Charles University in Prague

Faculty of Social Sciences
Institute of Economic Studies

MASTER THESIS

An Experimental Test of Design Alternatives for Spectrum Auctions with Communication Channels

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, May 16, 2014

Jindřich Matoušek

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Abstract

The multi-unit auction mechanisms are one of the most important instruments used for the allocation of spectrum licenses, airport time slots, delivery routes, networking or furniture allocation. This thesis experimentally examines the attributes of complex multi-unit auction mechanisms (Simultaneous Multi-Round Auction and its combinatorial extension Simultaneous Multi-Round Package Bidding) in the presence of an opportunity to collude among the bidding participants due to a provision of a simple communication channel - a chat window. The results suggest that in our parameter setting, the combinatorial bidding format does not bring higher efficiency. Interestingly, allowing for communication increases efficiency in both examined auction formats. Bidders are able to split the auctioned goods in a collusive agreement, which results in a better allocation compared to the auction formats without the communication channel. Combinatorial bidding on packages probably makes the decision-making problem of bidders hard to process and cause inefficiencies, especially for designs with large number of auctioned goods. When suspicion of potential collusion is present during the preparation phase of the auction, policymakers should favour non-combinatorial auction formats due to the simplicity of their bidding languages.

JEL Classification	C91, D43, D44, L96
Keywords	combinatorial auctions, spectrum auctions, experimental economics, communication, collusion, market imperfection, telecommunications

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Abstrakt

Složité aukční mechanismy určené k dražbě velkého počtu zboží současně jsou jedny z nejdůležitějších nástrojů pro alokaci spektrálních licencí, letištních intervalů, doručovacích tras, tvorby sítí či alokaci nábytku. Tato diplomová práce experimentálně zkoumá vlastnosti komplexních mechanismů určených k dražbě velkého počtu zboží současně (*Souběžné vícekolové aukce* a jejího rozšíření umožňujícího kombinační příhozy na ucelené soubory zboží, tedy *Souběžné vícekolové aukce pro souborné příhozy*), do nichž zavádí možnost koluzivního chování mezi jednotlivými účastníky skrz jednoduchý komunikační kanál. Výsledky experimentu naznačují, že kombinační příhozy při našem nastavení parametrů aukce nezvyšují její efektivitu. Umožnění a povolení komunikace mezi účastníky zvyšuje efektivitu v obou zkoumaných aukčních formátech. Zájemci si jsou schopni rozdělit dražené zboží mezi sebe v rámci koluzivní dohody, což má za následek lepší alokaci zboží v porovnání se standardní aukcí bez možnosti komunikace. Kombinační příhozy na ucelené soubory zboží pravděpodobně stěžují rozhodovací proces účastníků natolik, že jsou tito jen špatně schopni zpracovat relevantní informace. To způsobuje neefektivitu, zvláště pak v případech s vysokým počtem draženého zboží. Při podezření na přítomnost koluze v přípravné fázi aukce by měli zákonodárci upřednostňovat nekombinační aukční formáty kvůli jednoduchosti jejich mechanismů přihazovaní.

Klasifikace	C91, D43, D44, L96
Klíčová slova	kombinační aukce, aukce spektra, experimentální ekonomie, komunikace, koluze, třní nedostatky, telekomunikace

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Acronyms

3G	Third generation
4G	Fourth generation
CC	Combinatorial Clock auction format
CDA	Continuous double auction
CMA	Combinatorial Multi-round auction
CSO	Czech Statistical Office
CTO	Czech Telecommunications Office
CZK	Czech Crown
ECU	Experimental currency unit
EUR	Euro currency
FCC	Federal Communications Commission
HPB	Hierarchical package bidding combinatorial auction format
MPB	Modified package bidding format
RA	British Radio-communications Agency
RAD	Resource allocation design
SMR	Simultaneous multi-round auction format
SMRPB	Simultaneous multi-round package bidding auction format
UMTS	Universal Mobile Telecommunications System
WDA	Winner Determination Algorithm
XOR	Logical Exclusive OR (Boolean)

Master Thesis Proposal

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Proposed Topic:

An Experimental Test of Design Alternatives for Spectrum Auction in Czech Republic

Topic Characteristics:

Motivation

The mobile telecommunication sector in the Czech Republic can hardly be considered as a highly competitive. Only a handful of players which seem to keep an unwritten cartel agreement give evidence of it. However there is a flash of hope for the consumers in the nearest future. The Czech Telecommunications Office (CTO - the Czech regulator for telecommunications and postal services) published recently it would announce an auction for a new allocation of rights to mobile frequency spectrum intervals for the next 15 years. The result of this auction should lead to higher competition in the market and therefore to the gains for consumers. But will it be so? It depends on the auction type used by the CTO, on the execution of the auction itself and also on the auction results and future development of the market.

Several block intervals in the 800 MHz, 1800 MHz and 2600 MHz in paired spectrum and also 2600 MHz in unpaired spectrum will be auctioned. In the 1800 MHz paired spectrum (GSM technologies) the unallocated portion of the spectrum will be also offered for sale. This should ensure the entrance of new operator into the market. The upset prices in the auction will range from 24 up 1100 millions of Czech crowns per one block of the particular spectrum. The CTO plans to use the auction with two phases. In the first phase the SMRA-S type of auction will be performed. It is a simultaneous multiple round auction with possibility of renouncement of the highest bid. In the second phase the frequency intervals on the basis of profits from the first phase will be distributed. This will be done in form of selection of specific frequency segments or intervals ranked by the offered price with the right of priority selection.

The crucial question is whether this particular type of auction will be the most effective method from the point of view of the maximal revenues and auction results. And if not, what are the reasons of this? Insufficient verification of the particular auction type by the regulator? Corruption? Unprofessional approach of the authorities? As the mobile frequency spectrum intervals are considered a scarce resource, this auction is crucial for the future competition in the telecommunication market in the Czech Republic as well as it can bring substantial revenues to the state treasury. Because of these facts the spectrum auction in the Czech Republic should be definitely subject to detailed scientific examination.

Current state of the affairs

The Czech telecommunication spectrum auction is currently in its middle stage. In January 2011 the Government of the Czech Republic approved the methods and intention of the Czech Telecommunication Office in the matter of the managing the telecommunications spectrum (Usnesení vlády ČR č.78/2011 sb.). Based on this resolution the CTO started the preparation phase of the auction. In this preparation phase it compiled the proposal of principles of the public tender, which was published on the 1st September 2011 on the CTO's web page. This stage resulted in the first quarter of 2012, when the public tender for purpose of allocation of rights to use the particular telecommunication frequencies was published on 20th March (Český telekomunikační úřad, 2012).

According to this document the CTO should finally announce the tender on 22nd June 2012. The dates set by the CTO are only provisional, but the deadline for the delivery of applications to this tender should be at the beginning of the August 2012. The auction itself should be performed at the end of the November 2012 and the announcement of the results of the auction phase at the beginning of the December 2012. The Czech Telecommunications Office then has to grant the rights until the end of December 2012. All the dates can be found in the documentation to the public tender (Český telekomunikační úřad, 2012). According to the importance and complexity of the Czech telecommunications spectrum auction I suppose that a certain delay in the deadlines can be expected.

Importance of Experimental Approach

Academicians as well as authorities often examine efficiency and revenues not only of the spectrum auctions. The problem is, that real auctions typically brigs different results than theoretically predicted. The evaluation of auction outcome is therefore a very interesting question. For this purpose an experimental approach is normally used. It seems to be a common practice in the United States (Banks, et al., 2003, Goree, et al., 2006), but also in Britain (Abbink, 2005) or Taiwan (Chinn-Ping Fan, 2011). Moreover the current literature shows that the results vary with same types but different settings of the auctions (Holt, 2006). Therefore performance of the specific economic experiment with exact settings and parameters is important in each particular case.

In the thesis I would like to carry out such experiment in the specific setup of the Czech environment. Furthermore I would like to compare the specific auction type used by the Czech Telecommunications Office to three other most suitable auction settings as in Brunner, et al. (2010). Using a proper experimental design and subjects I would like to compare the outcomes, revenues and efficiency of examined auction types. By this procedure I would like to evaluate the appropriateness of finally used settings in the Czech spectrum auction.

Hypotheses:

1. The Czech Telecommunications Office used the most efficient auction setting for the purpose of Czech spectrum auction. If not, what are the reasons of it?

2. The setting of the Czech telecommunications spectrum auction will bring the highest possible revenues for the state treasury.

3. The Czech telecommunications spectrum auction led to increased competition in the market.

Methodology:

I would like to conduct a full-computerized laboratory experiment. The design of this experiment as well as the number of participants and other details will depend on the specific setup of the Czech telecommunication spectrum auction announced by the Czech telecommunications office. The CTO planes to use the SMRA-S type of auction in the first stage. It is a simultaneous multiple round auction with possibility of renouncement of the highest bid. In the second stage of the spectrum auction the frequency intervals on the basis of profits from the first phase will be distributed. This will be done in the form of selection of specific frequency segments or intervals ranked by the offered price in the auction with the right of priority selection by the winners. I would like to compare the SMRA-S type of auction with other possible ones as the Brunner et al. (2010) did in their paper. They found, that the combinatorial auction formats clearly differ both in terms of efficiency and sellers revenue. The SMR auction types have not perform the best among other examined alternatives in their work. Therefore I would like to include other types of the auction as well (Combinatorial Clock type, Resource Allocation Design...).

Prior to the experiment itself I would like to run a pilot-version to verify the structure of the experiment and calibrate the tasks. The number of sessions and total number of participants will depend on the design of the experiment as well as the funding possibilities. After the experiment I will process the gained data by proper econometric methods.

Moreover I would like to place my thesis into the institutional framework of antitrust economics and theory of regulation. Through this the degree and improvement of competition on the Czech telecommunications market can be studied and the functioning of the regulator can be put in question. I would like to provide simple tests for market concentration such as Herfindahl indices before and after the auction in the thesis. The assessment of structure of the market and its functioning should also be included.

Outline:

1. Introduction
2. Institutional background
3. Basics of telecommunication technologies
4. The Czech telecommunication spectrum auction setup
5. Experimental design
6. Data analysis
7. Results
8. Conclusions

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1 INTRODUCTION

"The circumstances in which an economic system maintains its own structural properties may be quite narrow and fragile. This is of course of great concern to the economic engineer, whose machines are supposed to work for several years, in different contexts and without the constant supervision of their manufacturer."

(Guala, 2001, p. 15)

The multi-unit auction mechanisms are one of the most important allocation instruments for complex real life situations. Used for the allocation of spectrum licenses, airport time slots, delivery routes, networking or furniture allocation, they are one of the few masterpieces of modern economics engineering (De Vries and Vohra, 2003, Guala, 2001). The main concern of every auctioneer is the efficiency. However, allocating the objects for sale to those who value them the most is not a simple task, especially when real auctions do not always bring the results as theoretically predicted. Academicians as well as authorities therefore often examine efficiency and revenues of various complex auction mechanisms. It seems to be a common practice in the United States (Banks et al., 2003, Goeree et al., 2006), but also in Britain (Abbink et al., 2005) or Taiwan (Fan, 2011). Moreover, the recent literature shows that the results vary with same types but different settings of the auctions (Holt, 2005).

The topic of Simultaneous multi-round auctions is of great importance since these are widely used for big real-life auctions. Recently most scrutinized spectrum auctions are just an important tip of the iceberg. One of the main concerns in real auctions is a tangible possibility of collusion among the bidders. There is strong evidence that ascending auctions are very vulnerable to collusion behaviour of bidders and also very likely deter entry into the auction (Klemperer, 2004). Although many rules were adopted since the early nineties in order to prevent various forms of signalling (for example precise determination of bid up levels), there still exists options for collusion, notably in the situations with repeated interaction among bidders and their long-term acquaintance from the real market.

A variety of experimental studies examine the evolution of collusion in auction mechanisms (Zhou and Zheng, 2010, Burtraw et al., 2009, Hu et al., 2011, Bachrach, 2010). However, the collusion in complex simultaneous auctions of multiple goods was not yet properly examined for mechanisms with more than only a few objects for sale. The spectrum auctions with their usually large number of goods are typical candidates for collusive behaviour of bidders (Kwasnica and Sherstyuk, 2013). There is evidence that allowing for combinatorial bidding on packages of goods may break collusion in the multi-unit auctions, but this evidence is not sufficient (Kwasnica and Sherstyuk, 2013). Moreover, *"Combinatorial auctions have been studied analytically for several years, but only limited experimental results are available for auctions with more than 10 items"*(Scheffel et al., 2012, p. 667).

Auctioning of the radio spectrum in Czech Republic has been one the most recent applications of the complex auction mechanisms. The long prepared public procurement should have brought more competition to the market that comprised of only a handful of players with excessive profits and strong suspicions to collusion (CTO, 2012a). The Simultaneous multi-round auction, an instrument developed in the early 80s' on the request of US Federal Telecommunications Commission precisely for the allocation of spectrum intervals, was finally used for this purpose (Guala, 2001, CTO, 2012b, CTO, 2013d). Two Auctions was eventually conducted since the first 2012 Auction was terminated by the Czech Telecommunications Office, a regulator of the market and responsible authority, due to unrealistically high bids (CTO, 2013a). The second auction took place in November 2013 and resulted in an eight-day poor contest with low level of participant activity, final prices and auctioneer revenues. The distribution of market power remained the same; only three original incumbents participated in the second Auction. No competition seemed to be present while bidders split the objects for sale almost at the upset prices (CTO, 2013b, CTO, 2013c).

The Czech Spectrum Auctions may serve as representative of simultaneous auction with high suspicion to collusion. Its "double execution" created repeated nature of the game, where all three final winners of the 2013 Auction known each other's strategies from the previous 2012 Auction. Moreover, all three winners while being well established and the only market incumbents, were already accused from tacit collusion by the CTO in 2012 (CTO, 2012a). Even though the collusion among the incumbents was not proved (Bányaiová, 2012), the CTO in its report stated that "*the relevant market is not efficiently competitive market*" (CTO, 2012a). All facts underlying the Czech Spectrum Auctions make it a perfect model example of collusive parameter setting. Since there were too many external exogenous effects in the background of the Auction, the real situation would be almost impossible to replicate in an experimental setting. However, the crucial parameter worth replication lies in the suspicion of collusive behaviour of its incumbents and the structure of the market that can be found also in other countries and industries. Using the parameter setting of Czech Spectrum Auctions, I continue in the direction toward the basic research in this thesis.

This thesis studies complex auction formats under the possibility of communication during the auction. Its objective is the experimental evaluation of two Simultaneous multi-round auction formats within a specific setting with communication channel facilitating potential collusion among participants. I employ similar setting as in Brunner et al. (2010), who experimentally examined the Simultaneous multi-round auction and three other combinatorial auction formats. I replicate half of their paper and provide an extension by adding the dimension of communication similar as in (Miralles, 2010). In four experimental treatments, I examine two multi-round auction formats: the Simultaneous multi-round auction format and Simultaneous multi-round package bidding auction format. I set against each other a simple generalization of English auction for multiple goods and its extension allowing for combinatorial bidding. I employ two treatments with basic setting and two treatments with presence of communication channel in both auction formats. In this experimental design, I compare all four alternatives in terms of their efficiencies, bidder surpluses and auctioneer revenues. I develop an econometric model of relative efficiency by which I explain the underlying logic and the results of my experiments.

