TECHNOLOGICAL AND ECONOMIC DEVELOPMENT OF ECONOMY
Baltic Journal on Sustainability
2010
16(3): 487–501

THE EXPERIMENTAL INVESTIGATION OF THE PROFIT DISTRIBUTION IN INDUSTRIAL SUPPLY CHAINS WITH AN OUTSIDE OPTION

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Received 22 July 2009; accepted 5 August 2010

Abstract. There is an industrial supply chain, where an individual customer selects a supplier and excludes other ones. If the excluded supplier has the possibility to overtake the relationship afterwards, he has big influence on the relationship among the cooperation partners. A profit distribution rule has been developed that considers the impact of the excluded supplier. The paper presents round based games in which the present values change and influence the cooperative relationships. First, examples with ideal-typical numbers are calculated and depicted by the software "MATLAB". Internet experiments are made with participants on the basis of the software "z-tree" in order prove the relevance of the proposed profit distribution rule. Finally, the experimental data is compared with the theoretical predictions.

Keywords: stability of agreements, profit distribution rule, outside option, experiments, MATLAB, z-tree.

Reference to this paper should be made as follows: Stein, H. D.; Ginevičius, R. 2010. The experimental investigation of the profit distribution in industrial supply chains with an outside option, *Technological and Economic Development of Economy* 16(3)*:* 487–501.

1. Introduction

An individual customer selects a supplier and excludes other ones in an industrial supply chain. It is a principal-agent model (Göbel 2002), where the customer is the principal and the potential suppliers are the agents. An agreement is made between the principal and the supplier with the most advantageous offer. It is assumed that the agreement is not stable because the potential supplier with the second-best offer has the possibility to overtake the business relationship with the principal in a later moment. Circumstances have to change, which allow the excluded supplier to make a better offer than the current supplier. The

ISSN 2029-4913 print/ISSN 2029-4921 online doi: 10.3846/tede.2010.30
http://www.tede.vgtu.lt

continuously changing circumstances are the reason for the "ubiquitous time-inconsistency of agreements" (Stein 2010). Therefore the excluded suppler has tremendous influence on the relationship among the cooperation partners. A new profit distribution rule has been developed (Stein and Ginevičius 2010) that considers the impact of the excluded agent, the outside option (OOCS-rule). This profit distribution rule is based on the idea of the auction procedure of Vickrey (1961), where the principal gains at least the maximal bid of the losing bidder and additionally a part of the difference of the both maximal bids (Ginevičius and Podvezko 2008, 2009).

The paper investigates the relevance of the profit distribution rule in a round based auction model where the principal is looking for the most advantageous supplier and is able to revise his decision in each round. After a decision is made, it can be revoked in another round, and **the supplier can be switched under negligible or low costs**. (If the switching costs are high, it is another investigation). The 4 cases are regarded where

- The information about future events is **complete** (i.e. all future events are expected), the information about the maximal bids of the potential suppliers is **public (chapter 3)**,
- The information about future events is **incomplete** (i.e. some future events are unexpected), the information about the maximal bids of the potential suppliers is **private (chapter 4)**,
- The information about future events is **complete**, the information about the maximal bids of the potential suppliers is **public (chapter 5)**,
- The information about future events is **incomplete**, the information about the maximal bids of the potential suppliers is **private (chapter 6)**.

After a short presentation of the investigated profit distribution rule, 4 cases with ideal-typical numerical examples are calculated and depicted by the software "MATLAB". Afterwards, the results of the **4 experiments** with test persons are presented. Each of the experiments has been repeated **48 times**. In general, the set of players has been arranged for each game particularly. However some of the players have been participating repeatedly,

The participants have been playing against each other over an internet based program. The program has been made with the software for economic experiments "z-tree", which has been developed at the university Zürich (Fischbacher 2007). Finally, the empirical results are compared with the theoretical predictions.

2. Description of the "outside-option modified profit distribution rule for coalition structures"

The relevant profit distribution rule (Stein 2010) for the described situation is the introduced **outside-option modified profit distribution rule for coalition structures (OOCS-rule)**.

