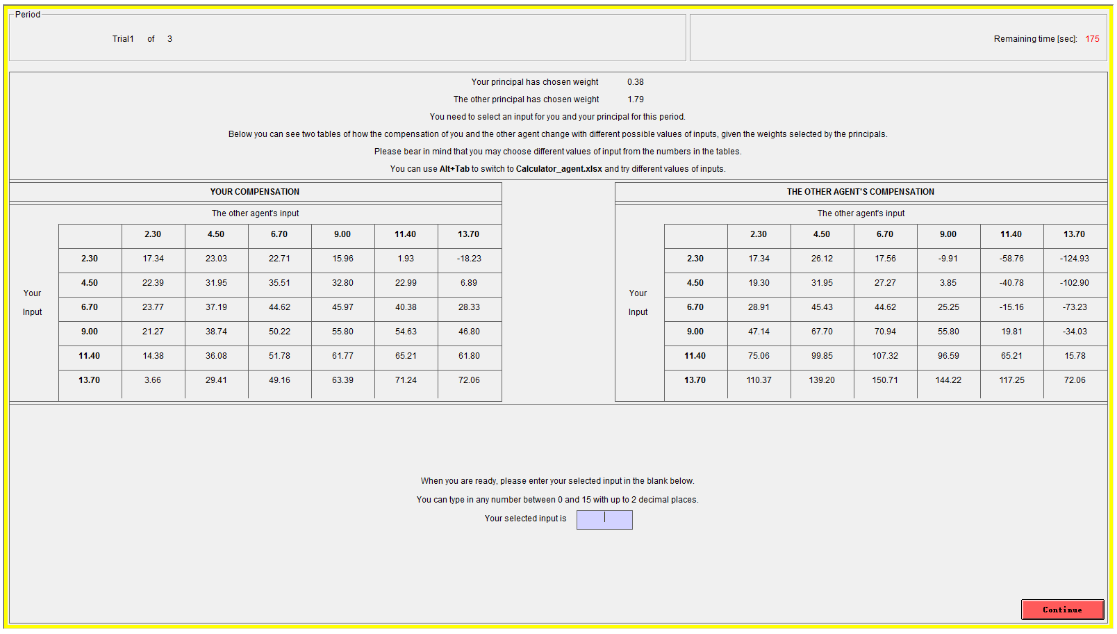
The tables you see here in the instructions are only to help you understand the experiment. Please note that the numbers may be different in the actual experiment. The values for the inputs in the rows and columns chosen are for illustration only. Agents can also select other values than those in the tables, as long as they are in between 0 to 15.

When you are assigned your roles, an experimenter will come and help you open a calculator file "Calculator_principal.xlsx". You can use "**Alt+Tab**" to switch to the calculator file and try different possible values for the weights and inputs of you and the other pair. You can move the scrollbars in the calculator file to try different value combinations, and you will see the earnings and compensations for that specific combination you try. You will also see two similar tables showing how each agent's compensation depends on different possible values of inputs selected by them. As you move the scrollbars, the numbers in the two tables will change accordingly.

When you are ready, you can use "**Alt+Tab"** to switch back to the experiment interface and type in your choice of weight in the blank on screen. Please pay attention to the time limit.

Information for the agent

If you are an agent, when you need to choose an input, your screen will look like the graph below. You will first be reminded of the weight chosen by your principal and the other principal. You will then see two tables, the one on the left showing how your compensation depends on the input choices of both agents, the one on the right showing how the compensation of the other agent depends on the input choices of both agents, given the compensation weights chosen by the principals. In the two tables, the first column includes some possible values of input you can choose, and the first row includes some possible values of input from which the other agent can choose. The numbers in other cells of the tables represent the compensations of you (left table) or the other agent (right table) for each specific combination of inputs. For example, the number 17.34 in the second row and second column of the left table indicates that given the weight (0.38) chosen by your principal, your compensation is 17.34 points, when both you and the other agent choose an input of 2.3; similarly the number 19.3 in the third row and second column of the right table indicates that given the weight (1.79) chosen by the other principal, when you choose an input of 4.5, and the other agent chooses an input of 2.3, the other agent's compensation is 19.3.



Period

Trial1 of 3

Remaining time [sec]: 175

Your principal has chosen weight 0.38

The other principal has chosen weight 1.79

You need to select an input for you and your principal for this period.

Below you can see two tables of how the compensation of you and the other agent change with different possible values of inputs, given the weights selected by the principals.

Please bear in mind that you may choose different values of input from the numbers in the tables.

You can use **Alt+Tab** to switch to **Calculator_agent.xlsx** and try different values of inputs.