My main results include I have found that, contradictory to Brunner et al. (2010), that the relative efficiency of Simultaneous multi-round auction format is generally higher than the one of its package bidding alternative, especially in treatments allowing for communication. Communication increases efficiency of auctions in setting employed in this experimental design. Allowing for combinatorial bidding may prevent collusion.

The thesis is structured as described in the following paragraph. This introduction is considered a first chapter of the thesis. Chapter 2 describes the structure of the market for mobile telecommunications in the Czech Republic, provides an insight into the recent market situation and the topic of Czech Spectrum Auctions. Chapter 3 provides a review of literature concerning respective auction experiments, collusion in auctions and other concepts related to topic of this thesis. Chapter 4 describes underlying methodology, model specification, parameters settings and states the hypotheses of the experiments. Chapter 5 introduces the general procedures of the experiment. Chapter 6 provides the qualitative analysis of the data. Chapter 7 explores the econometric model of relative efficiency and develops further alterations. Chapter 8 contains the summary of main findings. Chapter 9 concludes. There are complete procedures regarding the econometric analysis as well as complete experimental instructions provided in the appendices.

2 MARKET SITUATION

The research in this thesis is based on the model situation of recent evolution of the market for mobile telecommunications in the Czech Republic. This segment went through rapid changes in last three years when transforming out of the rigid institutional structure to the situation more resembling the market of third millennium. Even though it is not the aim of this thesis to evaluate Czech telecommunications market from the institutional and regulatory point of view (nor engage in the policy evaluation), it is necessary to put the topic into its proper context. This chapter should provide an insight into the recent market situation and introduce the reader into the topic of Czech spectrum auctions held in 2012 and 2013.

2.1 FORMER SITUATION

There are no objections that the telecommunication markets create the infrastructure of third millennium. With the growing amount and width of provided services, the expenditures on telecommunications are huge. In the 2010 the aggregate expenditures on telecommunications services in Czech Republic were 144 billions of Czech crowns (Rašín 2012), which was about 3,8% of GDP[1] (ČSÚ, 2013). At the end of the first decade of the third millennium, the mobile telecommunication sector in the Czech Republic could hardly be considered highly competitive. The market was characterized by long-term stable situation comprised of only three big players with profits high above European average (Eurostat, 2014b) and strong suspicion of collusion (CTO, 2012a).

Prices for mobile telecommunication services in Czech Republic were by 58,54 %2 higher compared to the EU 27 average in 2010 and were steady for long time horizon (Eurostat, 2014b). Three market incumbents, *Telefónica Czech Republic*, *T-mobile Czech Republic*, and *Vodafone Czech Republic*, were all held by foreign owners, which operated in telecommunications on the international basis. There was an unsuccessful investigation of a tacit collusion on the market for mobile telecommunications in 2012. The Czech Telecommunications Office found that there

[1] Own calculations based on the citations.

[2] Percentage points.

existed multiple enterprises with significant joint market power on the market. It identified three barriers to competition: i) denial of access to other entrepreneurs; ii) rejection of request for a wholesale offer; and iii) excessive price for origination, which did not allow possible replication of retail offer. Comparison of recent market evolution showed insufficient degree of competition in all observed aspects and demonstrated features of tacit collusion (CTO, 2012a).

Mobile and wireless connection devices operate based on the transmission of the signal through the space by the electromagnetic wave motion. The wave motion is a physical phenomenon. Only the limited number of frequencies of the electromagnetic waves can transmit the signal in a particular way. These frequency spectrum intervals are therefore considered a scarce resource. Its allocation, and therefore the degree of competition in the market, is regulated by the state represented in the Czech Republic by the Czech Telecommunications Office (CTO). The CTO is a state regulatory agency for telecommunications and postal services and has the privilege to administer the allocation of the rights for frequency spectrum intervals for the telecommunications services. It should supervise the market and welfare of the consumers. The CTO, aware of the unsatisfactory structure of the market, start planning an auction for new allocation of rights to mobile frequency spectrum intervals with estimated realization in 2012.

2.2 THE FIRST AUCTION

The CTO announced in June 2012 an auction for a new allocation of rights to mobile frequency spectrum intervals for the next 15 years. The result of this auction should have lead to higher competition in the market and therefore to the gains for the consumers.

Several block intervals in the 800 MHz, 1800 MHz and 2600 MHz in paired spectrum and 2600 MHz in unpaired spectrum should have been auctioned off. There was an unallocated frequency portion in the 1800 MHz paired spectrum interval (GSM technologies) also offered for sale. This should have ensured the entrance of new operator into the market. The upset prices in the auction ranged from 24 up 1100 millions of Czech crowns per one block of the particular spectrum. The CTO planned to implement the auction with two phases. In the first phase, a simultaneous multiple round type of auction (SMR) would have been performed to allocate individual general blocks of spectrum. Based on profits from the first phase, the exact frequency intervals should then have been distributed in the second phase of the auction. This should have been done by one round sealed bid auction of the right of priority selection of specific frequency segments or intervals ranked by the offered price (CTO, 2012b).

2.2.1 Termination of the First Auction

Four enterprises participated in the 2012 Auction. Three market incumbents and fourth enterprise, the PPF Mobile Services - potential new entrant to the market. The 2012 Auction began in November 2012 and continued up to March 2013 when it was cancelled due to the unrealistically high bids. This situation occurred due to misfortunate setup of the auction. Three current providers were able to increase the prices of auctioned goods high enough to daunt the fourth participant of the auction. CTO therefore cancelled the auction with an intention to start a new one in late spring 2013 with altered rules. The reasons for the termination were at least questionable. The CTO stated:

"*Total actual offer for auctioned frequencies* exceeded the limit of 20 billion *CZK* and was still growing. The CTO emphasized in the announcement of the auction that financial revenue is not its primary objective. Total size of current bid is, according to all models of the feasibility[3], economically unrealistic. In its consequences it would have led to a dramatic *and global* high price for the new fourth-generation telecommunication services and *to an* essential time delay in commissioning of new generation networks *to* commercial operation" (CTO, 2013a, author's translation).

The termination of the 2012 Czech Spectrum Auction with reference to the inability of participants to introduce new technologies to the market in time is highly disruptive. There were conditions and deadlines for (i) putting new technologies into operation, (ii) usage of full available spectrum, (iii) provision of other services, and others explicitly stated in the official Auction announcement (CTO, 2012b). Based on this material, it is highly improbable that there should be any institutional delay of the technology introductions.

Even though the financial revenue was not primary objective of the Auction, its termination at the level of 20 billion CZK, due to its excessive magnitude, had its counter-arguments. There is a strong evidence form the past spectrum auctions that this final price may not be as high at it may seem

When six European countries auctioned off spectrum licenses for 3G technologies, total final prices were substantially different for each auction. Germany and UK sold

[3] These models were not closely specified.

spectrum for over 600 EUR per person, which was over 2% of GDP. However, the prices in other countries were, according to the literature, substantially smaller when auctions in Austria, Netherlands, Italy, and Switzerland reached revenues of just 100, 170, 240 and 20 Euros per person, respectively. These numbers are small with respect to the original predictions of revenues of more than 400 EUR per person in both Swiss and Italian auctions (Klemperer, 2004, p. 103). Klemperer (2004) then suggests that these auctions were fiascos primarily because they were poorly designed. Data for both Czech cases, which are substantially lower than those presented above, are summarized in Table 1. Due to all above-mentioned facts is the termination of the 2012 Czech Spectrum Auction disputable.

Table 1: Czech Spectrum Auctions financial results

	Total selling price in EUR[4]	**Total selling price in EUR per capita**[5]	**Total selling price in % of 2012 GDP**[6]
Auction 2012	740 308 948 €	70,4 €	0,53%
Auction 2013	310 751 239 €	29,5 €	0,22%

Note: Own calculations; (Eurostat, 2014a); (ČSÚ, 2013); (ČSÚ, 2013)

2.3 THE SITUATION IN BETWEEN

The situation in between 2012 and 2013 Auctions was highly turbulent. Shortly after the beginning of the first Auction in the late autumn 2012, the CTO issued draft for Analysis of Relevant Market No. 8, which had a substantial impact on the market situation. The relevant market no. 8 consists of “access and call origination on public mobile telephone networks.” The CTO found sufficient evidence, that on the relevant market exist multiple enterprises with significant joint market power and identified three barriers to economic competition[7] in the analysis which demonstrated features of tacit collusion (CTO, 2012a).

Even though the collusion was latter not explicitly legally proven and punished (Bányaiová, 2012), its features were indisputably present in the market. The CTO

[4] EUR exchange rate for January 8, 2014 = 27,448; used for both table columns.

[5] Population of Czech Republic on 2012 = 10 509 000

[6] GDP of Czech Republic for 2012 = 3 84 5 900 millions of CZK

[7] Barriers already mentioned in the section 2.1 of this thesis.

consequently approached to the precaution by commanding compulsory permission of access to specific network elements and associated facilities for third party enterprises, i.e. allowed the “mobile virtual network operators” to enter the market. In reaction to the draft for Analysis of Relevant Market No. 8, the incumbents did not wait for specific form of disciplinary proceedings made by CTO and, even if they did not admit any discussions to this possibility earlier, started in April 2013 a price war[8].

Charges for mobile telecommunications went down rapidly when operators offered tariffs with unlimited mobile connection possibilities and a favourable data plans. The drop in prices for respective telecommunication services was about 1/5 of original values according to CTO data barometer[9]. This only confirms the conclusion of CTO stated in its analysis. Moreover, it shows how big the mark-up and profit reserve were before the price war. These considerable changes of situation on the market of mobile telecommunications in Czech Republic preceded the second Czech Spectrum Auction held in 2013.

2.4 THE SECOND AUCTION

The 2013 Czech Spectrum Auction was introduced in April 2013 with scenario very similar to the original auction. CTO used the same auction format, even though slightly adjusted from the previous auction in order to correct the errors (CTO, 2013d). Finally, there were five participants in the auction: *Telefónica*, *T-mobile*, *Vodafone*, *Revolution Mobile* and *Sazka Telecommunications*. The Auction has begun on 11th of November and lasted for only 8 days. Even though the exact record of the auction (log) is not available to the public, it seems that the two new applicants did not even start bidding. The incumbents auctioned off the spectrum nearly at the upset prices. The overview of the 2013 Auction is provided in the Table 2. Resulting market situation is therefore identical to the pre-auction period.

Table 2: Results of 2013 Czech Spectrum Auction, prices in millions of CZK

	CATEGORY OF BLOCKS

[8] Telefónica O2 succeeded in concealing this strategic move up to its very realization and introduced the specific tariff first. The two remaining incumbents, Vodafone and T-mobile followed closely in few weeks.

[9] The barometer is available online at: http://www.ctu.cz/ctu-informuje/srovnavaci-prehled-cen-a-podminek/cenovy-barometr.html ; The official analysis of prices is usually published annually in September of the subsequent year and for the 2013 was therefore not yet available during spring 2014.

		A	B	C	D
Telefónica	*number of blocks bought*	2	3	4	0
	total price paid	2386.5	96	320	0
	average price per block	1193.25	32	80	0
T-Mobile	*number of blocks bought*	2	2	4	0
	total price paid	2231	63	320	0
	average price per block	1115.5	31.5	80	0
Vodafone	*number of blocks bought*	2	4	4	0
	total price paid	2664	129	320	0
	average price per block	1332	32.25	80	0
total number of blocks sold		6	9	12	0
number of blocks originally for sale		6	24	14	9
total selling price per category		7281.5	288	960	0
average selling price per block		1213.5	32	80	0
original upset price per block		1100	30	80	30

Note: some of the blocks were adjusted for simplification[10]

2.4.1 More Pieces to the Puzzle?

Besides the analysis of There were other events happening behind scene of Czech Spectrum Auctions besides the Analysis of Relevant Market No. 8 and its resulting liberalization of mobile virtual operators. There have occurred significant changes in the ownership structure in the market during the 2013 Auction. PPF Mobile Services abandoned the intention of entering the market directly after the first Auction was terminated. Instead, it has overtaken Telefónica O2 during the year 2013 by acquisition exceeding 60 billion CZK. Moreover, there is a substantial long-term co-operation between two biggest incumbents of the telecommunications market. Telefónica O2 and T-Mobile are sharing their networks. They have made an agreement on sharing the 3G network in February 2011 (Telefónica, 2011) and on sharing the 4G LTE network in the beginning of May 2014 (Telefónica, 2014). Without assessing if this is right[11] or not, it suggests, that such deals are contributing to the significant "joint market power" as it was identified by the CTO.

[10] The numbers of spectrum blocks in the table are different in contrast to real auction. These parameters were adjusted within the categories without the loss of generality in order to simplify the information in the table.

[11] It is not possible to dispute weather it is legal, it is.

2.5 TOWARDS THE BASIC RESEARCH

All the above-mentioned arguments gave evidence that the recently executed 2013 Czech Spectrum Auction resulted in a poor contest. Only a low level of activity had occurred caused the revenues being insignificantly above the upset prices (CTO, 2013c). The resulting distribution of the market powers is identical to the pre-auction situation. There was a lot of evidence that the Czech market for mobile telecommunications may not be competitive, or that it is even prone to collusion. Answering whether the Czech Spectrum Auctions were really affected by the collusion of their participants belongs to the ground of legal authorities rather than to academia. However, an inspiration can be drawn out of this situation since all facts underlying the Czech Spectrum Auctions make it a good example of collusive parameter setting. Moreover, too many external exogenous effects in the background make it impossible to replicate the situation in a direct experimental policy evaluation setting. The subject of this thesis lies in the direction towards the basic research. It uses parameter setting of Czech Spectrum Auctions and applies it to the research of possibility of communication in the multi-unit combinatorial auctions.

3 LITERATURE REVIEW

Two theoretical dimensions are comprised in this paper. First, the dimension of multi-unit auction formats and second, the dimension of communication within those formats. This chapter provides a review of the most important research literature on both topics. There are concepts of multi-unit auctions outlined in the section 3.1 together with other related concepts in the following sub-sections. Literature on collusion in the auction mechanisms is reviewed in the section 3.2 of this chapter.

This thesis engages in the topic auction theory mostly from behavioural and experimental point of view. I have not found thorough theoretical foundations in most experimental papers concerned with combinatorial auctions I use - (Abbink, Irlenbusch et al. 2005; Brunner, Goeree et al. 2010). Moreover, Abbink et al. (2005, p. 507) explicitly states in their paper: "*Because of their complexity, spectrum auction environments are generally not conducive to a thorough game theoretic treatment.*" I therefore, base the design on the previous research rather than on my own theoretical foundations.