Similar to Myerson's axiomatization of the Shapley-rule (Shapley 1953; Myerson 1980), the OOCS-rule is defined by the axioms for the 3 agents $A, B, C \in N$, if 2 of the agents are united in the productive component Z:

- Component-Pareto-efficiency: $\sum_{i \in Z} OOCS_i(N, v, g) = v(Z)$ for the productive component,

- Modified axiom of balanced contributions;
- The modification of the axiom of balanced contributions consists of a pre-stage, where the winning cooperation partner transfers the value of the loosing cooperation partner to the main agent. Afterwards the balanced contributions axiom is used in the usual way (Podvezko 2009).

$OOCS_i\left(N,v,g\right)$ is the share of the total profit of "productive component" Z, which agent i of N obtains, if the characteristic function is v and the graph is g (Wiese 2005).

Thus:

1. For the agents *A, B, C* ∈ *N*: if *A* has to select the cooperation partner and $v\left(AB\right)>v\left(AC\right)$, then A selects B and first demands the amount: $v\left(AC\right)$ by agent *B*.
2. Afterwards the contributions are balanced:

$$OOCS_A\left(N,v,g\right)-OOCS_A\left(N,v,g\setminus\{B\}\right)=OOCS_B\left(N,v,g\right)-OOCS_B\left(N,v,g\setminus\{A\}\right),$$

so that A and B divide the difference of B's and C's offer equally.

In a coalition structure, with A and B in the "productive component" Z and C and the outside option for A, the OOCS-rule provides for the agents $A,B,C\in N$ with $v\left(AB\right)>v\left(AC\right)$:

$$OOCS-rule(A,B,C)=\left(\frac{v\left(AB\right)+v\left(AC\right)}{2};\frac{v\left(AB\right)-v\left(AC\right)}{2};0\right).$$

In comparison, the Aumann-Drèze-rule (Aumann and Drèze 1975) and Myerson-rule (Myerson 1976; Nouweland 2003) for coalition structures provide:

$$Aumann-Drèze-rule(A;B;C)=Myerson-rule\_for\_coalition\_structures(A;B;C)=\left(\frac{v\left(AB\right)}{2};\frac{v\left(AB\right)}{2};0\right).$$

It is abbreviated in the paper as "ADMCS-rule". The ADMCS-rule is different, as does not consider the impact of the outside option in the relationship between the actual cooperation partners (Rubinstein 1998; Zavadskas and Turskis 2008; Zavadskas *et al.* 2009). It is relevant, if the costs of switching the cooperation partner are that high that it cannot become beneficial (high agent switching costs), for instance because of contractual punishment. In opposite, the OOCS-rule is used if the switching costs are low.

3. Expected events, information about maximal bids by suppliers is public

3.1. Simulation of an ideal-typical example

In figure 1 the case is shown where

- **all events are expected**,
- the suppliers' **maximal bids are public information** and
- the costs of switching the supplier are low.

The numbers in the ideal-typical example are selected in a way that both suppliers can provide increasing present values through the rounds. For instance, this can be the result of improving skills.

The left and the middle image in figure 1 show slopes of the present values of both suppliers that are close to each other. The numbers are chosen with the intention to give an incentive to the weaker supplier to participate in the bidding. Practical experience in the preparation phase of the experiments has shown that the weaker supplier does not participate in the bidding, if he sees that the difference to the stronger bidder is too big (Vega-Redondo 2003; Zentes *et al.* 2005). For both suppliers the present values rise, for instance due to the acquirement of skills or particular information about the environment. **However, all these changes have been expected.**

In the right image it can be seen that in the beginning the principal should select the 1st supplier and switch to the 2nd one, if the suppliers and the principal act rationally. The vertical axes refer to the present values (PV, left and middle image) and the residual net present values (residual NPV, right image).

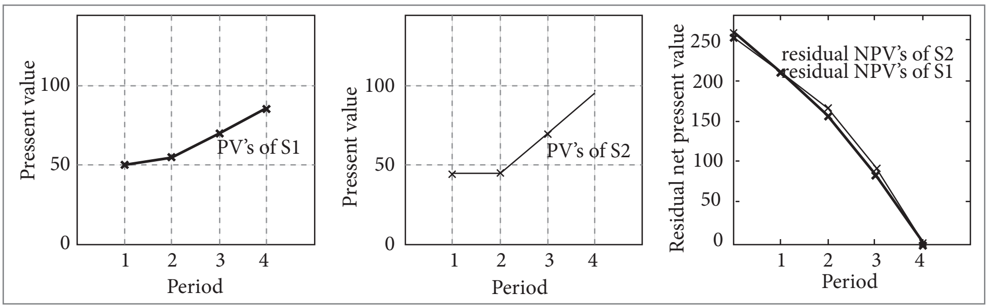

Fig. 1. Ideal-typical example of low agent switching costs and public information about the suppliers' maximal bids, present values of both suppliers (left, middle) and comparison of residual net present values (right)

3.2. Experiments with test persons and internet based program

The empirical data of all experiments has been saved in "Microsoft Excel" files. The categorization and the analysis of the data have been made with "MATLAB".