YOUR COMPENSATION

		The other agent's input					
		2.30	**4.50**	**6.70**	**9.00**	**11.40**	**13.70**
Your Input	**2.30**	17.34	23.03	22.71	15.96	1.93	-18.23
	4.50	22.39	31.95	35.51	32.80	22.99	6.89
	6.70	23.77	37.19	44.62	45.97	40.38	28.33
	9.00	21.27	38.74	50.22	55.80	54.63	46.80
	11.40	14.38	36.08	51.78	61.77	65.21	61.80
	13.70	3.66	29.41	49.16	63.39	71.24	72.06

THE OTHER AGENT'S COMPENSATION

		The other agent's input					
		2.30	**4.50**	**6.70**	**9.00**	**11.40**	**13.70**
Your Input	**2.30**	17.34	26.12	17.56	-9.91	-58.76	-124.93
	4.50	19.30	31.95	27.27	3.85	-40.78	-102.90
	6.70	28.91	45.43	44.62	25.25	-15.16	-73.23
	9.00	47.14	67.70	70.94	55.80	19.81	-34.03
	11.40	75.06	99.85	107.32	96.59	65.21	15.78
	13.70	110.37	139.20	150.71	144.22	117.25	72.06

When you are ready, please enter your selected input in the blank below.

You can type in any number between 0 and 15 with up to 2 decimal places.

Your selected input is

Continue

The table you see here is only to help you understand the experiment. Please note that the numbers may be different in the actual experiment. The values for the inputs in the rows and columns chosen are for illustration only. You and the other agent are free to choose other values from 0 to 15.

When you are assigned your roles, an experimenter will come and help you open a calculator file "Calculator_agent.xlsx". You can use "**Alt+Tab**" to switch to the calculator file and try different possible values of inputs. You first need to type in the weights selected by the two principals, and then you can use the two scrollbars to try different possible values for inputs. As you move the scrollbars, you can see how the compensations change with different combinations of inputs you try.

When you are ready, you can use "**Alt+Tab**" to switch back to the experiment interface and type in your choice of input in the blank on screen. Please pay attention to the time limit.

Summary

1. You are assigned a role of a principal or an agent.
2. The experimenter opens the calculator file for you.
3. A principal and an agent form a principal-agent pair for 3 rounds.
4. Each principal selects a weight which determines how the compensation of her agent depends on her own earning and the earning of the other principal. The weight is fixed for 3 rounds.
5. In each round, the principal-agent pair are randomly matched to another pair. The weights are revealed to all four participants matched together.
6. Given the weights set by the principals, each of the two agents selects a level of input between 0 and 15. The inputs are chosen anew in each round.

7. The two input levels determine the earnings of the two principals.
8. The earnings of the principals, together with the weights, determine the compensation of the agents.
9. After 3 rounds, new principal-agent pairs are randomly formed.
10. In total there are 3 trial rounds and 21 rounds that count towards your payment.
11. After the experiment one of the 21 rounds will be randomly chosen for payment, with an exchange rate of 3 points for 1 Euro.

You can now go over the instructions on your own and ask clarifying questions (if any). When you are ready, you can answer the practice questions on your screen to check if you have understood the instructions. Please raise a hand if you have a question.
Please be reminded that you are not allowed to communicate with other participants throughout the experiment.

Practice questions

Please answer the practice questions below:

1. You are a principal. In one round, your screen is exactly like the graph on page 3. After you and the other principal have selected your weights, your agent selects an input of 11.4, and the other agent selects an input of 6.7. Your earning will be __________ points. The other principal's earning will be __________ points. If this round is selected for payment at the end of the session, your points equal __________ Euro.
2. You are an agent. In one round, your screen is exactly like the graph on page 4. After knowing the weights selected by the two principals, you choose an input of 9, and the other agent choose an input of 11.4. Your compensation will be __________ points. The other agent's compensation will be __________ points. If this round is selected for payment at the end of the session, your points equal __________ Euro.

Please raise a hand if you have finished or if you have a question.
Please be reminded that you are not allowed to communicate with other participants throughout the experiment.

A.3.2 Screenshots of the external profit calculators in Complements treatment

Figure A3: External profit calculator for the principal in Complements treatment

You can move the scrollbars below to try different values of weight that can be chosen by you and the other principal
You will need to choose a weight for your agent in the experiment interface.
Please move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below. Please DO NOT change the numbers in the cells.
Please DO NOT type in the cells.

TRY:	Your choice of weight	0.55	**TRY:**	The other principal's choice of weight	1.80

You can move the scrollbars below to try different values of input that can be chosen by your agent and the other agent
Please move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below.
Please DO NOT type in the cells.