3.1 CONCEPTS OF MULTI UNIT AUCTIONS

This thesis consists of experimental test of two Simultaneous multi-round auction formats within a specific setting that encompasses communication among bidders. Two auction formats were used in the design of the experiment: Simultaneous multi-round auction (SMR) and Simultaneous multi-round package bidding auction (SMRPB), which allows for bidding on packages of goods instead of on single units. The SMR auction format was originally developed in early nineties by the US Federal Telecommunications Commission (FCC) for their Spectrum Auctions. The description of the process of designing, testing and implementing the FCC auctions as one of the few cases of complex economic engineering is available in Guala (2001).

Apart from the initial experimental evaluation of the SMR design and performance, one of the first experimental tests of the SMR auction was conducted by Banks et al. (2003). On the request of the Congress of the United States, they compared the SMR auction to the design, which allowed for combinatorial bids. In its first part, the paper provides unusually extensive review of the previous experiments and conceptual issues relevant to the spectrum auctions. The main body is concentrated around the experimental study, which evaluates the SMR auction type and examines its alternatives that might promote the allocation of efficient combinations of complementary licences. The Combinatorial Multi-round Auction (CMA), an alternative developed for the FCC as a combinatorial mechanism to allocate spectrum intervals, led to more efficient allocations but lower revenues in comparison to SMR. The SMR auction should have had particular features that decrease its efficiency and create a trade-off between efficiency and length of the auction. The CMA leads to more efficient allocations but lower revenues in comparison to SMR, because many bidders experienced losses in their SMR design due to the exposure risk problem (Banks et al., 2003).

The paper by Brunner et al. (2010) deals with the different formats in flexible combinatorial spectrum auctions in complementarities environments. They compare widely used Simultaneous multi-round auction (SMR) with three other formats: the simultaneous multi-round format with package bidding – SMRPB, combinatorial clock (CC) auction and the “Resource allocation Design” – the RAD auction. The last two are considered also as package-bidding formats. They used a series of laboratory experiments for evaluation these alternative multi-unit auction formats in the article. The results of their experiments suggest that all three combinatorial (package bidding) auction procedures are more efficient than the SMR auction format, when value complementarities are present. As the interrelation of auction objects is a common feature not only of the spectrum auctions, this finding is crucially important for practice. In addition, all formats in their setting had different results in terms of efficiency as well as sellers revenue.

Peter Cramton (2012) also analyzes the standard Simultaneous Multi-round ascending auction used to assign the licences for spectrum intervals in telecommunications. He examines the strengths and weaknesses of the standard approach using the examples from the US spectrum auctions. Moreover, he presents the alternative of combinatorial clock auction (CC) as a more precise and fitting format for the spectrum auctions. His paper suggests that the CC auction is a large step ahead over the simultaneous ascending auction. The CC should eliminate the exposure risk problem, most of the gaming behaviour and it should encourage competition. The author recommends the CC format for settings, in which the local regulator does not know in advance how the spectrum should be organized. This format should also be highly transparent, which is useful for the allocation of public resources (Cramton, 2012).

Brunner et al. (2010) and Cramton (2012) are of the crucial importance as they are changing the institutions of the auction formats across various treatments. Testing of hypotheses in this thesis encompasses very similar procedures.

The results contrary to the mainstream theoretical literature provide a paper by Bichler, Shabalin et al. (2013b). They put in question results favouring the combinatorial auction formats in efficiency. They compare the Combinatorial Clock auction to SMR, while analyzing the efficiency, auctioneer revenue and examine bidding behaviour in both cases. Their experiments are based on two value models resembling single and multi-band spectrum auctions which often offer thousands possible bundles. The efficiency of the CC auction was significantly lower than that of the SMR in the multi-band model in their case. Moreover, the auctioneer revenue was lower in both value models for CC. Second recent paper dealing with high numbers of auctioned goods in the same multi-band models is (Bichler et al., 2013a). They suggest that: "*with thirty licenses for sale the number of possible bidding combinations already exceeds a billion, which are far too many for bidders to express their values for*" (Bichler et al., 2013a, p. 2). They found that simplicity of bid language has a substantial positive impact on the efficiency of the auction. Moreover, simplicity of the payment rule has a substantial positive impact on the revenue. The CC auction scores the worst on both dimensions in their experiment, favouring the simple SMR auction format. Such results are in contradiction with Brunner et al. (2010) and Cramton (2012) that prefer combinatorial bidding auction formats.

3.1.1 Elimination of Exposure Risk

Winning of some valuable package of interest or a particular set of licences with specific value to the bidder can get complicated in the combinatorial auctions. Bidders with high value complementarities may have to bid more for some licences then they are actually worth individually for them. When only a part of desired package is won, the bidder can incur big losses. This is considered as "exposure risk problem" in the auction literature. It may lead to conservative bidding in the auction and therefore lower revenues and inefficient allocation (Brunner et al., 2010)

An extensive paper dealing with the value complementarities and exposure risk problems is written by Goeree and Lindsay (2012). They evaluate the impact of exposure risk on imaginary real estate market and its performance, where complementarities arises when the selling of the old house have to precede purchase of the new one. The authors however suggest important implications for many other markets and situations, among which the telecommunication frequencies allocation is not absent.

This paper reports a series of laboratory experiments comparing a variety of auction formats and treatments. It provides a setting of continuous double auction (CDA) with high and low degree of exposure risk. Even though the CDA shows to be very effective in a wide range of settings, it reports poor results in the treatment with high degree of exposure risk (around 20%). The article introduces a simple package market and show that it effectively handles the exposure risk. This package market is only a simple extension of the continuous double auction and, as noted above, could be applied in various situations (Goeree and Lindsay, 2012).

The exposure risk problem in combinatorial auctions is also dealt in (Goeree and Holt, 2010). This paper suggests that even though the combinatorial auction can solve the problem of license packaging by letting the competition among the bidders determine the market structure, the decision-making problem in big complicated auctions that all rational bidders have to accomplish after each round, can be computationally hard to do. It claims precisely (Goeree and Holt, 2010, p.3): *"...bidders will not be able to reproduce the outcome of a round to understand why their bids did not win, unless they solve a NP-hard* (non-deterministic polynomial-time hard) *problem quickly.[12]"*

Goeree and Holt (2010) then propose a new hierarchical package bidding (HPB) combinatorial auction format which should be computationally manageable. It provides the feedback and instructions for the multi-round auction participants to distinguish the winning bid strategies for subsequent rounds and identify the mechanism for matching up the optimal responses. Moreover, it compares the HPB with two other formats. Firstly, with Modified Package bidding (MPB) format that involves the flexible package bidding mechanism and, secondly, with classical SMR format. The general result of this article is that the proposed HPB format is a "*paper & pencil*" package auction format. It is trivial to implement, transparent and easily verifiable by the bidders. In addition, it generally outperforms the other two approaches (Goeree and Holt, 2010).

3.1.2 British 3G/UMTS Auction and the English Hybrids[13]

Above, I have already mentioned the examples when the values of specific auctioned goods are interrelated and therefore the possibility of higher valuations by some bidders, for example by the established incumbents, arises. What if, then, the auctioneer would like to assign a specific part of the object or good to the new, not established entrant - to the new telecommunications operator in our case? By this

[12] I have observed exactly this type of situations during the execution of experiment.

[13] Universal Mobile Telecommunications System (UMTS).

intention, it could achieve higher competition in the market and therefore, possibly lower prices for consumers. Exactly this problem was concern of the 2000 British 3G/UMTS auction.

Abbink, Irlenbusch et al. (2005) were testing the two hybrids of standard English auction in the preparation phase of the British spectrum auction. The regulator, British Radio-communications Agency (RA), was reluctant to use the ascending SMR auction, because of strong beliefs, that such a design would discourage the new entrants from participation. The RA was planning to use one of the two hybrid designs, both based on the Anglo-Dutch concept developed by (Klemperer, 1998). Abbink, Irlenbusch et al. (2005, p.506) describe these types as follows: *"These Anglo-Dutch auctions are hybrids consisting of an ascending bid ("English") first part and a sealed-bid ("Dutch") second part. In the first part, the price for a licence is increased until all but five bidders have quit the auction. In the second stage, each of the remaining five bidders submits only one best and final offer, where their bid must be at least as high as the last prevailing price of the first stage. The licences are then sold to the four highest bidders. The two formats differ in the price successful bidders pay. In the discriminatory Anglo-Dutch auction, the four winners pay their respective bids. In the uniform Anglo-Dutch auction all four winners pay the lowest winning bid."* The third stage can be therefore considered as a *"first-price"* and kind of *"second-price"* parameter of the auction.

The paper reports experimental tests of the two hybrid auction designs in a specific setup of the 2000 British 3G/UMTS auction. Moreover, apart from comparing these two formats to one another, it compares them to the classical pure ascending English auction. The results show only small differences in efficiency, revenue, winners curse avoidance and chances for new entrants among these designs. These differences even get smaller as the number of rounds increases and when the bidders are sufficiently experienced, all three formats shows "experimental revenue equivalence." The two hybrid Anglo-Dutch auction designs are therefore neither more, nor less efficient or revenue generating than the classical English auction. The highest chances for the new entrants to get into the market were observed also in the English version of the auction(Abbink et al., 2005). The experiment was carried out for the specific situation of the 2000 British 3G/UMTS auction with its design adjusted for this purpose and therefore its conclusions cannot be theoretically generalized. However, this piece of work is important precisely for its design specific characteristics.

3.1.3 The Presence of Ambiguity

The theoretical auction literature as well as experimental applications very often relies on the assumption that bidders know the object valuations of other bidders. That is, they have perfect information about their competitors. However, in many real situations this assumption does not hold true. As an example, we can realize the various sorts of internet auctions that became very common today. The bidders in such auctions are mostly locally dispersed and have absolutely no information about their opponents.

The uncertainty about the distribution of valuations of other bidders caused by missing information is called *ambiguity*. Chen, Katuščák et al. (2007) focus in their research precisely on this information assumption. They study the impact of ambiguity on the bidders' behaviour and revenues in the first and second price sealed bid auctions. For this purpose, they are using the controlled laboratory experiment. Their work relies on the applications of the Ellsberg paradox according to which people's choices can be affected importantly by the ambiguity (Ellsberg, 1961). They develop theoretical auction model, which incorporates the risk and ambiguity conditions. Through the experimental analysis, the authors then encounter several important implications of the presence of ambiguity on sealed bid auction theory. The main finding of their research is that under the assumption of ambiguity, the bids in the first price sealed bid auctions are lower than without this premise. They also discovered that: *"the first price auction generates significantly higher revenue than the second price auction with and without the presence of ambiguity"* (Chen et al., 2007, p.514). The paper confirms previous theoretical findings that the presence of ambiguity affects the behaviour of auction participants, but its conclusions vary at the same time. The implications of these results for setting the auction designs are that the reduction in ambiguity among the bidders can lead to higher revenues, especially in the first price auctions (Chen et al., 2007).

3.1.4 The Surveys

Apart from the literature described above, there are several useful surveys of combinatorial auctions providing a solid theoretical background for research. Milgrom (2007) reports the advances in research of package allocation problem where auctioneers are willing to sell packages or combinations of goods. De Vries and Vohra (2003) refer to various combinatorial auctions examples in different applications of airport time slot allocations, delivery routes, networking or furniture allocation. They also stress the main features of complementarities or substitution effects across different assets and its combinations. Very useful insight can be also found in Cramton, Shoham et al. (2007).

3.2 COLLUSION IN AUCTIONS

The research underlying this thesis is, in its second dimension, based on the introduction of communication channel into two Simultaneous multi-round auction formats. There is strong evidence that ascending auctions are very vulnerable to collusion behaviour and very likely deter entry into the auction (Klemperer, 2004). Experimental studies show that collusion can and actually do occur with communication present in auctions. Bidders simply tend toward collusive payoff-maximizing strategies. In the multiunit auctions, bidders may split objects and therefore keep the competition on low levels throughout the auction. Sequential and multi-round auction formats appear to be the most leading to bidder conspiracies (Kwasnica and Sherstyuk, 2013).

There are various other collusion-related problems of auction concepts. There is a serious threat of entry deterrence and predation in the ascending and other forms of auctions. The auctions with small number of participants can easily become unprofitable for the auctioneer and potentially inefficient (Klemperer, 2004). One of the main entry deterrence factors may be the “winners curse,” when the winning bidder faces the danger of overestimating the value of goods he has won. Another serious threat arises when bidders with value complementarities incur losses if only a subset of desired goods is won, i.e. an “exposure risk problem.” There are also many situation-specific features, such as various pre-auction signalling and intimidation etc., which can deter potential participants from entering the auctions (Klemperer, 2004).

Collusion in auction mechanisms has been studied for years (Robinson, 1985, Crawford, 1998, Kwasnica and Sherstyuk, 2013). Traditionally, collusion has implied explicit communication among bidders, but also the tacit collusion, during which participants silently coordinate on low-price outcomes, has been observed and studied. Bidding rings are theoretically well-described method of collusion (Krishna, 2009).

Various single unit auctions have been the object of wide research interest but more recently, the multiunit cases are also scrutinized. In the multiunit auctions, bidders may split objects and therefore keep the competition on low levels throughout the auction. “*Valley et al. (1996) studied a double oral auction both without communication and with communication via cheap talk, either written or face-to-face. They found that either written or face-to-face communication often allowed subjects to coordinate on single price or split-the-difference outcomes that revealed enough of their private information to take them outside the incentive-efficiency* *bound for unrestricted mechanisms*” (Crawford, 1998, p. 296). However, the multiunit nature of auctions may also bring complexities into the environment (Kwasnica and Sherstyuk, 2013).

Experimental studies show that collusion can and actually do occur with communication present in auctions. A large number of bidders are not sufficient condition for hindering the collusion as long as the bidders can share among themselves sufficiently large number of goods sold in the auction. Bidders simply tend toward collusive payoff-maximizing strategies (Kwasnica and Sherstyuk, 2013, p. 478).

The spectrum auctions with their usually large number of offered goods are typical candidates for collusive behaviour of bidders. Markets are often form by only a handful of players and the entry deterrence together with high initial costs of establishment may cause the numbers of new interested entrants are low or even none. The most leading to bidder conspiracies appear to be sequential and multi-round auction formats. Kwasnica and Sherstyuk (2013, p. 479) notes that: “*There is some (but not enough) evidence that allowing for combinatorial bids may break collusion.*”

3.2.1 Communication Mechanisms

Phillips, Menkhaus et al. (2003) documented an impact of practices that may facilitate low final prices in a repeated multi-unit English auctions. They have created laboratory markets of English auctions with symmetric structure of bidders. By employing two sizes of the market (two and six bidder structures) they control for competitive and rivalry environments. Three practices are identified as potentially facilitating collusion among the bidder: (i) knowledge about the number of units for sale; (ii) familiarity through repeated interaction; and (iii) communication. The repeated interaction, according to their results, should allow buyers to learn bidding strategies of their opponents even without communication. Moreover, if the agents can talk or exchange the information, the agreements become easier and bid prices lower.

Lopomo, Marshall et al. (2005) dispute in their paper an idea that collusion creates inefficiencies at sealed-bid auctions, but not at ascending bid auctions. They show that if there is no communication before the auction and the ex-post budget balance is satisfied by the collusive mechanism, collusion actually does affect auction efficiency. They state in particular: “*Any collusive mechanism that increases cartel members’ expected payoffs relative to non-cooperative play results in inefficiency* *either in the allocation among cartel members or in the allocation between cartel and non-cartel bidders, or both*" (Lopomo et al., 2005, p. 4).