Figure 2 shows the 1st stage of the game of figure 1, i.e. the auction and decision masks of the referring "z-tree game" (expected events, low switching costs, only public information). Each participant sees on the left side the maximal bids of the suppliers, and makes his bid by pushing the "make bid" button on the left side below the information about the "maximal bids". As principal it is advantageous to make a high bid. For each supplier it is advantageous to keep the bid as low as possible.

They bargain iteratively, while it is advantageous for the principal to assert an agreement with a bid that is as high as possible and for both suppliers as low as possible. Time is limited in consideration of the degree of practice of the participants. They are asked before each game whether they prefer 90, 60 or 30 seconds. If the time is over, no agreement is made and each agent gains 0. However such a result is in contradiction with the postulate of collective rationality, i.e. Pareto-efficiency. A bargain is made either if a supplier pushes the "sell" button or the principal pushes the "buy" button.

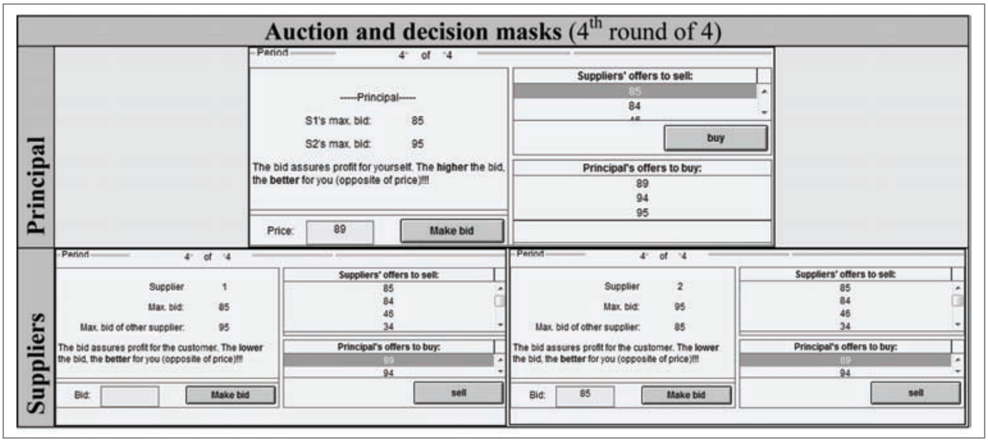

Fig. 2. 2-step initial bargaining: irrevocable determination of the supplier, profit division with him

In the 2nd and 3rd stage of this z-tree game, each participant can see his owns and the other agents' profits, in order to compare them, which is illustrated in figure 3. On the left side, the present round's profits, the total profits and the history of all previous rounds are listed. On the right side the profits are depicted in a bar chart for all 3 participants and all rounds.

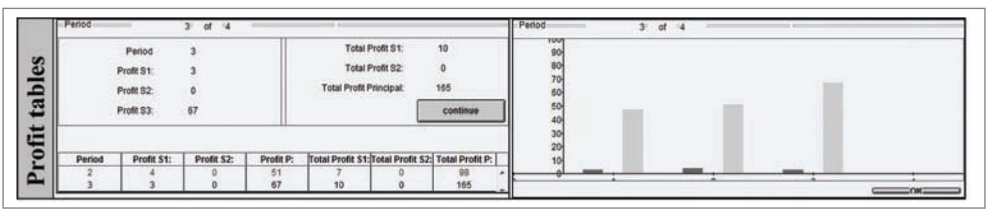

Fig. 3. Present round's profit, total profit and profit history listing (left) and bar chart depiction (right)

In table 1 the "average deviation ratios" are calculated, in order to compare the accuracy of the profit distribution rules. They are the average of the percent deviations between the respective profit distribution rule (OOCS-rule or ADMCS-rule) and the empirical data for each round of the game. The results are shown for each of the 4 rounds and the maximal bids for the respective round are listed in accordance with the figures 1 and 2. Finally, the relative deviations of the average empirical results in comparison with the ADMCS-rule and the OOCS-rule are shown.