TRY:	Your agent's choice of input	0	**TRY:**	The other agent's choice of input	0

For every combination of weights and inputs you try above, you can see below the earnings and compensations of you, the other principal, your agent and the other agent with the above selected values.

Your earning	0.00	**The other principal's earning**	0.00
Your agent's compensation	0.00	**The other agent's compensation**	0.00

Below you can see how the compensation tables of your agent and the other agent changes as you try different values of weight

YOUR AGENT'S COMPENSATION

		The other agent's input					
		5.60	**6.70**	**7.50**	**9.00**	**12.00**	**14.00**
	5.60	38.53	41.33	42.68	43.66	39.55	32.31
Your agent's	**6.70**	40.85	44.62	46.68	48.98	47.51	42.03
Input	**7.50**	41.71	46.18	48.75	52.01	52.46	48.26
	9.00	41.42	47.21	50.74	55.80	59.85	58.05
	12.00	33.41	41.84	47.29	55.95	67.20	70.20
	14.00	22.57	32.76	39.49	50.55	66.60	72.80

THE OTHER AGENT'S COMPENSATION

		The other agent's input					
		5.60	**6.70**	**7.50**	**9.00**	**12.00**	**14.00**
	5.60	38.53	34.94	29.60	13.37	-43.39	-99.23
Your agent's	**6.70**	47.24	44.62	39.98	25.07	-29.05	-83.13
Input	**7.50**	54.79	52.88	48.75	34.80	-17.40	-70.20
	9.00	71.71	71.12	67.95	55.80	7.20	-43.20
	12.00	116.35	118.40	117.15	108.60	67.20	21.60
	14.00	154.11	157.92	157.95	151.80	115.20	72.80

Figure A4: External profit calculator for the agent in Complements treatment

This calculator is ony for you to get a better idea of the experiment. The numbers you try here will not be recorded.
When you are ready, please switch back to the experiment page and enter your decisions there.

Please enter below the weights selected by your principal and the other principal in this period.
Please enter the weights you see on the experiment interface.

Your principal's weight	0.00	The other principal's weight	0.00

You can move the scrollbars below to try different values of input that can be chosen by you and the other agent
Please move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below.
Please DO NOT type in the cells.

TRY:	Your's choice of input	0	**TRY:**	The other agent's choice of input	0

You can see below the compensations of you and the other agent with the above selected values

Your compensation	0.00	**The other agent's compensation**	0.00

A.3.3 Instructions in the Substitutes treatment

Welcome to the experiment. We will first go over the instructions together. After that, you will be given some time to read the instructions at your own pace and ask questions. Please do not write on the instructions. If you need to take notes, you can use the extra blank paper.

During the experiment, you will interact with other participants in this room and make some decisions. The earnings that you make during the experiment are denoted in points. The number of points you earn depends on your decisions, the decisions of other participants, and chance. At the end of the experiment, we will exchange your points into Euro according to a conversion rate of **4 points = 1 Euro**. In addition, you will receive a participation fee of **3 Euro**. The payment shall be transferred to your bank account within one working day.

Please be quiet during the experiment and do not talk with any other participants. If you have a question, please raise your hand and an experimenter will come to you.

The task

There will be two roles: **Principal** (denoted by **P**), and **Agent** (denoted by **A**). You will either be a principal or an agent. A principal is matched with one other principal, let's call them Principal 1 (P1) and Principal 2 (P2). Each principal has to select an input level, $Input_1$ for P1 and $Input_2$ for P2. These input levels determine the earning of each principal. Specifically, the earnings of P1 are given by the following equation:

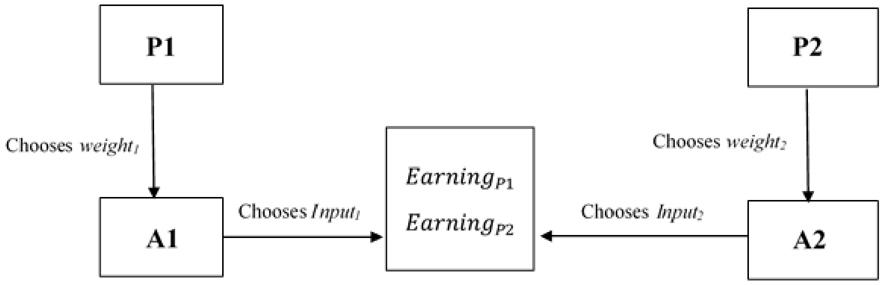
$$Earning_{P1} = 40 \times Input_1 - \frac{25}{9} \times Input_1^2 - \frac{20}{9} \times Input_1 \times Input_2$$

The earnings of P2 are determined in a similar way.