Miralles (2010) analyzes a generalization of Campbell's self-enforced collusion mechanism in simultaneous auctions. While Campbell (1998) based his collusion mechanism on complete comparative cheap talk and endogenous entry with only two bidders, Miralles examine cases of more than two bidders with prior symmetric design. His paper focuses on self-enforced and simple mechanisms without side-payments or trigger strategies. He uses just a pre-play cheap talk, which is "*clearly difficult to prosecute by competition authorities*" (Miralles, 2010, p. 2). Two important results arise out the analysis: (i) a full comparative cheap talk equilibrium exists if the number of objects is large enough; and (ii) a partial cheap talk equilibrium, in which each bidder splits the objects into two sets, the favourite one and the rest, and lets the other bidders know about that split, always exists.

4 METHODOLOGY

In this chapter, I systematically describe all components of the methodological procedure. It consists of the experimental design, parameterization of the experiment and formulation of hypotheses. First, I describe the experimental design in general, with focus on SMR and SMRPB auction formats, collusion, player valuation modelling and other individual design components. The second part of this chapter is devoted to the parameters. It describes the connection of experimental parameters to the real situation of the Czech Spectrum Auction. The hypotheses of the experiment are stated in the third sub-chapter.

4.1 EXPERIMENTAL DESIGN

In a full-computerized laboratory experiment, I introduce the possibility of communication into simultaneous auctions of multiple goods. I employ the Simultaneous multi-round auction format (SMR) and compare it with its combinatorial version, Simultaneous Multi Round Package bidding (SMRPB) format to see the effect of package bidding on the efficiency and revenues and evaluate the original policy format with its most naturally offering extension. Next, I incorporate the dimension of communication and therefore allow for coordinated strategies in the experiment.

I compare both formats in two basic sets of treatments: I) without possibility of any communication; and II) with possibility of communication given to whole group. The treatment matrix of the experimental design is shown in Table 3.

Table 3: Treatment matrix of the experimental design

set	I.	**SMR** no communication	**SMRPB** no communication
	II.	**SMR** communication all	**SMRPB** communication all

The first set of treatments involves the comparison of basic SMR and SMRPB auction formats. The second set of treatments introduces the opportunity of collusive behaviour by implementing a simple communication channel via electronically transmitted messages – a “chat window” – into both SMR and SMRPB auction formats. I hypothesise that the resulting situation will resemble the oligopoly with four players.

4.1.1 General Parameters of the Design

There are four types of goods in the experiment (A; B; C; D) which represent four types of spectrum licences offered in the Czech Spectrum Auctions. Each type of the good has multiple homogeneous units in stock and has different level of valuation. The good types are therefore of heterogeneous nature between each other. Each player has different valuation for each type of the good sold in the auction.

Four players compete within the auction design for all goods in the tender. Each player was assigned her own personal valuations for goods sold in the auction. These were determined randomly by the procedure specified in the respective sub-chapter. At the end of the auction players either earn profit or incur losses in the experiment.

4.1.2 Simultaneous multi-round auction (SMR)

This auction format was developed by the Federal telecommunications commission in 1994 particularly for the allocation of the spectrum intervals (Guala, 2001). It is a simultaneous multi-round ascending auction (SMR), a simple generalization of the English auction design for multiple objects. All items are therefore offered at the same time and the bidders are allowed to submit their bids only for individual desired items in a sequence of rounds. The process continues until nobody is willing to submit a higher bid for any item (Brunner et al., 2010).

An important rule determining the eligibility of each bidder to act through allocated amount of activity points occurs in this auction. Each bidder receives a certain amount of activity points at the beginning of the auction. Bidder’s activity in each round is determined by the sum of his provisional winning bids and of the submitted bids (to the extent of bidder’s current activity limit), i.e. bidder’s activity limit falls if the current activity is less than the bidder’s activity limit in the previous round. This rule was introduced to prevent bidders from gaming behaviour. It means that the bidder cannot play the “snake-in-the-grass” strategy, where she is waiting at the very last moment of the auction and then reveals her true preferences. This rule ensures that if the bidder wants to play seriously and win at the end her portion of desired goods, she has to maintain the activity throughout the whole auction. If not, she would lose the activity points and eligibility for the subsequent rounds (Cramton, 2012).

Next, there is a simple system of proportional ascending bidding originally introduced into the SMR auctions to prevent signalling via the determination of prices. The bidders can therefore submit their offers only in pre-determined levels, usually a percentage share of upset prices. There is a one-level raising algorithm in the programme used for this experiment. Bidders can either keep their previous bid or raise their bid for a good by 20% of respective upset price for simplicity[14].

Additional, but also not unusual rule is the possibility of bid withdrawal in case the bidder won unwanted set of licenses in some auction round. All bidders can withdraw their provisionally winning bids in at most 2 rounds of the auction. This should diminish the exposure risk problem present in this type of auctions, even though it is not fully efficient in this respect. Each bidder has to pay a certain monetary penalty for withdrawing the bid, which depends on her provisional winning bid. The activity points for subsequent round are diminished respectively after withdrawing the provisional winning bid.

At the end of each round, bidders receive information about the provisionally winning bids in this round. The identity of the provisionally winning bidders is known. The bidders also have complete information about their own bids.

4.1.3 SMR auction with the possibility of package bidding (SMRPB)

The Simultaneous multi-round package bidding auction format is a natural extension of SMR, which allows for bidding on packages of goods instead of single units. The SRMPB is a combinatorial auction format, designed to prevent the exposure risk problem of bidders. The provisional winning bids in each round are calculated according to maximization of the revenues for the seller. However, there is also an exclusive *"XOR[15]"* rule imposed on the bidders. It means that each bidder can have only one provisionally winning bid in each round at maximum (Brunner et al., 2010).

The activity and eligibility rule is imposed differently in this design: "In each round a bidder's activity is calculated as the maximum of (1) the size of the largest package the bidder is provisionally winning and (2) the size of the largest package the bidder is bidding for" (Brunner et al., 2010, p.23).

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[14] Originally, the level of 10% of upset price was chosen for raising algorithm. However, the extent of percentage share was increased due to the experimental reasons since the whole task would take too long.

[15]XOR is a standard logical operation that outputs true value whenever both inputs differ, i.e. one is true, the other is false.

The system of proportional ascending bidding is in this auction format same as in the SMR auction. Even though potentially redundant in combinatorial auction formats, I have introduced the opportunity of bid withdrawal also into the SMRPB format. This was done mainly in order to eliminate the differences and therefore being maximally consistent between two auction formats. Players were given a chance to withdraw their provisionally winning bids in at most 2 rounds of the auction. Whole package bid submitted in the auction round was withdrawn if the option was utilised. There was no monetary penalization for withdrawing the bid; however, a certain percentage penalization in activity points occurred.

At the end of each round, the bidders receive the information about all provisionally winning bids of all other bidders. They also receive information about the current prices of all licences and complete information about their own bids. The auction ends when no new bids are submitted for any other item or a package of the items.

4.1.4 Winner Determination Problem

The winner determination algorithm (WDA) is in both formats provided by the random mechanism. All four types of the goods are handled separately in SMR auction format. The winner of each unit of good is in case of an excess demand (for the respective type) determined randomly, i.e. when more units of good is demanded by the bidders than is for sale in the auction, the winner for each unit is determined individually at random in the SMR auction format. In the SMRPB auction format on the other hand, are the items handled in packages. The winner of each package of goods is in case of an excess demand (for any type) determined randomly, i.e. more units of goods is demanded by the bidders than is for sale in the auction, the winner is determined based on the package with highest price. When two or more players submit bids for the same package, the winner of this package is determined randomly[16].

[16] The winner determination algorithm applied in the programme is simple. Each player involved in the problem is assigned a random number. The player with the smallest number wins and is allocated the item. There is a mechanism sorting the packages according to its highest price in the SMRPB. The loser resulting from WDA in SMRPB auction is put into a subsequent place and if she satisfies conditions for winning her package out of remaining goods, she wins it. This process continues down to the bottom if needed.

4.1.5 Communication

The communication channel is introduced via simple chat window. No verbal contact between participants was allowed during the experiment. All communication was monitored and recorded. This approach was already used in e.g. Phillips, Menkhaus et al. (2003).

A combination of Phillips, Menkhaus et al. (2003); Lopomo, Marshall et al. (2005); and Miralles (2010) was used to implement the communication via chat into the experimental design. Enough time for communication has been provided prior to each auction like in Miralles (2010). Since the number of objects in the auction is large, the comparative cheap-talk equilibrium should, according to Miralles (2010), exist. The chatting window was also available during the whole auction phase as in Phillips, Menkhaus et al. (2003).

In order to be consistent with Lopomo, Marshall et al. (2005), there was only a limited amount of information available to the bidders in the pre-auction phase of communication. The bidders did not know their exact valuations for goods and therefore were able to communicate only on the collusive mechanisms they can employ, not directly on their own private values. There was however no ex- post budget balancing in our experiment; the effect of collusion on auction efficiency is therefore beforehand ambiguous. The only information revealed to the participants during the pre-auction communication phase was the types and numbers of auctioned goods. All three features facilitating collusion from Phillips, Menkhaus et al. (2003) were therefore satisfied.

4.1.6 Player Valuations Modelling

There were four types of players in the experiment. Such market structure (three incumbents plus one potential newcomer) can be found also in other countries and industries and was modelled for example in experiments done by Bichler, Shabalin et al. (2013b) or by Abbink, Irlenbusch et al. (2005) who used two symmetric tetrads of bidders in their experiments. For each player-type, its license valuations were randomly drawn from a publicly known interval (the same interval for all players so there was an ex-ante symmetrical setting for each auctioned good) prior to the experiment only once. Then in each session, each subject of the experiment was randomly assigned to one player type. This prevented any additional external variation between the treatments possibly caused by the random draws of valuations on place.[17]

Valuations of goods were based on two components. The first part represents *common value component* (CVC), the second represents *private value component* (PVC) of each particular good. Common value arises from the overall market potential and is the same for all players, private value stems from the private expected profits depending on individual potential of bidder's business concept (Abbink et al., 2005). The bidder's total valuation for a good was therefore the sum of the CVC and PVC as in Abbink, Irlenbusch et al. (2005).

The CVC of the signal was for each type of the good randomly drawn from the integer interval. Players did not have the information about the exact random draw of CVC nor did they know the interval boundaries from which it was drawn. Each bidder received instead an independent private signal on the CVC and was informed about the fact that these signals were determined by uniform random draws from the integer interval [CVC - α; CVC + α][18] (Abbink et al., 2005, p. 511).

The PVC of the signal was for each type of the good randomly drawn from the integer interval [-β; +β]. Parameter β was proportionally lower to the CVC component. Each bidder is informed about her own PVC[19].

4.1.7 Modelling the Value Complementarities

For modelling the complementarities in player-type valuations of goods I followed Brunner et al. (2010). The interrelations among licenses are modelled in a linear manner. If the player acquires multiple goods, then the value of each good raises by the factor of $[1 + \alpha \cdot (K - 1)]$, where K stands for the number of goods types won and the α is the synergy factor. I.e. the player should be motivated to win all four types of the goods.

[17] This approach is similar as in Brunner et al. (2010).

[18] The exact intervals for CVC in Abbink et al. (2005) were [1000; 1500] for the CVC interval and [CVC - 200; CVC + 200] for the independent private signal known to the bidders. We assume quite similar setting in our experiment.

[19] See more on the exact setting of parameters in the respective sub-chapter.

Since I assume there is a high level of complementarities among the types of spectrum licenses I set the synergy factor equal to 0,1. This setup ensures that if bidder wins all four types of goods his valuation for all of them raises by 30%.

4.1.8 Determining the Final Profit

Final profit was for each player determined at the end of the auction by the difference of her total valuation for all goods won in the auction and total price paid for those goods. There was no endowment assigned to the players since the budget constraint is irrelevant in the experimental design. Bidders either earned profit or incurred losses in the experiment.

4.1.9 Efficiency Measurement

I measure and compare the efficiency levels of individual auction formats with different collusive properties. I use the efficiency measurement mechanism employed in the Goeree and Offerman (2002), who studied the efficiency in auctions with private and common values. I generalize this approach to the multiple-object case by taking the average across all *n* experimental goods sold in the auction. The efficiency is therefore determined as follows:

Let PVC_{winner} denote the private value component of *i-th* good of the auction winner and let PVC_{max} and PVC_{min} be the private value component of *i-th* good of subject with maximum and minimum valuation of this good in the group, respectively. Then the partial efficiency for each unit of good *i* sold in the auction is measured by the following equation (4.1):

$$e_i = \frac{PVC_{winner} - PVC_{min}}{PVC_{max} - PVC_{min}}, \quad \forall i \in 1; \dots; n \tag{4.1}$$

Subsequent equation (4.2) represents the average taken across all partial efficiencies of the auction format and measures the efficiency *E* of the auction format.

$$E = \frac{\sum_1^n e_i}{n} \cdot 100\% \,. \tag{4.2}$$

4.1.9.1 Optimal and Relative Efficiency calculation

The absolute measure of efficiency E provided by equation (4.2) may not be directly comparable with different efficiency measures in the literature. I therefore normalize this efficiency measure by the optimal allocation with maximum possible degree of efficiency to obtain comparable parameter. The distribution of individual units of goods in the optimal allocation is provided in the Table 4. It was obtained by maximization of quantities subject to (I) efficiencies per unit e_i from the equation

(4.1) and (II) activity points at disposal for each player type. The partial efficiency is obtained by taking the sum of quantities times the efficiency per respective unit over all player types: $e^p = \sum_1^n q_i \cdot p_i$, where n is number of player types and i number of types of goods. Total optimal efficiency is then calculated by summing up all partial efficiencies and dividing it by the total number of goods in the auction, i.e. by 53. The total absolute efficiency (e) of each observation is then normalized by the optimal efficiency (*e_optimal*) resulting in the relative efficiency measure (*e_r*).

Table 4: Optimal efficiency allocation

		player type			
GOOD		**- 1 -**	**- 2 -**	**- 3 -**	**- 4 -**
	quantity	1	0	2	1
A	*PVC*	66	-93	80	45
	efficiency per unit e_i	0,919075	0	1	0,797688
	quantity	10	14	0	0
B	*PVC*	3	3	-3	-2
	efficiency per unit e_i	1	1	0	0,166667
	quantity	0	14	0	0
C	*PVC*	-2	0	-10	-2
	efficiency per unit e_i	0,8	1	0	0,8
	quantity	0	0	0	9
D	*PVC*	-2	-3	-4	0
	efficiency per unit e_i	0,5	0,25	0	1
	total activity	20	28	20	19
	activity disposed	27	28	26	25
	partial efficiency	10,91908	28	2	9,797688
	optimal efficiency		0,95692		

4.2 MODEL SPECIFICATION

I model the relative efficiencies of complex Simultaneous multi-round auctions with a specific setting of multiple heterogeneous goods within the environment allowing for collusion. I employ experimental treatments with and without package bidding auction format; and with and without the presence of communication channel. Detailed structure of all treatments is described in the section 4.1. The model tries to explain the relative efficiency of the auction formats on basic auction variables and respective dummies for presence of communication channel and package bidding format. There is only an initial model described in this chapter. Its alterations and further specifications are described in the chapter 7.