The deviations by the OOCS-rule are by far lower, in both the unfiltered and the filtered data. The "average deviation ratio" of the OOCS-rule is: 0.1013 = 10.13%. The average deviation ratio of the ADMCS-rule is: 0.8847 = 88.47%.

Table 1. Maximal bids and the comparison of the OOCS-rule and the ADMCS-rule with the empirical results for **low** agent switching costs and maximal suppliers' bids that are **public** information

Case	t	Max. bid		Agent	Experiment: Average profit distributions		Prediction: Profit distribution rules		Deviation ratio	
		S_1	S_2		N = 48	N = 40 (rational)	OOCS	ADMCS	OOCS	ADMCS
Switching costs: Low **Events:** Expected **Max bids:** Public information	**1**	**50**	45	P	45.7	46.6	47.5	25	98%	186%
				S_1	3.4	3.5	2.5	25	138%	14%
				S_2	0.5	0	0	0	–	–
	2	**55**	45	P	48.2	49.1	50	27.5	98%	179%
				S_1	6.0	5.9	5	27.5	118%	21%
				S_2	0.2	0	0	0	–	–
	3	**70**	**70**	P	65.6	66.3	70	35 35	95%	189%
				S_1	2.4	2.0	0	35 0	–	12%
				S_2	1.9	1.7	0	0 35	–	10%
	4	85	**95**	P	86.9	89.7	90	42.5	100%	211%
				S_1	0	0	0	0	–	–
				S_2	5.7	5.3	5	42.5	106%	12%
Average deviation ratio:									10.13%	88.47%

4. Expected events, information about maximal bids by suppliers is private

4.1. Simulation of an ideal-typical example

In figure 4 the case is shown where

- **all events are expected**,
- the suppliers' **maximal bids are private information** and
- the costs of switching the supplier are low.

The numbers in the ideal-typical example are selected in a way that both suppliers can provide increasing present values through the rounds. For instance, this can be the result of improving skills.

The suppliers do not know the "strength" of the respective other one. Therefore they have stronger incentive to participate in the bidding. Therefore, the differences between the maximal bids of both suppliers can be bigger. If the suppliers and the principal play rationally, the principal selects and reselects the second supplier in each round.

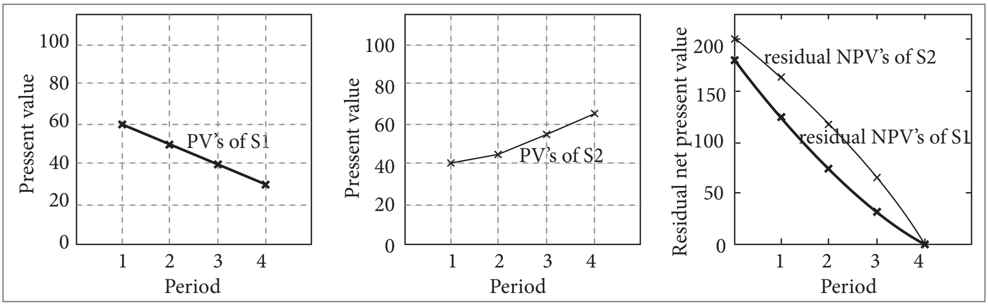

Fig. 4. Ideal-typical example of low agent switching costs and private information about the suppliers' maximal bids, present values of both suppliers (left, middle) and comparison of residual net present values (right)

4.2. Experiments with test persons and internet based program

Figure 5 depicts the variant of the previous game where the principal does not see the maximal bids of the suppliers and the suppliers just know their own bids (Harsanyi 1967, 1977). Therefore the stronger supplier is able to fool the principal about his real maximal bid. However, the principal has the possibility of imposing pressure upon this supplier by letting the time pass.