However, the input decisions will not be made by the principals themselves. Every principal is matched with an agent. The input decision is made by the agent to whom the principal is matched. That is, Agent 1 (A1) chooses the input level ($Input_1$) for P1, and Agent 2 (A2) chooses the input level ($Input_2$) for P2. The only decision a principal makes is how her agent is compensated. The compensation of A1 depends on the earning of P1 and the earning of P2, with a weight set by P1. That is, the compensation of A1 is given by the following equation:

$$Compensation_{A1} = weight_1 \times Earning_{P1} + (1 - weight_1) \times Earning_{P2}$$

where $weight_1$ is selected by P1. Similarly, the compensation of A2 is determined by the weight ($weight_2$) chosen by P2. In other words, the compensation of each agent is determined by the earning of his own principal and the earning of the other principal, weighted by a weight chosen by his own principal.



The graph on the previous page can help you understand the task. Four participants will interact together: two principals and two agents. The principals P1 and P2 will select their weights simultaneously and independently. After that, the two agents, A1 and A2, will be informed about these weights, and each agent chooses an input for his principal simultaneously and independently. These inputs determine the earnings of each principal. These earnings in turn determine the compensation (earnings) of the agents.

Timing

As soon as the experiment starts, you will be randomly assigned a role of a principal or an agent. Then each principal is randomly matched with an agent to form one principal-agent pair. Each principal selects a weight **from 0 to 2** for her agent's compensation (as explained above). Every principal-agent pair remain together for three rounds, and so does the weight selected by the principal. After three rounds, each principal will be randomly matched with another agent, and must select a weight for her new agent's compensation.

At the beginning of each round, each principal-agent pair will be randomly matched with another principal-agent pair to form a four-person group. The weights selected by the two principals will be revealed to both principals and agents. After learning the weights, each agent selects an input **from 0 to 10** for his principal. At the end of every round, you will be informed of your own earning/compensation, as well as the decisions of all four participants in the same group as you. You will also see a history table of the four decisions (two weights and two inputs) and your earning/compensation of all previous rounds. After each round, each principal-agent pair will be randomly matched with another pair.

Before the experiment, there will be three trial rounds. These trial rounds are for you to get familiar with the experiment and will not be counted towards your payment. After the three trial rounds, there will be 21 rounds in total. After all the 21 rounds, you will answer a short questionnaire. At the end of the experiment, one of the 21 rounds will be randomly selected for your payment. Each round has an equal chance of being selected for payment. Please treat your decision in every round with care. Your points earned in the selected round will be exchanged into

Euro according to a conversion rate of **4 points = 1 Euro**.

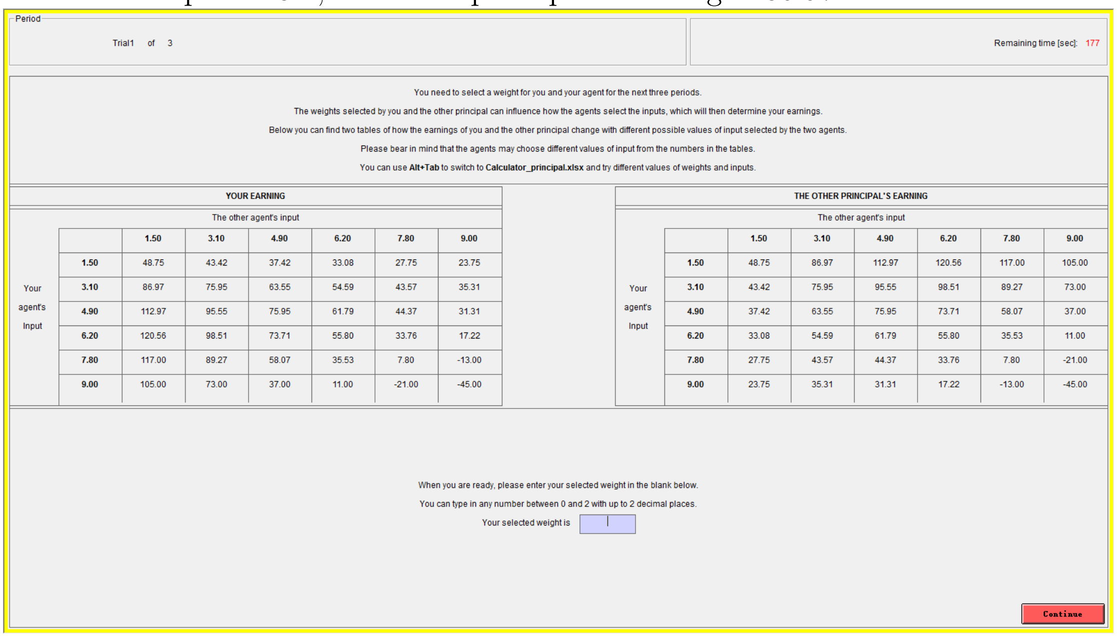
Your decisions in the three trial rounds will not be timed. In the 21 rounds that follow, you have three minutes to make up your mind for each decision. When the time is up, you will be given 10 seconds more. If still no decision is made after 10 seconds, the experiment moves on to the next stage and take your decision as the default level 0.