4.2.1 The Initial Model

The initial model of relative efficiency is specified in the equation (4.3).

$$e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 P + \beta_5 q_a + \beta_6 q_b + \beta_7 q_c + \beta_8 q_d + \beta_9 p_a + \beta_{10} p_b + \beta_{11} p_c + \beta_{12} p_d + \varepsilon, \tag{4.3}$$

where *SMR* and *chat* are respective dummy variables; π is a total final profit of respective player; P is a total final price paid by the respective player; q_a-q_d is a vector of final individual good quantities of respective player and p_a-p_d is a vector of individual prices relevant to those goods.

4.3 PARAMETRIZATION

Many experimental designs come out from real situation settings. The experimental evaluation of auction designs goes back into early eighties when Rassenti, Smith et al. (1982) examined combinatorial auction mechanisms for allocation of airport time slots. When the US Federal Telecommunications Commission (FCC) developed the SMR auction format for their Spectrum Auctions, the experimental evaluation of its design and performance was a natural component of the process (Brunner et al., 2010). Up to this date, experimental researchers refer to the real life situations while conducting experiments on combinatorial auction formats. Abbink, Irlenbusch et al. (2005) explore the design alternatives for the British 3G/UMTS auction; or more recently Bichler, Shabalin et al. (2013b) use a band plan with two bands of blocks, which can be found in several European countries, in their base value model.

The parameters used in the experiment are based on the real situation of the Czech Spectrum Auctions. Although slightly adjusted, Table 5 shows parameters in the real Czech Spectrum Auction held in 2012 and 2013[20]; while Table 6 shows actual parameters used in the experiment. The experimental parameters are adjusted and

[20] Blocks A3 and B1 were adjusted in order to be homogeneous with other blocks in respective categories. One specific block A3 of 2x10 MHz was split up to two blocks of 2x5 MHz which is in accordance with other category A blocks. One specific block B1 of 2x15 MHz was split up to fifteen blocks of 2x1 MHz which is in accordance with other category B block. The upset prices, activity points per block etc. were also homogenized according to this principle.

simplified. The experimental upset prices per unit were multiplied by the coefficient 1,3 due to the experimental reasons[21].

4.3.1 Common and private value components, activity in the experiment

The reasoning under calculations of common and private value components is the following. The 2012 Czech Spectrum Auction was stopped at the threshold of 20 billion CZK (CTO, 2013a). Although the auction did not end in natural way and the bidding would therefore probably continued further, there is no other evidence of how far the actual prices would have been raised. However since the amount of 20 billion CZK was reached, we can, without the loss of generality, take it as a threshold for the analysis. In order to stay in the framework of the Czech Spectrum Auctions I assume this threshold to be the upper bound of the permissible interval for the calculation of the common value component of auctioned goods. The upset prices are taken for the lower bound of this interval.

Since the information about the upper threshold is known only for the whole set of auctioned goods, it is necessary to determine a percentage parameter, which will always be added on the top of the upset price of each particular type of the good to obtain its common value component. The calculation of this parameter δ in equation (4.4) resulted in 5645 million CZK, which is approximately 65% of the total upset price for all goods sold in the auction.

$$\delta = \frac{B_{up} - B_{low}}{2} \cdot \frac{1}{\sum p_{upset}} \cdot 100\% \tag{4.4}$$

Where B_{up} and B_{low} are upper and lower bound respectively; and p_{upset} are upset prices of goods. The common value component of each type of the good is therefore calculated by 1,65-multiple of its upset price. The common value component is the same for each player. Private value component is different for each player and is determined by a random draw from the interval < -0,1·CVC ; +0,1·CVC >.

The activity points per one unit of good used in the experiment are determined by taking the respective *activity per block in spectrum interval* from the real parameters of the auction and rounding it up to integers. Total activity in the experiment is then slightly higher than in the real situation but it is more convenient for the experimental

[21] The setting with original price vector had to be changed after the pilot experiment since the whole task would be too long and therefore unfeasible, i.e. the upset prices were increased together with percentage level of price-raising algorithm.

Table 5: Parameters in real auctions

Category of auction blocks	Frequency spectrum interval	Blocks in category	UPrice per block; bill. CZK	Total UPrice in category; bill. CZK	Total UPrice for interval; bill. CZK	UPrice per block in spectrum interval, roundup avg.; bill. CZK	Activity per block	Activity total	Total activity for interval	Activity per block in spectrum interval; roundup avg.
A1	800 MHz	1	1010	1010	6560	1100	10	10	60	10
A2		3	1110	3330			10	30		
A3		2	1110	2220			10	20		
B1	1800 MHz	15	30	450	720	30	0,5	7,5	16,5	0,7
B2		9	30	270			1	9		
C	2600 MHz	14	80	1120	1120	80	1	14	14	1
D	2600 MHz	9	30	270	270	30	0,5	4,5	4,5	0,5
TOTAL		**53**		**8670**	**8670**	**1240**		**95**	**95**	**12,2**

UPrice = Upset price; roundup = rounded up; avg. = average.

Table 6: Parameters used in the experiment

Category of goods	Number of units per category	UPrice per unit, tokens (original values)	Total UPrice for category, tokens	CVC; roundup	PVC interval (±0,1·CVC); <	Activity per unit, roundup	Total activity for category	1/4 total activity in the game
A	6	1400	8400	1820	± 182	10	60	15
B	24	40	960	50	±5	1	24	6
C	14	180	2520	140	± 14	1	14	4
D	9	40	360	50	± 5	1	9	3
TOTAL	53		12240				107	28

UPrice = Upset price; roundup = rounded up; avg. = average.

purposes. Each player has her initial activity based on the ¼ of total activity in the experiment while her precise activity endowment is determined by a random draw from the interval < -3 ; +3 >[22], which is added to the ¼ of total activity in the experiment.

4.3.2 Experimental parameters

Following tables summarize the random draws used for the determination of final experimental parameters. Table 7 shows basic parameters of experimental goods; Its numbers, upset prices, activity per unit, its common and private values. Table 8 determines random draws for private value component and activity points. Table 9 shows final individual valuations for goods and final endowment of activity points for each player. Table 10 summarizes the common value component and its private signal intervals. Table 11 shows actual random draws of final private signals on common value components.

Table 7: Basic parameters of goods

GOODS	Goods in stock	Upset price per unit	Activity per unit	CVC	PVC Valuation intervals	
A	6	1400	10	1820	-182	182
B	24	40	1	50	-5	5
C	14	180	1	140	-14	14
D	9	30	1	50	-5	5

Table 8: Random draws for Private Value Component and activity points

PLAYERS	PVC Random draws				Activity random draw
	A	B	C	D	
Blue	66	3	-2	-2	-1
Pink	-93	3	0	-3	0
Red	80	-3	-10	-4	-2
Green	45	-2	-2	0	-3

[22] Each tail of this interval represents rounded 10% of the ¼ of total activity in the experiment.

Table 9: Final parameters determined by random draws

PLAYERS	Final individual valuations for goods				Activity endowment
	A	B	C	D	
Blue	1886	53	138	48	27
Pink	1727	53	140	47	28
Red	1900	47	130	46	26
Green	1865	48	138	50	25

Table 10: Common Value Component and private signal intervals

GOODS	CVC	CVC variance	CVC private signal intervals	
A	1820	200	1620	2020
B	50	5	45	55
C	140	10	130	150
D	50	5	45	55

Table 11: Random draws for private signals on Common Value Components

PLAYERS	CVC Private signal random draws			
	A	B	C	D
Blue	1718	51	141	48
Pink	1859	50	145	46
Red	1770	50	148	54
Green	1947	49	141	50

4.4 HYPOTHESES

Based on the previous literature, I assume that in the first wave of treatments without communication the degree of competition should be high. I employed setting with high complementarities among goods, which should favour the combinatorial SMRPB format in efficiency. Prices should reach the competitive levels closely. High revenues for the auctioneer and low or even negative surpluses of bidders should occur. The exposure risk problem and winners curse may affect the SMR treatment.

The SMRPB should avoid exposure risk but winners curse may also be present. It is practically a replication of the Brunner, Goeree et al. (2010) result in a different parameter setting.

The second wave of treatments introduces communication. In the extreme case of coordinated collusion I expect the prices to stay down at the upset base, similarly as in (Valley et al., 1996) in the case of double oral auction. If the collusion equilibrium is stable, no or very little competition among bidders should be present resulting in shift in distribution of rents from auctioneer revenues to bidders' surpluses. I am interested in whether allowing for combinatorial bidding will break collusion. The package-bidding format SMRPB should in that case increase competition. Prices should go up, approaching more the competitive level. Respective change in rents distribution should appear. The impact of communication on efficiency is ambiguous. Collusive behaviour may under certain circumstances increase the efficiency, when collusive agreements result in better allocation of goods among players than competitive processes.

Table 12 summarizes comparison of partial hypotheses *within formats* and setting *without* and *with communication allowed* in the auction. Table 13 summarizes comparison of partial hypotheses *between formats* and setting *without and with communication allowed* in the auction.

Table 12: Comparison of partial hypotheses within formats

	SMR	**&**	**SMR & Coll**	**SMRPB**	**&**	**SMRPB & Coll**
Total Prices	P_{SMR}	$>$	P_{SMR}^{Coll}	P_{SMRPB}	$>$	P_{SMRPB}^{Coll}
Efficiency	E_{SMR}	? ?	E_{SMR}^{Coll}	E_{SMRPB}	? ?	E_{SMRPB}^{Coll}
Auctioneer's revenue	R_{SMR}	$>$	R_{SMR}^{Coll}	R_{SMRPB}	$>$	R_{SMRPB}^{Coll}
Bidders' surpluses	S_{SMR}	$<$	S_{SMR}^{Coll}	S_{SMRPB}	$<$	S_{SMRPB}^{Coll}

Table 13: Comparison of partial hypotheses between formats

	SMR	&	SMRPB	SMR & Coll	&	SMRPB & Coll
Total Prices	P_{SMR}	<	P_{SMRPB}	P_{SMR}^{Coll}	<	P_{SMRPB}^{Coll}
Efficiency	E_{SMR}	<	E_{SMRPB}	E_{SMR}^{Coll}	? ?	E_{SMRPB}^{Coll}
Auctioneer's revenue	R_{SMR}	<	R_{SMRPB}	R_{SMR}^{Coll}	<	R_{SMRPB}^{Coll}
Bidders' surpluses	S_{SMR}	>	S_{SMRPB}	S_{SMR}^{Coll}	>	S_{SMRPB}^{Coll}

Table 14 summarizes main hypotheses of the experiment. Basic SMR auction should overall perform worse than its combinatorial counterpart basic SMRPB format. The same relationship should be valid also for these two formats while allowing for collusive behaviour; the SMRPB should, therefore (to indistinct extent), break the collusion. Generally, both formats should naturally perform better without the collusion. However, the performance of both auction formats in terms of efficiency is in all treatments (with exception of basic SMR and SMRPB settings) uncertain.

Table 14: General hypotheses

Null *H0*	Alternative *HA*
$\text{SMR} < SMRPB$	$\text{SMR} > \text{SMRPB}$
$\text{SMR Coll} < SMRPB\ Coll$	$\text{SMR Coll} > \text{SMRPB Coll}$
$\text{SMR} > SMR\ Coll$	$\text{SMR} < SMR\ Coll$
$\text{SMRPB} > SMRPB\ Coll$	$\text{SMRPB} < SMRPB\ Coll$
$E_{SMR} = E_{SMR}^{Coll}$	$E_{SMR} \neq E_{SMR}^{Coll}$
$E_{SMRPB} = E_{SMRPB}^{Coll}$	$E_{SMRPB} \neq E_{SMRPB}^{Coll}$
$E_{SMR}^{Coll} = E_{SMRPB}^{Coll}$	$E_{SMR}^{Coll} \neq E_{SMRPB}^{Coll}$

5 GENERAL PROCEDURE OF THE EXPERIMENT

I have conducted a computerized laboratory experiment on complex auction formats with possibility of communication among participants. I have executed four experimental sessions with 24 subjects per each session, resulting in 96 subjects in total. The experiment was realized in the Laboratory of Experimental Economics at University of Economics in Prague[23]. The experiment was fully computerized using the program Z-TREE (Fischbacher, 2007).

Subject pool for the experiment was invited through the online ORSEE system of Laboratory of Experimental Economics (Greiner, 2004). Additional criteria were imposed to the selected subject pool in order to ensure they would understand the task and would be capable of taking part in the experiment; specifically I preferably invited economic majors with previous experience in auction experiments. The experiment was conducted in Czech.

The core of the laboratory experiments in economics lies in the fact that participants face incentives in form of a monetary reward. The payoff in real money should provide enough incentives to take the task seriously and therefore generate effort to win the game. Subjects were paid according to their performance in the experimental treatment. Each treatment lasted approximately two hours and the average pay for whole treatment was expected to be on average 500 CZK[24] per subject, which is above the students' regular hourly wage rate.

5.1 INSTRUCTION PROCEDURES

The complexity of the required task was expected to be highly demanding. I was not able to train subject specifically before the experiment and carry out complicated procedures used for example in Abbink, Irlenbusch et al. (2005); Brunner, Goeree et

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[23] (LEE at VŠE); *www.**vse-lee**.cz/eng*

[24] Resulting levels of competition during the experimental auctions and random draws determining the treatments for payments resulted in lower average payoff than 500 CZK. Payoffs from all treatments oscillated around 400 CZK per subject.

al. (2010) or even Bichler, Shabalin et al. (2013b). This was mainly due to the necessity of high over-recruitment rates in case of such training and highly constrained funding possibilities of the research. Therefore, I used simpler procedure instead.

The participants were invited five days prior to the experiment and three days prior were asked to fill in an online questionnaire based on the partial instructions available online. This online material consisted of general instructions common to all treatments of the experiment. The instructions were concluded by a 5-question quiz[25]. Each invited participant who had filled in the questionnaire correctly was preferred in invitation into actual experiment conducted in the lab. Whole procedure regarding instructions in advance and questionnaire was described in the invitation email for the experiment and was therefore publicly known. There were no difficulties with the online questionnaires since the rate of successful completion was over 95%.

5.2 PILOT VERSION OF THE EXPERIMENT

Prior to the experiment itself, I had run a pilot-version to verify the structure of the experiment, functioning of the programs and to calibrate the task. The pilot session was rewarded in the same manner as real sessions. During the pilot session, I found out that the originally intended calibration of parameters is impossible to use. Bid increments were too small and whole auction was therefore very slow. In order to make the auction feasible, I decided to increase the upset prices and the level of bid increment[26]. Such parameters should comply even with time needs of package bidding format as it requires, on average, about 20% more rounds of bidding than the SMR auction (Goeree et al., 2006).