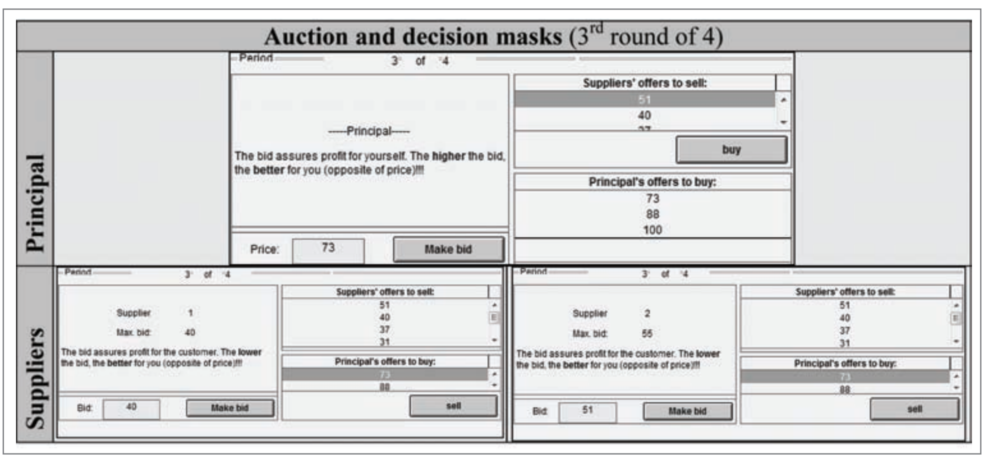

Fig. 5. 2-step initial bargaining: irrevocable determination of the supplier, profit division with him

Equally with table 1, in table 2 the accumulated and average results of the experiment are compared with the predictions of the ADMCS-rule and the OOCS-rule for each round. Afterwards the relative deviations are calculated.

Table 2. Maximal bids and the comparison of the OOCS-rule and the ADMCS-rule with the empirical results for **low** agent switching costs and maximal suppliers' bids that are **private** information

Case	t	Max. bid		Agent	Experiment: Average profit distributions		Prediction: Profit distribution rules		Deviation ratio	
		S_1	S_2		N = 48	N = 32 (rational)	OOCS	ADMCS	OOCS	ADMCS
Switching costs: Low **Events:** Expected **Max bids:** Private information	1	**60**	40	P	48.5	47.9	50	30	95%	160%
				S_1	11.1	12.1	10	30	121%	40%
				S_2	0.0	0	0	0	–	–
	2	**50**	45	P	45.3	47.0	47.5	25	99%	188%
				S_1	2.5	3.0	2.5	25	119%	12%
				S_2	0.2	0	0	0	–	–
	3	40	**55**	P	45.0	47.6	47.5	27.5	100%	173%
				S_1	0.9	0	0	0	–	–
				S_2	6.3	7.4	7.5	27.5	98%	27%
	4	30	**65**	P	45.1	45.8	47.5	32.5	96%	141%
				S_1	0.1	0	0	0	–	–
				S_2	17.0	19.2	17.5	32.5	110%	59%
Average deviation ratio:									7.53%	65.46%

The average deviation ratio of the OOCS-rule is: 0.0753 = 7.53%. The average deviation ratio of the ADMCS-rule is: 0.6546 = 65.46 %

5. Unexpected events, information about maximal bids by suppliers is public

5.1. Simulation of an ideal-typical example

In figure 6 the case is shown where

– **some events are unexpected**,

– the suppliers' **maximal bids are public information** (Rutkauskas *et al.* 2008; Rutkauskas and Ramanauskas 2009; Turskis *et al.* 2009) and

– the costs of switching the supplier are low.

The left and the middle columns depict the present values for the suppliers in the referring rounds. The right column shows the residual NPV's. In the upper row the result of the information is shown, which is available before the 1st for all participants. The second row depicts the surprising change of the present values at supplier 2. For instance, the skills of the 2nd supplier rise in an **unexpected** way.

Suddenly it is clearly advantageous for the principal to cooperate till the end of the game with supplier 2. The second shock takes place in the 3rd round and is depicted in the 3rd row. Surprisingly, it becomes beneficial for the principal to switch to the 1st supplier for the remaining 2 rounds.