Information

Some information will be provided to help you understand how your earning or compensation is determined and to make better decisions.

Information for the principal

If you are a principal, when you need to choose a weight, your screen will look like the graph on the next page. You will see two tables on the screen, the one on the left showing how your earning depends on the input choices of both agents, and the one on the right showing how the earning of the other principal depends on the input choices of both agents. In both tables, the first column includes some possible values for input from which your agent may choose, and the first row includes some possible values for input from which the other agent may choose. The numbers in other cells of the tables represent the earnings of you (left table) or the other principal (right table) for a specific combination of inputs. For example, the number 48.75 in the second row and second column of the left table indicates that your earning is 48.75 points, when both your agent and the other agent choose an input of 1.5; the number 86.97 in the second row and third column of the right table indicates that when your agent chooses an input of 1.5, and the other agent chooses an input of 3.1, the other principal's earning is 86.97.


Period

Trial1 of 3

Remaining time [sec]: 177

You need to select a weight for you and your agent for the next three periods.
The weights selected by you and the other principal can influence how the agents select the inputs, which will then determine your earnings.
Below you can find two tables of how the earnings of you and the other principal change with different possible values of input selected by the two agents.
Please bear in mind that the agents may choose different values of input from the numbers in the tables.
You can use **Alt+Tab** to switch to **Calculator_principal.xlsx** and try different values of weights and inputs.

YOUR EARNING

Your agent's Input \ The other agent's input	**1.50**	**3.10**	**4.90**	**6.20**	**7.80**	**9.00**
1.50	48.75	43.42	37.42	33.08	27.75	23.75
3.10	86.97	75.95	63.55	54.59	43.57	35.31
4.90	112.97	95.55	75.95	61.79	44.37	31.31
6.20	120.56	98.51	73.71	55.80	33.76	17.22
7.80	117.00	89.27	58.07	35.53	7.80	-13.00
9.00	105.00	73.00	37.00	11.00	-21.00	-45.00

THE OTHER PRINCIPAL'S EARNING

Your agent's Input \ The other agent's input	**1.50**	**3.10**	**4.90**	**6.20**	**7.80**	**9.00**
1.50	48.75	86.97	112.97	120.56	117.00	105.00
3.10	43.42	75.95	95.55	98.51	89.27	73.00
4.90	37.42	63.55	75.95	73.71	58.07	37.00
6.20	33.08	54.59	61.79	55.80	35.53	11.00
7.80	27.75	43.57	44.37	33.76	7.80	-21.00
9.00	23.75	35.31	31.31	17.22	-13.00	-45.00

When you are ready, please enter your selected weight in the blank below.
You can type in any number between 0 and 2 with up to 2 decimal places.
Your selected weight is