5.3 GENERAL PROCEDURE

A group of 24 participants of the experiment came into to lab for each session and randomly draw the number of their seats. Each subject was seated at the respective computer station with no possibility to see anybody else's screen or to talk to each other. This rule was strictly kept for entire experiment. They were provided with (I) a set of written general instructions to the experiment (same set which they should

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[25] The general instructions together with the online questionnaire are available in the appendix.

[26] As it was already stated above the upset prices were raised by the coefficient of 1,3 and the bid increment was set to 20% of the upset price.

already seen in the online questionnaire); (II) treatment-specific supplement to the instructions; (III) consent form[27]; (IV) pencil and blank sheet of paper for the notes. Complete sets of the instructions are available in the appendix. Participants had 15 minutes for self-study of the instructions when they arrived to the laboratory. Computerized questionnaire with several control questions was launched for all subjects after this time expired. A practice auction round was conducted in order to be sure subjects understood the experimental interface, how to read their parameters, enter bids on the screen, and that they were acquired with the auction procedures.

To prevent misunderstandings and make the task easier, only one type of auction (one treatment) was performed in each session, i.e. the between subject design was used for the experiment. In each session, each participant was randomly assigned to one of four player types, which remained stable across the whole session. It ensured that no additional external variation caused by random draws was present in the experiment. The player types were then randomly assigned to the groups of four players who competed in the auction among themselves. Each participant took part only in one auction format, while there were multiple auctions performed within the session and therefore within the auction format. The number of manageable sharp auctions stabilized at three per experimental session. All groups were randomly re-matched with condition of stranger matching at the beginning of each auction within one session[28].

There was a predefined exchange rate of experimental currency units (ECU) and real money used in the experiment, by which the participants were paid in cash after whole procedure. This exchange rate was set to 1/3, i.e. one CZK was worth 3 ECU. Participants knew this exchange rate in advance from the instructions. The payment from the experiment was not aggregated over all auctions executed in a session but rather depended on one specific session round determined by a random draw.

When the participants have accomplished the experimental task and the auction was over, they were called separately to the adjacent room, where they were paid in private and left.

[27] If the participant refused to give consent with the experiment, she was paid the show-up fee and sent away.

[28] There is an in-built matching computation feature in Z-TREE, which calculates automatically the stranger matching procedures for assigned number of subjects and periods.

5.4 EXPERIMENTAL TASK

The experimental subjects participated in the auctions within the respective treatments they attended. The objective of the task was to win the desired goods in the auction and gain a profit, which was at the end converted to real money. At the very beginning of each auction, a chat window was displayed for two minutes in two respective treatments with communication. After the chat window, a screen with subject-specific experimental parameters was showed for one minute in all treatments. Then the first auction round began. The auction itself progressed in series of simultaneous rounds where players were bidding for the collections of goods of their interest. Bidding was realized by adding the goods into the bidding basket. Players could submit their baskets within the auction round time limit of two minutes when ready. There were an auction interface with parameters for all goods; bidding basket; player's personal account; history of past rounds and in respective treatments also a chat window displayed on the auction round screen[29].

After all players submitted their bids, the system executed all background computing and the summary of the auction round was displayed[30]. Each player received complete information about her resulting situation in current auction round and from the previous auction round (his provisionally winning goods). The history of past rounds and in respective treatments also a chat window were displayed on the summary round screen. There was a button for opening the bid withdrawal interface implemented in this stage of the round. By entering this interface, players could withdraw any of their provisionally winning licences for goods in case of SMR, or the whole package in case of SMRPB treatments. When the time limit of one minute for the summary phase ran out or when all players clicked the proceed button, next round occurred. Whole process was repeated until the final round of the auction in which no player submitted any higher bid.

[29] Its screenshot is available within the instructions in the appendix.

[30] Its screenshot is available within the instructions in the appendix.

6 DATA DESCRIPTION

This chapter provides qualitative analysis of the data. It consists of examining the characteristics of efficiencies, final profits, auctioneer revenues and total prices. There are differences among the variables in different experimental treatments tested in the section 6.3 of this chapter. Descriptive statistics of the dataset are provided in the technical appendix.

6.1 PARTICIPANT SAMPLE DESCRIPTION

There was 96 participants in the experiment plus 24 in the pilot version[31]. The majority of participants were Czechs (74%), followed by Slovaks[32] (21.8%). The rest (4.2%), four participants, did not state their nationality even though one entry indicated “Ukraine.” There were 74% of male participants. Even though there was imposed a selection criterion for preference of economic majors in the recruitment system. There were 68.8% of participants indicating a high school; 28.1% a bachelor university degree, and 3.1% a master university degree as their highest education attained[33]. Participants were paid privately at the end of the experiment, the average payment was 500CZK (app. 25 USD) out of which they had a guaranteed show-up fee of 100CZK (app. 5 USD).

6.2 QUALITATIVE ANALYSIS

Table 15 shows sample statistics of the most important variables between treatments. There are variables representing relative efficiency (*e_r*); final profit (*final_profit*); total price of all goods per subject (*p_total*); and revenue for the seller (*rev*) included in the table. I examine all of the variables in this section.

[31] Only a subset of treatments was run during the pilot session and it was affected by the initial problems with the program. I have therefore did not include the data into the analysis.

[32] Czech and Slovak languages are mutually highly, but not perfectly, understandable.

[33] Captured by the variable *edu_quality*: 1 == high school; 2 == bachelor degree; 3 == master degree.

6.2.1 Relative Efficiency

The means of relative efficiencies in Table 15 are generally very low compared to those in other experimental papers. Even though I employ different efficiency measurement mechanism than for example in (Brunner et al., 2010); or (Bichler et al., 2013a) the relative measure should ensure comparable results.[34] There are few possible explanations: (I) actual parameters of the experimental task; (II) insufficient comprehension of the task; and (III) actual setting of player parameters. The actual parameters of the experiment were selected based on the real setting of Czech Spectrum Auctions. Even though adjusted because of experimental reasons, final configuration of parameters should not have in the ultimate consequence such dramatic impact on relative measure of efficiency. The optimal efficiency allocation is case-specific for any parameter setting and so is the efficiency of any other subset of goods within this setting. Since the relative efficiency is normalized by this case-specific optimal allocation, it cannot be affected by the actual parameter settings. Second possible explanation of this fact may indicate that the difficulty of the task was too demanding for some participants of the experiment. This may cause an additional unwanted variation in the decisions, which would affect the auction results. I am aware that the difficulty of this task was high above the usual average of experiments taking place in LEE. I believe I have employed every feasible mechanism for facilitating the comprehension of the task I could with respect to the funding possibilities. It was not possible to employ for example an extreme complex pre-experimental mechanisms such as in Bichler, Shabalin et al. (2013b) who recruited the subjects from a class on auction theory and market design[35].

The third explanation seems quite relevant. The player parameters were set according to the real situation of Czech Spectrum Auctions, even though its relevance to real market is very limited. All the player parameters were specified by the random draws within a set of pre-determined intervals. Unfortunately, the random draws came out highly discriminating for some players. For example, the second player had only a very limited possibility to outplay others in terms of profit. The random draw also

34 There is a normalization procedure imposed on the efficiency measure in those papers. The efficiency is normalized by the difference between the actual surplus and the surplus resulting from a random allocation.

35 The subjects were grouped into teams of two persons and were invited to the lab two weeks prior to the experiment. During the two weeks, they prepared their own strategy and wrote a term paper to describe their strategy.

weakened the position of goods C and D since all the private valuation for those goods came out negative or equal to zero. The player parameters were therefore unfortunate but at the same time not in conflict with any potential situation. The relative character of the efficiency measure should also control for this fact. I statistically test for the above-mentioned factors of impact on efficiency in the section 6.3 of this chapter.

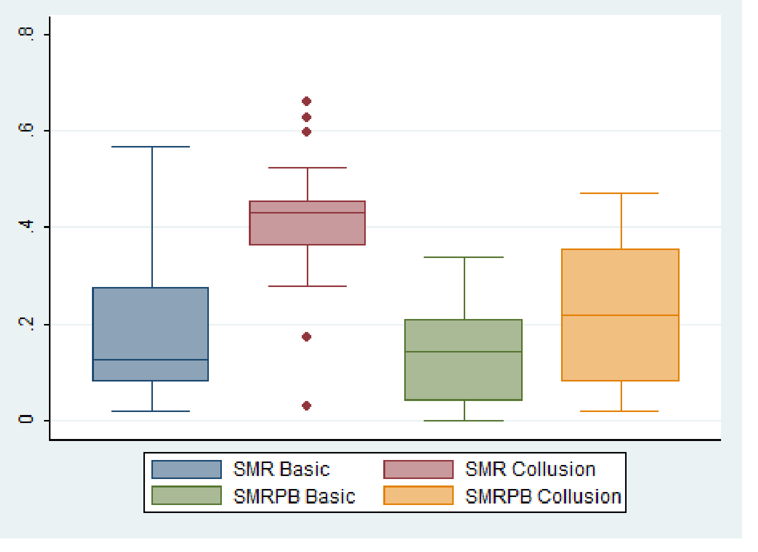
Table 15: Sample statistics between treatments

	SMR Basic	**SMR Collusion**	**SMRPB Basic**	**SMRPB Collusion**
Variable	**Mean**			
e_r	0.18	0.41	0.14	0.23
final_profit	174.57	597	-23.38	500.09
p_total	1466.28	2672.44	1445.89	1891.28
rev	5865.11	10689.78	5783.56	7565.11
Variable	**Std. Dev.**			
e_r	0.16	0.15	0.10	0.15
final_profit	356.86	416.17	361.96	669.71
p_total	1858.58	1260.92	2168.78	1810.49
rev	3414.89	2435.19	4080.25	3031.87
Variable	**Min**			
e_r	0.02	0.03	0.00	0.02
final_profit	-190	-750	-1717.2	-1013.8
p_total	0	0	0	0
rev	72	4312	0	2464
Variable	**Max**			
e_r	0.57	0.66	0.34	0.47
final_profit	1625.9	1593.3	573.6	2269.9
p_total	4948	4480	5368	5328
rev	11136	12768	14944	12360

6.2.1.1 Relative Efficiency Comparisons

The SMR format shows generally higher average efficiency than the SMRPB, which would reject the partial null hypotheses that combinatorial package-bidding format should outperform the basic SMR in efficiency. This result contradicts to those presented by Brunner, Goeree et al. (Brunner et al., 2010). However, at the same time, it corresponds to Bichler, Goeree et al. (Bichler et al., 2013a) who find that simplicity of the bid language in combinatorial auctions has a substantial positive impact on the auction's efficiency. Graph 1 shows the box plots of relative efficiencies comparing individual treatments. The SMR treatments are generally more efficient than SMRPB treatments. Collusion improves efficiency in both auction formats of our setting. The outliers in SMR treatment with collusion are caused by the exceptional situations of highly collusive behaviour on the upper tail and by the inadequate behaviour of players on the lower tail[36].

Graph 1: Box plots of relative efficiencies between treatments[37]



6.2.1.2 Instability of Collusion in SMR Treatment

Instability of several collusive agreements arose during the SMR treatment with collusion when a few players were capable of deluding their opponents within the group. These players manipulated their group to collusion in such a way that they lost as little activity points as possible during the first round (e.g. they bid for a lot of seemingly low-profitable goods, while openly letting others to bid for the high-profitable ones). In the subsequent round, pretending they will finish together with others, they bid once more for the high-profitable goods they had originally desired and therefore outplayed others. Such observations have generally lower relative efficiency.

6.2.2 Final Profits

Final profits of the individual bidders are represented by the variable *final_profit* in the Table 15. Its means and standard deviations vary substantially. Overall, the profit is higher for collusive treatments than for basic ones that corresponds with the original hypotheses. Low average final profit in the third treatment (SMRPB without collusion) is caused by the player parameters setting and a few outlier situations with

[36] The outliers will be for purposes of quantitative data analysis dealt within the respective chapter.

[37] The partial plots are arranged within the graph as follows: 1) SMR Basic; 2) SMR Collusion; 3) SMRPB Basic; 4) SMRPB Collusion.

highly negative profit. Since the player parameters played a discriminatory role in the experiment, the weak players were not able to outplay their stronger opponents in the package bidding auction format and the majority of them ended up with zero profit. Due to a high number of zero profits, even a minimum of high-level outliers outperformed other observations and drag the average down. This situation is illustrated also by the highest standard deviation of final profit in this treatment.

6.2.3 Total Prices and Auctioneer's Revenues

The variable *p_total* in the Table 15 represents the average total price paid by one bidder for his set of won goods; the auctioneer's revenues are represented by the variable *rev* in the same table. The means of revenues in individual experimental treatments corresponds with quadruples of the average total prices paid by the bidders (*p_total).* The correlation of these two variables is 0.5147, which means that variable revenue shares approximately 26% of its variability with total price[38] (Chen et al., 2003). The average total prices are generally lower in non-collusive treatments. This is caused by higher competition present in those treatments resulting in players were winning a lower number of goods per one player. The average quantities of goods won in individual treatments are shown in Table 16.

Table 16: Average quantities of goods won per treatment

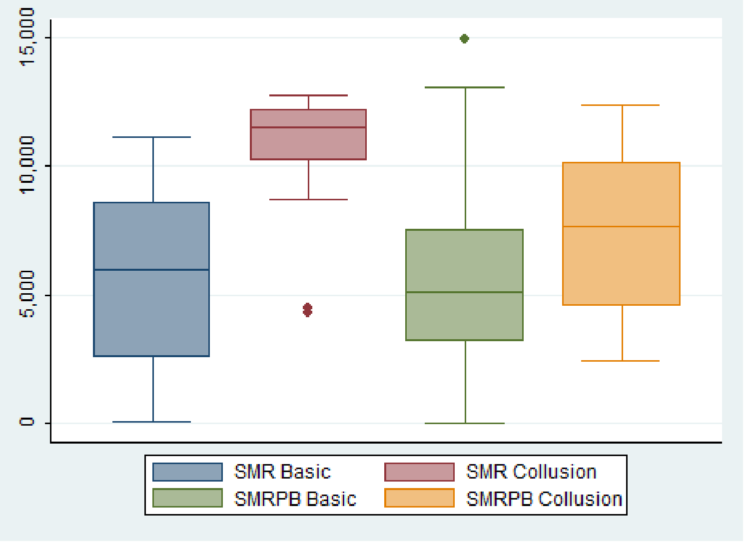
	SMR Basic	SMR Collusion	SMRPB Basic	SMRPB Collusion
Mean	3.15	7.85	2.75	4.53
Max	24.00	21.00	19.00	18.00

6.2.3.1 Profit-Revenue comparisons

There seems to appear a positive relationship between the average final profit of the bidder and average revenue of the seller. This situation again corresponds to the degree of competition in respective treatments. A successful collusion among the players emerged in treatments with the possibility of communication where players split the goods in the offer and therefore each of them won more units of goods (confirmed by Table 16) and therefore paid higher total price but also reached higher individual profits. With more goods with positive relationship of valuation minus price sold in the auction therefore also a higher revenues arose. Overall situation of auctioneer's revenues is displayed on the box plots in Graph 2.

[38] The percentage of the variability shared is determined by squaring the correlation and then multiplying it by 100.