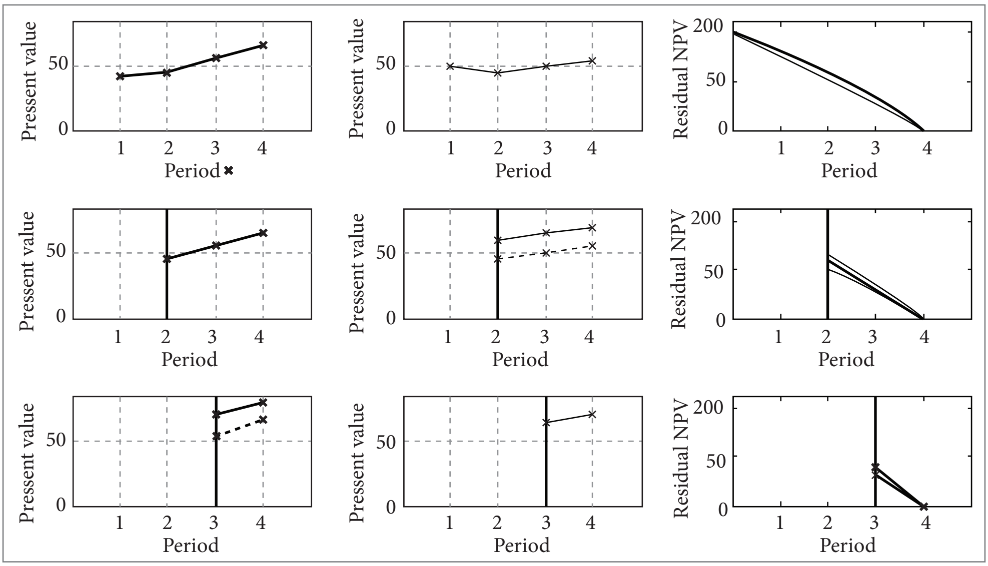

Fig. 6. Ideal-typical example of low agent switching costs and public information about the suppliers' maximal bids, present values of both suppliers (left, middle columns) and comparison of residual net present values (right column), suddenly changed situations because of 2 shocks in the 2nd and 3rd rounds (middle, lower rows)

5.2. Experiments with test persons and internet based program

The results in table 3 refer to the z-tree experiment game of figure 6.

The average deviation ratio of the OOCS-rule is: 0.1262=12.62%. The average deviation ratio of the ADMCS-rule is: 0.8081 = 80.81 %

Table 3. Maximal bids and the comparison of the OOCS-rule and the ADMCS-rule with the empirical results for **low** agent switching costs and **public** information, unexpected events implicit

Case	t	Max. bid S_1	Max. bid S_2	Agent	Experiment: Average profit distributions N = 48	Experiment: Average profit distributions N = 40 (rational)	Prediction: Profit distribution rules OOCS	Prediction: Profit distribution rules ADMCS	Deviation ratio OOCS	Deviation ratio ADMCS
Switching costs: Low **Events:** Unexpected **Max bids:** Public information	**1**	40	**50**	P	43.2	44.8	45	25	100%	179%
				S_1	0.3	0	0	0	–	–
				S_2	6.1	5.2	5	25	105%	21%
	2	45	**60**	P	49.0	51.2	52.5	30	98%	171%
				S_1	0.2	0	0	0	–	–
				S_2	9.3	8.8	7.5	30	117%	29%
	3	**70**	65	P	64.8	66.5	67.5	35	98%	190%
				S_1	4.9	3.5	2.5	35	141%	10%
				S_2	0.2	0	0	0	–	–
	4	**80**	70	P	71.7	73.4	75	40	98%	184%
				S_1	6.5	6.6	5	40	132%	16%
				S_2	0.8	0	0	0	–	–
Average deviation ratio:									12.62%	80.81%

6. Unexpected events, information about maximal bids by suppliers is private

6.1. Simulation of an ideal-typical example

In figure 7 the case is shown where

- **some events are unexpected**,
- the suppliers' **maximal bids are private information** and
- the costs of switching the supplier are low.

Initially, it is advantageous for the principal to select the 1st supplier. However, the 1st shock in the 2nd round decreases surprisingly the residual present values of supplier 1 (left column, middle row). The 2nd shock rises in the 3rd round the residual present values of supplier 2 (middle column, lower row). Suddenly it is advantageous for the principal to switch the supplier from the 1st one to the 2nd one.