Continue

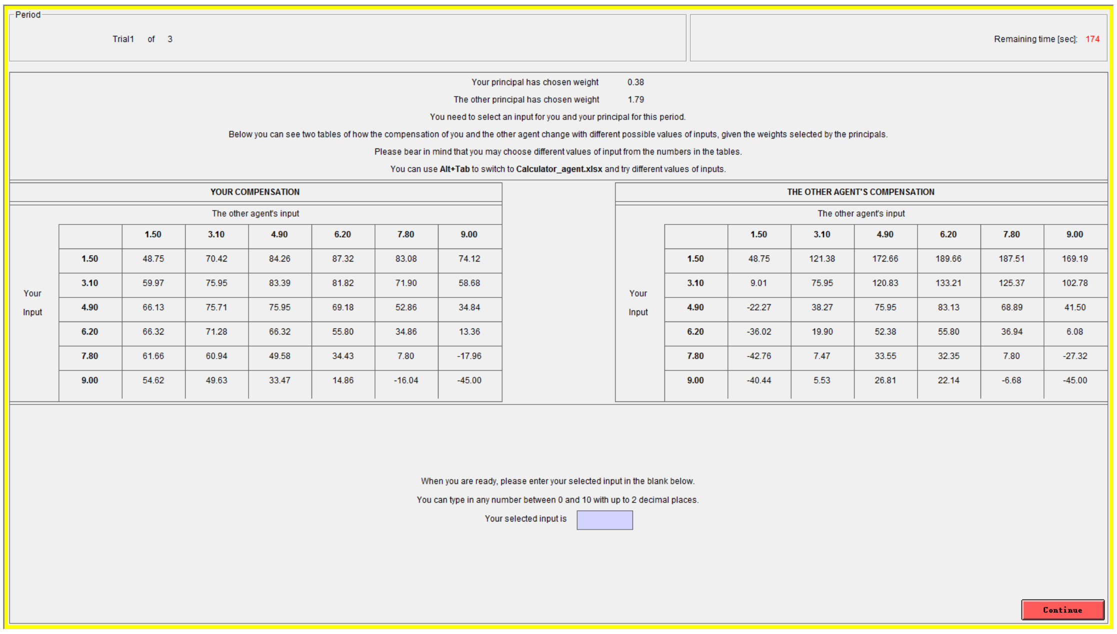
The tables you see here in the instructions are only to help you understand the experiment. Please note that the numbers may be different in the actual experiment. The values for the inputs in the rows and columns chosen are for illustration only. Agents can also select other values than those in the tables, as long as they are in between 0 to 10.

When you are assigned your roles, an experimenter will come and help you open a calculator file "Calculator_principal.xlsx". You can use "**Alt+Tab**" to switch to the calculator file and try different possible values for the weights and inputs of you and the other pair. You can move the scrollbars in the calculator file to try different value combinations, and you will see the earnings and compensations for that specific combination you try. You will also see two similar tables showing how each agent's compensation depends on different possible values of inputs selected by them. As you move the scrollbars, the numbers in the two tables will change accordingly.

When you are ready, you can use "**Alt+Tab"** to switch back to the experiment interface and type in your choice of weight in the blank on screen. Please pay attention to the time limit.

Information for the agent

If you are an agent, when you need to choose an input, your screen will look like the graph below. You will first be reminded of the weights chosen by your principal and the other principal. You will then see two tables, the one on the left showing how your compensation depends on the input choices of both agents, the one on the right showing how the compensation of the other agent depends on the input choices of both agents, given the compensation weights chosen by the principals. In the two tables, the first column includes some possible values of input you can choose, and the first row includes some possible values of input from which the other agent can choose. The numbers in other cells of the tables represent the compensation of you (left table) or the other agent (right table) for each specific combination of inputs. For example, the number 48.75 in the second row and second column of the left table indicates that given the weight (0.38) chosen by your principal, your compensation is 48.75 points, when both you and the other agent choose an input of 1.5; similarly the number 9.01 in the third row and second column of the right table indicates that given the weight (1.79) chosen by the other principal, when you choose an input of 3.1, and the other agent chooses an input of 1.5, the other agent's compensation is 9.01.



Period

Trial1 of 3

Remaining time [sec]: 174

Your principal has chosen weight 0.38

The other principal has chosen weight 1.79

You need to select an input for you and your principal for this period.

Below you can see two tables of how the compensation of you and the other agent change with different possible values of inputs, given the weights selected by the principals.

Please bear in mind that you may choose different values of input from the numbers in the tables.

You can use **Alt+Tab** to switch to **Calculator_agent.xlsx** and try different values of inputs.

YOUR COMPENSATION

	The other agent's input					
Your Input	**1.50**	**3.10**	**4.90**	**6.20**	**7.80**	**9.00**
1.50	48.75	70.42	84.26	87.32	83.08	74.12
3.10	59.97	75.95	83.39	81.82	71.90	58.68
4.90	66.13	75.71	75.95	69.18	52.86	34.84
6.20	66.32	71.28	66.32	55.80	34.86	13.36
7.80	61.66	60.94	49.58	34.43	7.80	-17.96
9.00	54.62	49.63	33.47	14.86	-16.04	-45.00

THE OTHER AGENT'S COMPENSATION

	The other agent's input					
Your Input	**1.50**	**3.10**	**4.90**	**6.20**	**7.80**	**9.00**
1.50	48.75	121.38	172.66	189.66	187.51	169.19
3.10	9.01	75.95	120.83	133.21	125.37	102.78
4.90	-22.27	38.27	75.95	83.13	68.89	41.50
6.20	-36.02	19.90	52.38	55.80	36.94	6.08
7.80	-42.76	7.47	33.55	32.35	7.80	-27.32
9.00	-40.44	5.53	26.81	22.14	-6.68	-45.00

When you are ready, please enter your selected input in the blank below.