Graph 2: Box plots of auctioneer's revenue[39]



6.3 TESTING THE DIFFERENCES

In this section, I explore statistical differences of individual variables between treatments and between different player types. I have checked for the difference of all important variables of the model, i.e. relative efficiency (*e_r*); final profit (*final_profit*); and total price of all goods per subject (*p_total*). I have omitted the seller's revenues since it is partially correlated with the total price variable. I have used the two-sample t-tests with equal variances and have checked all results with a non-parametric analogy for non-normally distributed dependent variables, the Wilcoxon-Mann-Whitney test (W-M-W test). It is a non-parametric k-sample test on the equality of medians, which tests the null hypothesis that the k samples were drawn from populations with the same median. Its results are provided below the p-values of t-tests[40]. The results of statistical testing are generally quite straightforward. There are statistical differences not only between the experimental treatments, but for the important variables also between the player types.

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[39] The plots are arranged within the graph as follows: 1) SMR Basic; 2) SMR Collusion; 3) SMRPB Basic; 4) SMRPB Collusion.

[40] Much of the style of the analysis was inspired by the web resources of UCLA – the Academic Technology Series, which can be found here: http://www.ats.ucla.edu/stat/stata/; its proper citation: (Chen, Ender et al. 2003)

6.3.1 Pairwise Comparison of Efficiencies

Additionally to the qualitative analysis provided in the section 6.2.1, I statistically test for the difference of individual relative efficiency means of different experimental treatments using two-sample t-tests with equal variances. The results of cross-comparison t-tests of relative efficiencies are provided in Table 17. Presented means of relative efficiencies are the same as in the Table 15. At the bottom of each quadrant, there are p-values with their respective alternative hypotheses. The null hypothesis is the same for all cases (H0: diff = 0).

Table 17: T-tests of relative efficiencies between treatments

t-test; Basic; by SMR				**t-test; Coll.; by SMR**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	0.14	0.012	*SMRPB Coll.*	72	0.23	0.017
SMR Basic	72	0.18	0.029	*SMR Coll.*	72	0.41	0.018
combined	144	0.16	0.011	*Combined*	144	0.32	0.015
Ha: diff ≠ 0		p-value	0.0557	Ha: diff ≠ 0		p-value	0.0001
W-M-W test:		p-value	0.4427	W-M-W test:		p-value	0.0000
t-test; SMRPB; by chat				**t-test; SMR; by chat**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	0.14	0.012	*SMR Basic*	72	0.18	0.019
SMRPB Coll.	72	0.23	0.017	*SMR Coll.*	72	0.41	0.018
combined	144	0.18	0.011	*combined*	144	0.30	0.016
Ha: diff ≠ 0		p-value	0.0001	Ha: diff ≠ 0		p-value	0.0000
W-M-W test:		p-value	0.0002	W-M-W test:		p-value	0.0000

We can see from the results that in three of four cases we can reject the null hypotheses of mean difference being equal to zero, i.e. the there is a difference between means of relative efficiencies of individual treatments and this difference is highly statistically significant. Fourth case is on the boundary of the 5% level of significance. However, the Wilcoxon test does not allow for rejecting its null and therefore this partial result is ambiguous. Overall, we can say that the relative efficiencies are statistically different for each individual treatment.

6.3.1.1 Cumulative Efficiencies of Individual Player Types

In the section 6.2.1 I have presented the argument about the impact of actual setting of player parameters to the levels of relative efficiency. In this section, I statistically test for the difference of cumulative efficiencies of individual player types using two-sample t-tests with equal variances. Without the loss of generality, I employ the absolute cumulative measure of efficiency for this purpose rather than relative one for simplicity of calculations. The partial efficiency is calculated according to the equation (4.1) in section 4.1.9 for each unit of a good won by the respective player. These partial efficiencies are then added together resulting in the player-specific efficiency measure. All four player-specific efficiencies in one group taken together correspond to the total efficiency measure for the group, i.e. cumulative efficiencies.

Table 18: T-tests of type-specific cumulative efficiencies

t-test; by Player 1				**t-test; by Player 2**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 1	72	0.10	0.012	*Player 2*	72	0.07	0.010
Others	216	0.04	0.004	*Others*	216	0.05	0.005
combined	288	0.06	0.005	*combined*	288	0.06	0.005
Ha: diff ≠ 0		p-value	0.0000	Ha: diff ≠ 0		p-value	0.1676
W-M-W test:		p-value	0.0000	W-M-W test:		p-value	0.5255
t-test; by Player 3				**t-test; by Player 4**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 3	72	0.01	0.002	*Player 4*	72	0.05	0.006
Others	216	0.07	0.006	*Others*	216	0.06	0.006
combined	288	0.06	0.005	*combined*	288	0.06	0.005
Ha: diff ≠ 0		p-value	0.0000	Ha: diff ≠ 0		p-value	0.2780
W-M-W test:		p-value	0.0000	W-M-W test:		p-value	0.8648

The results of t-tests of cumulative efficiencies across player types are provided in the Table 18. At the bottom of each quadrant, there are p-values with their respective alternative hypotheses. The null hypothesis is the same for all cases ($\mathrm{H0}: \mathrm{diff} = 0$). I have again checked the results with the non-parametric Wilcoxon-Mann-Whitney test, which gave even stronger results. The null hypothesis of mean difference being equal to zero is rejected in two out of four cases with very high statistical significance (even on the 1% level), i.e. there is a difference between efficiency mean of first player type and the others and also between efficiency mean of third player type and the others. The difference between first player type and others is positive in the senses that this player is much stronger in reaching higher level of efficiency. The difference between third player and others is, on the other hand, negative in the sense that this player is much weaker in the same manner. Generally, we can say that since the player-specific efficiencies statistically substantially differ, there is probably an impact of player type to the overall relative efficiency measure. The other two results do not reach enough significance for rejecting the null hypotheses, i.e. efficiency means of player 2 and player 4 should not differ from the general population of all player types.

6.3.2 Testing of Final Profits

I tested also for the difference of individual means of final profits in all experimental treatments using two-sample t-tests with equal variances. The results of cross-comparison t-tests of final profits are provided in the Table 19. Presented means of final profits are the same as in the Table 15. The null hypothesis is the same for all cases (H0: diff = 0). Again, three out of four cases reject the null hypothesis of zero difference of means on the very high level of significance. Final profits are therefore statistically different from each other. Only the difference between SMR and SMRPB, both cases allowing for collusion, is not statistically significant. I have again checked for the results with no assumption of normally distributed dependent variables, which gave a bit weaker, but still similar reasonable results.

Table 19: T-tests of final profits between treatments

t-test; Basic; by SMR				**t-test; Coll.; by SMR**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	-23.38	42.657	*SMRPB Coll.*	72	500.09	78.926
SMR Basic	72	174.57	42.056	*SMR Coll.*	72	597.00	49.047
combined	144	75.59	30.973	*Combined*	144	548.54	46.476
Ha: diff ≠ 0		p-value	0.0012	Ha: diff ≠ 0		p-value	0.2988
W-M-W test:		p-value	0.0242	W-M-W test:		p-value	0.1024
t-test; SMRPB; by chat				**t-test; SMR; by chat**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	-23.38	42.657	*SMR Basic*	72	174.57	42.056
SMRPB Coll.	72	500.09	78.926	*SMR Coll.*	72	597.00	49.047
combined	144	238.35	49.772	*combined*	144	385.78	36.719
Ha: diff ≠ 0		p-value	0.0000	Ha: diff ≠ 0		p-value	0.0000
W-M-W test:		p-value	0.0000	W-M-W test:		p-value	0.0000

6.3.2.1 Final Profits of Individual Player Types

The final profits of individual player types do not seem statistically different. We cannot reject the null hypothesis of zero difference in any of four tested cases. Final profits are therefore not dependent on the type of the player and seem to be equally distributed. Results of all t-tests of type-specific final profits are provided in the following Table 20.

Table 20: T-tests of type-specific final profits

t-test; by Player 1				**t-test; by Player 2**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 1	72	414.74	71.296	*Player 2*	72	260.26	47.887
Others	216	277.84	33.891	*Others*	216	329.33	38.366
combined	288	312.07	31.176	*combined*	288	312.07	31.176
Ha: diff ≠ 0		p-value	0.0571	Ha: diff ≠ 0		p-value	0.3383
W-M-W test:		p-value	0.1793	W-M-W test:		p-value	0.2102
t-test; by Player 3				**t-test; by Player 4**			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 3	72	278.74	58.887	*Player 4*	72	294.52	68.305
Others	216	323.17	36.687	*Others*	216	317.92	34.867
combined	288	312.07	31.176	*combined*	288	312.07	31.176
Ha: diff ≠ 0		p-value	0.5381	Ha: diff ≠ 0		p-value	0.7458
W-M-W test:		p-value	0.8093	W-M-W test:		p-value	0.7406

6.3.3 Total Prices of Individual Player Types

The statistical tests of total prices for individual player types were generally of less statistical power than of the others. I have again tested the individual means of total prices in all experimental treatments using two-sample t-tests with equal variances. The results of cross-comparison t-tests of final profits are provided in the Table 21. Presented means are the same as in the Table 15. Two out of four cases are statistically significant. The results suggest that the total prices paid by the individual players are different in SMR and SMRPB both option with collusion and even more significantly, between both SMR treatments (with and without collusion). All results were confirmed by the non-parametric Wilcoxon tests.

6.3.3.1 Total Prices of Individual Player Types

Total prices paid by the individual players do not statistically depend on the player types. We cannot reject the null hypothesis of zero difference in any of four tested cases, even though the results for player 3 and player 4 are on the boundary of statistical significance. W-M-W test than worsen the results for assumption of non-normally distributed dependent variables. Total Prices therefore do not seem to be dependent on the type of the player and seem to be equally distributed. Results of all t-tests of type-specific total prices are provided in the Table 22.

Table 21: T-tests of total prices between treatments

t-test; Basic; by SMR				t-test; Coll.; by SMR			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	1445.89	255.593	*SMRPB Coll.*	72	1891.28	213.368
SMR Basic	72	1466.28	219.035	*SMR Coll.*	72	2672.44	148.601
combined	144	1456.08	167.716	*Combined*	144	2281.86	133.606
Ha: diff ≠ 0		p-value	0.9518	Ha: diff ≠ 0		p-value	0.0031
W-M-W test:		p-value	0.6653	W-M-W test:		p-value	0.0196

t-test; SMRPB; by chat				t-test; SMR; by chat			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
SMRPB Basic	72	1445.89	255.593	*SMR Basic*	72	1466.28	219.035
SMRPB Coll.	72	1891.28	213.368	*SMR Coll.*	72	2672.44	148.601
combined	144	1668.58	166.932	*combined*	144	2069.36	141.194
Ha: diff ≠ 0		p-value	0.1831	Ha: diff ≠ 0		p-value	0.0000
W-M-W test:		p-value	0.1524	W-M-W test:		p-value	0.0001

Table 22: T-tests of type-specific total prices

t-test; by Player 1				t-test; by Player 2			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 1	72	1951.89	222.673	*Player 2*	72	1821.33	220.936
Others	216	1841.33	126.383	*Others*	216	1884.85	126.756
combined	288	1868.97	109.767	*combined*	288	1868.97	109.767
Ha: diff ≠ 0		p-value	0.6635	Ha: diff ≠ 0		p-value	0.8026
W-M-W test:		p-value	0.4548	W-M-W test:		p-value	0.6696

t-test; by Player 3				t-test; by Player 4			
Group	**N**	**Mean**	**Std. Err.**	**Group**	**N**	**Mean**	**Std. Err.**
Player 3	72	1499.72	209.331	*Player 4*	72	2202.94	221.317
Others	216	1992.06	127.826	*Others*	216	1757.65	125.788
combined	288	1868.97	109.767	*combined*	288	1868.97	109.767
Ha: diff ≠ 0		p-value	0.0520	Ha: diff ≠ 0		p-value	0.0790
W-M-W test:		p-value	0.0645	W-M-W test:		p-value	0.1250

7 MODEL EVALUATION

In this chapter, I explore the econometric model of relative efficiency of complex Simultaneous multi-round auctions in the environment allowing for collusion and with a specific setting of multiple heterogeneous goods. The model was originally set in the section 4.2 very simple on purpose. I evaluated the initial model and developed its further alterations by proper econometric methods. Complete analysis can be found in the technical appendix. Finally, I have found two resulting model specifications of relative efficiency that explain connections among variables.

This chapter is organized as follows: I describe the variables and their expected effects in the section 7.1. Final specifications of two models resulting from the analysis are described in section 7.2. The ultimate part of the analysis, estimating the models by the robust regression methods, is described in section 7.3 of this chapter. Discussion of the estimates of final models is provided in the section 7.4.

7.1 VARIABLES AND THEIR EXPECTED EFFECTS

The main purpose of the analysis is to determine factors that influence the level of relative efficiency of Simultaneous multi-round auctions. Which auction format scores the best in terms of efficiency? Does the potential collusion influence the efficiency in a negative way or would it be possible that it actually helps to allocate goods more accurately? In this section, I summarize all available factors and hypothesise their effects on efficiency levels.

One of the main factors that should influence the efficiency should be the way in which the goods will be sold, i.e. the auction format. I follow the proposition made by Brunner, Goeree et al. (2010) that allowing for package bidding raises the auction efficiency. I use a SMR dummy variable to model this element and assume that this variable will be highly significant with negative impact on the efficiency. Second factor that should have major impact is in our case the presence of communication channel. I assume that allowing for communication facilitates collusion among auction players who then can split the auctioned goods. I expect that lowering competition should improve the inner allocation mechanisms and possibly increase efficiency. I also expect that the collusion should have higher effect on efficiency than the format used in the auction.

Following the analysis in section 6.3.1, I expect the player types to have non-negligible effect to the outcome of the auction, the efficiency in the first instance. I expect that type one will have positive and type three will have negative impact on the levels of relative efficiency. Table 18 shows that other two player types, second and fourth, should not have statistically significant effect on the efficiency. The variable *final_profit* represents total profit from the auction for each individual participant. It is a combination of final prices, quantities and individual player valuations. I expect the coefficient of this variable to be positive and significant.

The outcomes of auctions are naturally dependent on the final prices and quantities resulting out of those auctions. The higher prices the lower probability that all players can find a profitable allocation with positive final profit. Even though the goods are complements and therefore the more a player buys the higher is her total value, with increasing price some of the weakest players start to fall behind, resulting only the strongest players stay until the end of the auction. Prices of individual goods should therefore be, according to my expectations, generally significant with negative sign of their coefficients. Total price paid by the individual players for final allocation of goods is ambiguous. It is the combination of all prices paid for the quantities won. Without the relationship to the valuation of players, I do not expect this variable to have significant impact on the relative efficiency. Quantities of sold goods, on the other hand, should generally increase the efficiency, in case the goods will be allocated to players who value it the most. If we assume the weaker players with lower valuations for individual goods fall behind throughout the auction, the higher quantities of goods sold the higher efficiency we should get. Sign of the quantities coefficients should be generally positive.

Differences between individual valuations of goods and their respective prices should add an additional explanatory power to the model as will be described in section A.2.2. The higher difference between valuation and price, the more prone should be the players to buy this good. In compliance with quantities, I expect these variables to have statistically significant positive impact on relative efficiency.