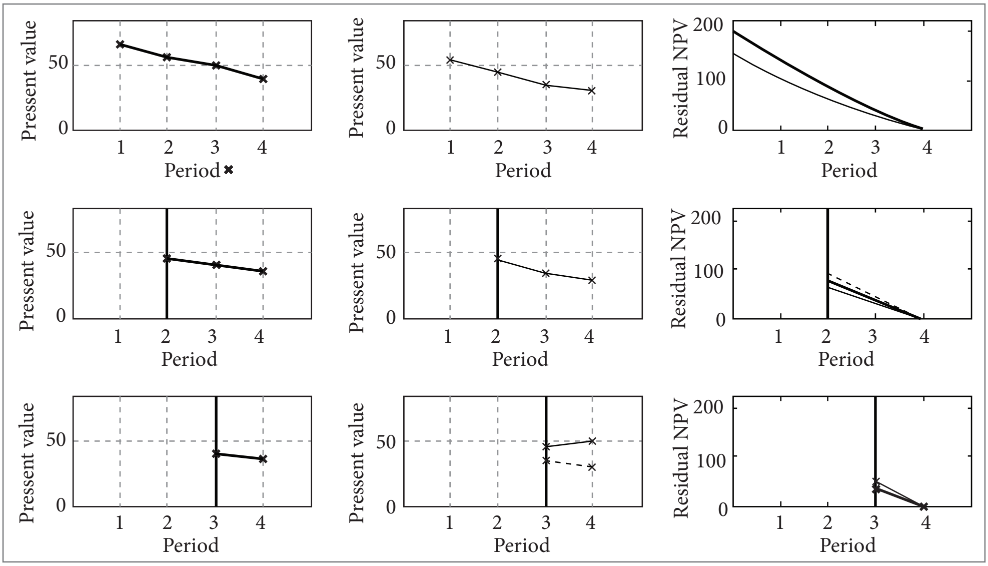

Fig. 7. Ideal-typical example of low agent switching costs and private information about the suppliers' maximal bids, present values of both suppliers (left, middle columns) and comparison of residual net present values (right column), suddenly changed situations because of 2 shocks in the 2nd and 3rd rounds (middle, lower rows)

6.2. Experiments with test persons and internet based program

The results in table 4 refer to the z-tree experiment game of chapter 3.4 and figure 4.

The average deviation ratio of the OOCS-rule is: 0.1591 = 15.91%. The average deviation ratio of the ADMCS-rule is: 0.7914 = 79.14%

7. Comparison of the OOCS-rule and the ADMCS-rule through the evaluation of the experiments

The 4 cases of individual customer experiments have been compared with the theoretic predictions (the costs of switching the agent, i.e. the supplier are low). The average deviation ratios for the OOCS-rule and the ADMCS-rule are collected from the 4 experiments and are listed in table 5.

Figure 8 shows for all 4 games with low agent switching costs the comparisons between the empirical data and the OOCS-rule, and between the empirical data and the ADMCS-rule:

It can be seen that in the case of low agent switching costs the introduced OOCS-rule provides a fundamentally better prediction than the ADMCS-rule.

Table 4. Maximal bids and the comparison of the OOCS-rule and the ADMCS-rule with the empirical results for **low** agent switching costs and **also private** information, unexpected events implicit

Case	t	Max. bid		Agent	Experiment: Average profit distributions		Prediction: Profit distribution rules		Deviation ratio	
		S_1	S_2		N = 48	N = 33 (rational)	OOCS	ADMCS	OOCS	ADMCS
Switching costs: Low **Events:** Unexpected **Max bids:** Private information	1	**65**	55	P	51.2	58.5	60	32.5	97%	179%
				S_1	7.5	6.5	5	32.5	130%	20%
				S_2	2.1	0	0	0	–	–
	2	**45**	**45**	P	39.3	40.8	45	22.5 22.5	91%	182%
				S_1	2.2	1.4	0	22.5 0	–	6%
				S_2	2.5	2.7	0	0 22.5	–	–
	3	40	**45**	P	37.6	41.3	42.5	22.5	97%	183%
				S_1	0.2	0	0	0	–	–
				S_2	4	3.7	2.5	22.5	149%	17%
	4	35	**50**	P	36.5	41.4	42.5	25	97%	165%
				S_1	0.3	0	0	0	–	–
				S_2	8.5	8.6	7.5	25	115%	34%
Average deviation ratio:									15.91%	79.14%

Table 5. The average deviation ratios for the OOCS-rule and ADMCS-rule, collected from the 4 experiments

Chapter	Events	Information of maximal bids	Recommended rule	OOCS-rule	ADMCS-rule
3	Expected	Public	OOCS	10.13 %	88.47 %
4	Expected	Private	OOCS	7.53%	65.46%
5	Unexpected	Public	OOCS	12.62%	80.81%
6	Unexpected	Private	OOCS	15.91%	79.14%