You can type in any number between 0 and 10 with up to 2 decimal places.

Your selected input is

Continue

The table you see here is only to help you understand the experiment. Please note that the numbers may be different in the actual experiment. The values for the inputs in the rows and columns chosen are for illustration only. You and the other agent are free to choose other values from 0 to 10.

When you are assigned your roles, an experimenter will come and help you open a calculator file "Calculator_agent.xlsx". You can use "**Alt+Tab**" to switch to the calculator file and try different possible values of inputs. You first need to type in the weights selected by the two principals, and then you can use the two scrollbars to try different possible values for inputs. As you move the scrollbars, you can see how the compensations change with different combinations of inputs you try.

When you are ready, you can use "**Alt+Tab**" to switch back to the experiment interface and type in your choice of input in the blank on screen. Please pay attention to the time limit.

Summary

1. You are assigned a role of a principal or an agent.
2. The experimenter opens the calculator file for you.
3. A principal and an agent form a principal-agent pair for 3 rounds.
4. Each principal selects a weight which determines how the compensation of her agent depends on her own earning and the earning of the other principal. The weight is fixed for 3 rounds.
5. In each round, the principal-agent pair are randomly matched to another pair. The weights are revealed to all four participants matched together.
6. Given the weights set by the principals, each of the two agents selects a level of input between 0 and 10. The inputs are chosen anew in each round.

7. The two input levels determine the earnings of the two principals.
8. The earnings of the principals, together with the weights, determine the compensation of the agents.
9. After 3 rounds, new principal-agent pairs are randomly formed.
10. In total there are 3 trial rounds and 21 rounds that count towards your payment.
11. After the experiment one of the 21 rounds will be randomly chosen for payment, with an exchange rate of 4 points for 1 Euro.

You can now go over the instructions on your own and ask clarifying questions (if any). When you are ready, you can answer the practice questions on your screen to check if you have understood the instructions. Please raise a hand if you have a question.
Please be reminded that you are not allowed to communicate with other participants throughout the experiment.

Practice questions

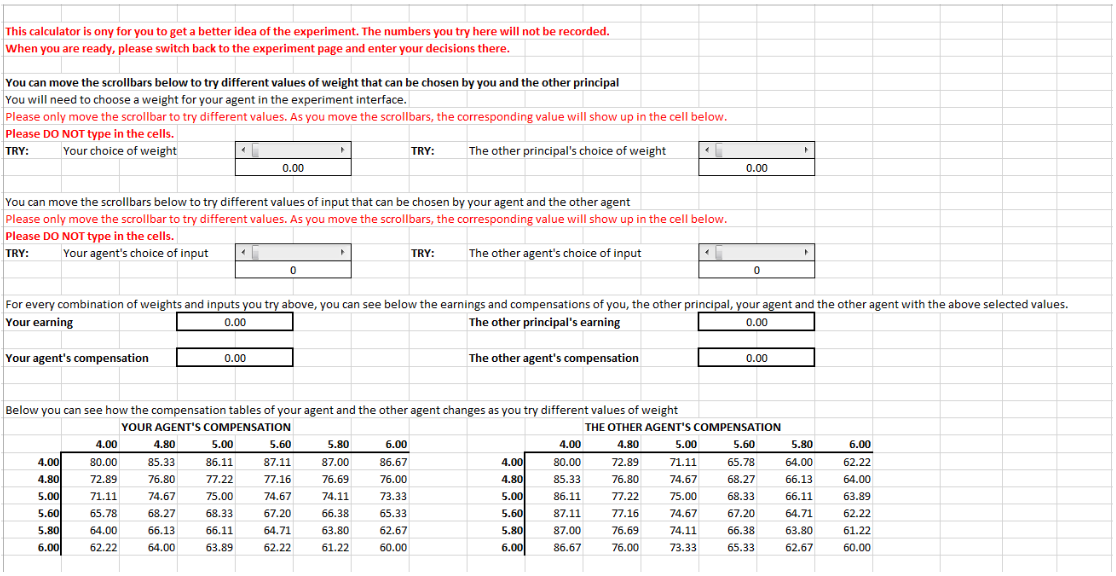
Please answer the practice questions below:

1. You are a principal. In one round, your screen is exactly like the graph on page 3. After you and the other principal have selected your weights, your agent selects an input of 6.2, and the other agent selects an input of 7.8. Your earning will be __________ points. The other principal's earning will be __________ points. If this round is selected for payment at the end of the session, your points equal __________ Euro.
2. You are an agent. In one round, your screen is exactly like the graph on page 4. After knowing the weights selected by the two principals, you choose an input of 9, and the other agent choose an input of 11.4. Your compensation will be __________ points. The other agent's compensation will be __________ points. If this round is selected for payment at the end of the session, your points equal __________ Euro.

Please raise a hand if you have finished or if you have a question.
Please be reminded that you are not allowed to communicate with other participants throughout the experiment.

A.3.4 Screenshots of the external profit calculators in Substitutes treatment

Figure A5: External profit calculator for the principal in Substitutes treatment


This calculator is ony for you to get a better idea of the experiment. The numbers you try here will not be recorded.
When you are ready, please switch back to the experiment page and enter your decisions there.

You can move the scrollbars below to try different values of weight that can be chosen by you and the other principal
You will need to choose a weight for your agent in the experiment interface.
Please only move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below.
Please DO NOT type in the cells.
TRY: Your choice of weight 0.00 **TRY:** The other principal's choice of weight 0.00

You can move the scrollbars below to try different values of input that can be chosen by your agent and the other agent
Please only move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below.
Please DO NOT type in the cells.
TRY: Your agent's choice of input 0 **TRY:** The other agent's choice of input 0

For every combination of weights and inputs you try above, you can see below the earnings and compensations of you, the other principal, your agent and the other agent with the above selected values.
Your earning 0.00 **The other principal's earning** 0.00
Your agent's compensation 0.00 **The other agent's compensation** 0.00

Below you can see how the compensation tables of your agent and the other agent changes as you try different values of weight

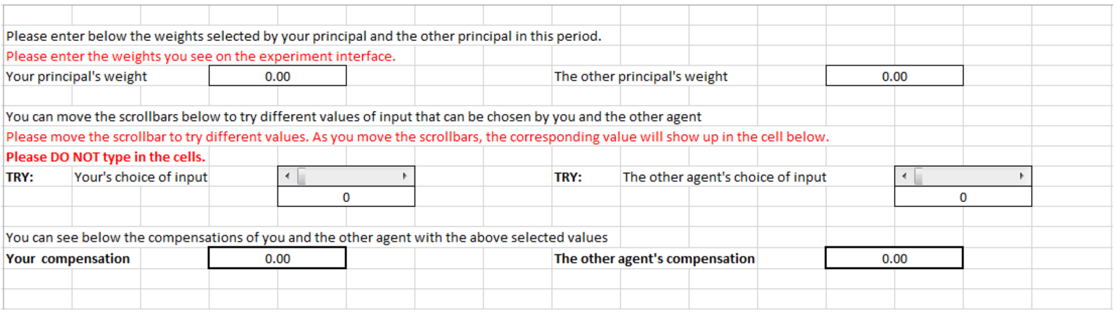
YOUR AGENT'S COMPENSATION

	4.00	**4.80**	**5.00**	**5.60**	**5.80**	**6.00**
4.00	80.00	85.33	86.11	87.11	87.00	86.67
4.80	72.89	76.80	77.22	77.16	76.69	76.00
5.00	71.11	74.67	75.00	74.67	74.11	73.33
5.60	65.78	68.27	68.33	67.20	66.38	65.33
5.80	64.00	66.13	66.11	64.71	63.80	62.67
6.00	62.22	64.00	63.89	62.22	61.22	60.00

THE OTHER AGENT'S COMPENSATION

	4.00	**4.80**	**5.00**	**5.60**	**5.80**	**6.00**
4.00	80.00	72.89	71.11	65.78	64.00	62.22
4.80	85.33	76.80	74.67	68.27	66.13	64.00
5.00	86.11	77.22	75.00	68.33	66.11	63.89
5.60	87.11	77.16	74.67	67.20	64.71	62.22
5.80	87.00	76.69	74.11	66.38	63.80	61.22
6.00	86.67	76.00	73.33	65.33	62.67	60.00

Figure A6: External profit calculator for the agent in Substitutes treatment


Please enter below the weights selected by your principal and the other principal in this period.
Please enter the weights you see on the experiment interface.
Your principal's weight 0.00 The other principal's weight 0.00

You can move the scrollbars below to try different values of input that can be chosen by you and the other agent
Please move the scrollbar to try different values. As you move the scrollbars, the corresponding value will show up in the cell below.
Please DO NOT type in the cells.
TRY: Your's choice of input 0 **TRY:** The other agent's choice of input 0

You can see below the compensations of you and the other agent with the above selected values
Your compensation 0.00 **The other agent's compensation** 0.00