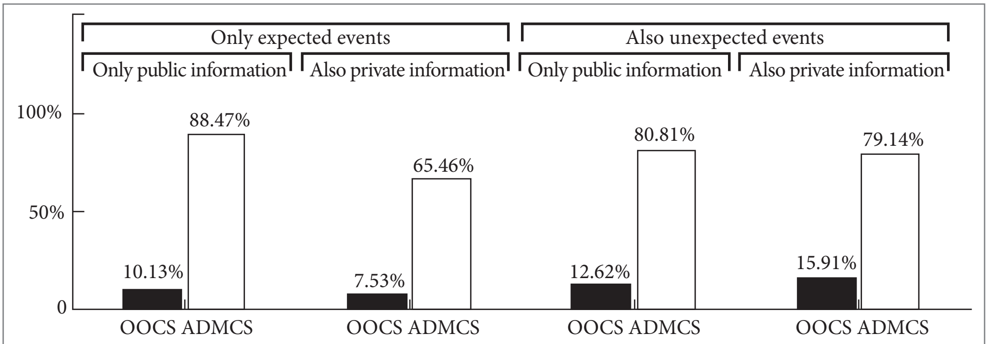

Fig. 8. Experiments with low agent switching costs, comparison between the OOCS-rule and the ADMCS-rule regarding the average deviations between the theoretic predictions and the experimental data

8. Conclusions

The "Outside-option modified profit distribution rule for coalition structures" (OOCS-rule)

The proposed profit distribution rule refers to the case of 3 agents and consists of the following axioms:

- Pareto-efficiency within the "productive component" in the coalition structure;
- "Modified symmetry", which is similar with the "Myerson-axiom of balanced contributions". An auction procedure is assumed, where a principal selects an agent. The principal gains the complete maximal bid of the weaker offerer and additionally gains the half of the difference of the maximal bids of the offerers. The stronger offerer gets the other half of this difference. The weaker offer does not get anything.

Stability of agreements / predictions

In an auction procedure with an industrial supply chain with 2 possible suppliers, an individual customer and a coalition structure it is distinguished between

- high costs and low costs of switching the cooperation partner and
- purely public information and the possibility of private information.
- In the case of low agent switching costs, the introduced OOCS-rule provides prediction about the negotiation result that enables a stable agreement under the assupmtion of rational deciders. It is superior towards the ADMCS-rule Oppositely in the case of high agent switching costs the ADMCS-rule provides the appropriate prediction about the profit division among the cooperating agents, due to the fact that the other agent is irrevocably excluded. If the information about the maximal bids of the agents is private, the use of the profit distribution rules is not affected.

Results of experimental investigation

For supply chains with individual customers the following has been shown through the analysis of the collected experimental data: The OOCS-rule has been proven as accurate and significantly more precise than the ADMCS-rule. The results are valid for all investigated games, i.e. games with expected events (chapters 3 and 4) and unexpected events (chapters 5 and 6) and for games with only public information (chapters 3 and 5) and games with private information (chapters 4 and 6). However the costs of revoking the decision have to be low of negligible. If these costs are high it should be investigated separately.

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PELNO PASKIRSTYMO PRAMONINĖSE TIEKIMO GRANDINĖSE EKSPERIMENTINIS TYRIMAS

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Santrauka. Paprastai pramoninio tiekimo grandinėje klientas pasirenka konkretų tiekėją ir atmeta kitus. Jei vėliau su atmestuoju tiekėju vis dėlto užmezgami santykiai, klientas įgyja didelę svarbą plėtojant partnerių santykius. Sukurta pelno paskirstymo taisyklė, įvertinanti atmesto tiekėjo įtaką. Straipsnyje pateikiama serija žaidimų, kuriuose kinta esama vertė ir daroma įtaka partnerių santykiams. Pirma, naudojantis MATLAB programine įranga apskaičiuojamos ir atvaizduojamos būdingosios reikšmės. Antra, pasitelkus *Z-tree* programinę įrangą atliktas internetinis eksperimentas siekiant įrodyti, kad pasiūlyta pelno paskirstymo taisyklė galioja. Galiausiai eksperimentiniai duomenys palyginami su teorinėmis prognozėmis.

Reikšminiai žodžiai: susitarimų stabilumas, pelno paskirstymo taisyklė, kraštinė sąlyga, eksperimentai, MATLAB, *Z-tree*.

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