Table 23: Predicted behaviour of variables in regressions

		Expectations	
VARIABLE	**LABEL**	**Signif**	**Sign**
SMR	SMR dummy	yes	-
SMRPB	SMRPB dummy		
SMR_chat	SMR & chat	yes	+
SMRPB_chat	SMRPB & chat	yes	+
chat	chat	yes	+
player_type	player type	yes	
final_profit	final profit within treatment	yes	+
q_a	q winner	yes	+
q_b	q winner	yes	+
q_c	q winner	yes	+
q_d	q winner	yes	+
p_total	total price of all goods	no	
p_a	price a within round	yes	-
p_b	price b within round	yes	-
p_c	price c within round	yes	-
p_d	price d within round	yes	-
vp_a_diff	valuation - price diff	yes	+
vp_b_diff	valuation - price diff	yes	+
vp_c_diff	valuation - price diff	yes	+
vp_d_diff	valuation - price diff	yes	+
control_time	control questions time	yes	-
female	female	yes	-
age	age	no	
cr	Czech native speaker	yes	+
edu_quality	highest edu	no	
edu_years	length of university edu	no	
edu_economics	economics edu 1-5	no	
edu_math	math edu 1-5	no	
edu_statistics	statistics edu 1-5	no	
edu_econometrics	econometrics edu 1-5	no	
experience	experimental exp	yes	+

Participant characteristics are of very variable nature. Control time, nationality and experimental experience are expected to be associated with an increase the understanding of the task and therefore raise efficiency. With growing time needed for participants to fill in the control questions correctly, their understanding of the task may be lower[41]. Sign of this variable should therefore be negative. Being a Czech native speaker should assure correct understanding of the experimental instructions. Both nationality and experience in economic experiments should increase efficiency. Since there was not sufficient age variance in the subject pool, I do not expect the variable *age* has any statistically significant impact. Following results of (Chen et al., 2012) I expect the variable female to have negative coefficient with ambiguous statistical significance. I do not a priori assume the other variables capturing subjective perception of participants' education to be statistically significant. Table 23 shows summary of predicted (and real) behaviour of variables in regression analysis.

7.2 FINAL MODEL SPECIFICATIONS

I have run the linear regressions for the initial model (4.3**)** provided in the section 4.2. First estimates were unsatisfactory as expected. Severe problems with normality of residuals and more importantly with multicollinearity of predictors occurred in this model. Many variables indicating high levels of multicollinearity were mutually correlated. After performing a reciprocal series of partial F-test for joint significant of collinear variables, I have approached to gradual reduction of those variables out of the model. I have reached two interchangeable reduced specifications[42]; both have resulted in stabilization of multicollinearity problems. Subsequently, I have added an additional explanatory power to the models by replacing price with variables for valuation-price differences *vp_x_diff*. Moreover, I have made further alterations to the model specifications. I have widened the inventory of variables by the dummies for individual player types. Significance of those variables was considerable. It seemed that a lot of variation in relative efficiency was caused by the player-type parametric setting of the experiment rather than by its original intention, i.e. the communication channel. Next, I have controlled for participant characteristics of the sample. I have run the model of relative efficiency solely on the participant characteristics first. Significant variables resulting out of this analysis were then used

[41] Without the loss of generality, I have noticed a clear pattern during the experiment itself: the faster completion of control questions the better understanding of the experiment. I am aware of potential differences in the learning processes of individuals, which gives only a limited power to this variable.

[42] I have reached specifications with p_total and with q_total. Since the correlation between *p_total* and q_a is above 96%, the elimination of either of them made almost no difference. Detailed analysis is provided in the appendix.

as proxies for the whole set of participant characteristics in the main model specifications.

I ended up with two complete model specifications of the relative auction efficiency. The first model, provided in the equation (7.1**)**, encompasses specification without player types and with sampling participant characteristics. The second model, provided in the equation (7.2**)**, encompasses specification with player types (10.2**)**together with sampling participant characteristics.

$$\begin{aligned} e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \ \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\ + \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \ \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \gamma_1 time^{control} + \gamma_2 cr \\ + \gamma_3 \mathrm{edu}^{\mathrm{math}} + \ \gamma_4 edu^{statistics} + \ \gamma_5 exp + \varepsilon \end{aligned} \tag{7.1}$$

$$\begin{aligned} e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \ \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\ + \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \ \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \beta_{10} pt^1 + \ \beta_{11} pt^2 \\ + \ \beta_{12} pt^3 + \gamma_1 time^{control} + \gamma_2 cr + \gamma_3 \mathrm{edu}^{\mathrm{math}} \\ + \ \gamma_4 edu^{statistics} + \ \gamma_5 exp + \varepsilon \end{aligned} \tag{7.2}$$

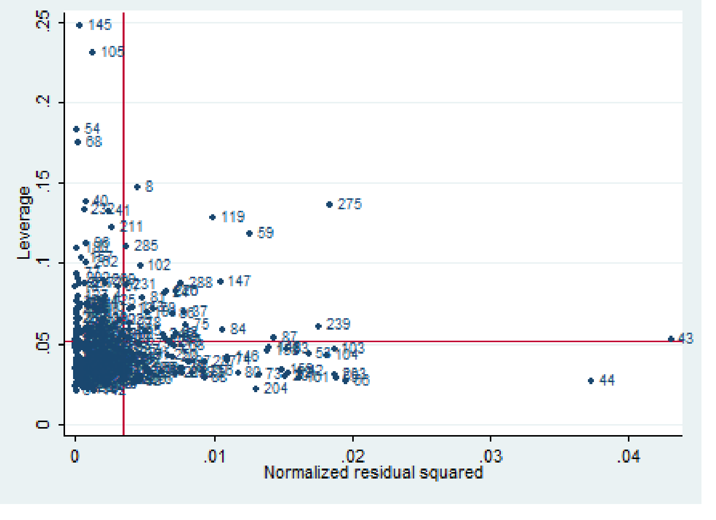
7.3 ROBUST REGRESSION ANALYSIS

Finally, we got two models, which include all relevant variables we have at disposal for our analysis. The first model explains relative efficiency on the auction format, presence of communication channel, final profit, quantities, differences between valuations and prices, and characteristics of the participant sample. The second model adds control variables for player types, which are case-specific for our experiment.

The inconsistencies in testing the model assumptions in previous sections suggest that some techniques beyond the scope of OLS should be used to check the appropriateness of the analysis (Chen et al., 2003). In this section of analysis, I deal with potential outliers and leverage points of resulting two models by employing robust regression techniques. First, I employ the robust standard errors to check for the non-normality in the data. Second, I use robust regression for weighting the observations in the regression according to their relevance. I provide some simple drafts of additional model analysis at the very end of this section.

Graph 3 shows the plot of leverage versus squared residuals of the model without player types.[43] Even though the situation is not dramatic, there are some points in the upper right quadrant that could be influential. In this section of analysis, I deal with potential outliers and leverage points of resulting two models by employing robust regression techniques. First, I employ the robust standard errors to check for the non-normality in the data. Second, I use robust regression for weighting the observations in the regression according to their relevance. I provide some simple drafts of additional model analysis at the very end of this section.

Graph 3: Leverage-versus-squared-residual plot



7.3.1 Robust Standard Errors

There were constant problems with normality of the residuals during the data analysis. Even though the normality is not required in order to obtain unbiased estimates of the regression coefficients, it can severely influence the heteroskedasticity tests (Chen et al., 2003). I therefore employ a technique that estimates the standard errors using the Huber-White sandwich estimators to obtain robust standard errors. The estimates of coefficients are with the robust standard errors option the same as in the original model, taking into account issues concerning heterogeneity and lack of normality. The estimates of both final models with robust standard errors option are provided in the Table 24 on page 59.[44]

[43] Actually, this plot depicts the leverage versus squared residuals of both models. The differences are not noticeable visually.

[44] Assumptions of both models were checked and remained stable.

7.3.2 Robust Regression

Although there are observations of high controversy in the data, I do not think these data points should be excluded from the sample. There are many observations of exceptionally good bidding strategies within the treatments with communication that definitely should remain in the dataset. However, it is necessary to deal with those observations in a way that would not distort the results. The robust regression is a method of weighted ordinary least squares, which gives higher weights to "better behaved observations." Weights of observations depend on the Cook's Distance[45] (Chen et al., 2003). Robust regression should therefore be a proper tool for our model. The estimates of both final models with robust regression method are provided in the Table 24 on page 59.[46] No observation was omitted from the analysis due to Cook's Distance; all models have the same number of observations. I have used calculation of goodness of fit for the robust regression (Chen et al., 2003)[47]. Robust regression has weakened the coefficients of determination of both model specifications. However, the decline in R-squared is not dramatic; both coefficients are still around 50%. Generally, the significance of coefficients of variables slightly decreased.

7.4 DISCUSSION OF THE RESULTS

This section discusses the estimates of final models. Both models have several significant variables with the effects of coefficients in the same directions. There are complete results of both regressions provided in the Table 24. First, quantities of goods are statistically significant in three out of four types of goods. All coefficients have positive sign and rate approximately between 0.01 and 0.02; i.e. raise of the quantity of particular good by one unit would, ceteris paribus, increase on average the rate of relative efficiency by about 0.013-0.02 percentage points depending on particular type of the good. It is interesting that the quantity of good A has not statistically significant impact on efficiency even though it is the strongest good from the point of view of absolute private valuations. Second, there is a positive statistically significant impact of the difference between valuation of good B and its price on the relative efficiency of the auction. The coefficients reach 0.003 and 0.006

[45] Potential extreme cases (Cook's Distance > 1) are excluded from the analysis.

[46] Assumptions of both models were checked and remained stable.

[47] There is a command rregfit in STATA available for download. This command was designed and written by the UCLA Statistical Consulting (Chen, X., P. Ender, et al. 2003).

for first and second model respectively; i.e. one ECU increase in the difference of good B would cause, ceteris paribus, 0.003 and 0.006 percentage point change in the relative efficiency of auction.

Third, the final profit of individual players is significant with a positive rate of approximately $4 \cdot 10^{-5}$ for both model specifications. It means that an increase in final profit by 100 ECUs would result, ceteris paribus, in an average increase of relative efficiency by 0.004 percentage points. The robust regression methods produced only a single significant variable out of the participant sample characteristics[48]. This variable captures the self-reported degree of mathematical education expressed on 1-5 scale. The coefficient of this variable is negative for both models. Its value reaches for the first and second specification -0.0248 and -0.0275 respectively; i.e. an increase in the self-reported quality of education by one unit would cause, ceteris paribus, the relative efficiency to decrease on average by -0.02 percentage points. Overall, there are initially expected effects on the relative efficiency with different degree of impact. Especially quantities have considerable effect with respect to the extent of the dependent variable *e_r*. An interesting effect on efficiency has the mathematical education of participants. The model suggests that with higher education the efficiency of realized auction decreases. However, Table 29 in the appendix reports the mean of mathematical education at rate 3.29 with minimum equal to 2 and maximum to 5. This may suggest that their actual rate is overestimated by the participants and the results are distorted.

[48] However, there is another significant variable, statistical education, present in the OLS with robust standard errors. The coefficient of self-reported degree of statistical education is positive; i.e. with higher education in statistics, participants achieve higher efficiencies.

Table 24: Results of robust regression analysis of relative efficiency models

VARs	(1) original model	(2) robust std. errors	(3) robust regression	(4) original model	(5) robust std. errors	(6) robust regression
		without p-types			*with p-types*	
SMR	0.0616***	0.0616***	0.0357**	0.0497***	0.0497**	0.0206
	(0.0184)	(0.0200)	(0.0181)	(0.0183)	(0.0195)	(0.0177)
chat	0.0599***	0.0599***	0.0501**	0.0290	0.0290	0.0171
	(0.0229)	(0.0214)	(0.0225)	(0.0240)	(0.0218)	(0.0231)
final profit	6.35e-05***	6.35e-05***	4.77e-05**	5.96e-05***	5.96e-05***	4.20e-05**
	(2.10e-05)	(1.90e-05)	(2.07e-05)	(2.09e-05)	(1.91e-05)	(2.01e-05)
q_a	-0.00574	-0.00574	0.000479	-0.0105	-0.0105	-0.00400
	(0.0109)	(0.00977)	(0.0107)	(0.0111)	(0.0103)	(0.0106)
q_b	0.0126***	0.0126***	0.0131***	0.0154***	0.0154***	0.0159***
	(0.00225)	(0.00201)	(0.00221)	(0.00233)	(0.00214)	(0.00225)
q_c	0.0168**	0.0168***	0.0174**	0.0200**	0.0200***	0.0204***
	(0.00823)	(0.00620)	(0.00808)	(0.00812)	(0.00661)	(0.00782)
q_d	0.0141***	0.0141***	0.0174***	0.00911**	0.00911*	0.0133***
	(0.00439)	(0.00537)	(0.00431)	(0.00458)	(0.00548)	(0.00441)
vp_b_diff	0.00117	0.00117	0.00264*	0.00398**	0.00398**	0.00571***
	(0.00138)	(0.00156)	(0.00136)	(0.00156)	(0.00163)	(0.00150)
vp_c_diff	0.000158	0.000158	0.000165	-9.73e-05	-9.73e-05	-0.000109
	(0.000253)	(0.000232)	(0.000249)	(0.000258)	(0.000226)	(0.000248)
pt_1				-0.0870***	-0.0870***	-0.0861***
				(0.0249)	(0.0229)	(0.0239)
pt_2				-0.0642***	-0.0642***	-0.0609***
				(0.0238)	(0.0231)	(0.0230)
pt_3				-0.0129	-0.0129	-0.00747
				(0.0208)	(0.0230)	(0.0200)
control time	-3.26e-05	-3.26e-05	-4.59e-05	-3.97e-05	-3.97e-05	-4.05e-05
	(7.44e-05)	(8.38e-05)	(7.30e-05)	(7.30e-05)	(8.21e-05)	(7.03e-05)
cr	0.0260	0.0260	0.0257	0.0194	0.0194	0.0186
	(0.0176)	(0.0184)	(0.0173)	(0.0174)	(0.0183)	(0.0168)
edu math	-0.0338**	-0.0338**	-0.0248*	-0.0383***	-0.0383***	-0.0276**
	(0.0142)	(0.0131)	(0.0140)	(0.0142)	(0.0132)	(0.0136)
edu statistics	0.0317*	0.0317*	0.0243	0.0388**	0.0388**	0.0281
	(0.0188)	(0.0165)	(0.0184)	(0.0186)	(0.0164)	(0.0179)
experience	-0.00105	-0.00105	0.000147	-0.000136	-0.000136	0.00140
	(0.00211)	(0.00228)	(0.00208)	(0.00209)	(0.00227)	(0.00201)
Constant	0.166**	0.166***	0.178**	0.231***	0.231***	0.239***
	(0.0718)	(0.0600)	(0.0705)	(0.0747)	(0.0637)	(0.0719)
Observations	288	288	288	288	288	288
R-squared	0.521	0.521	0.491	0.545	0.545	0.513

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

8 SUMMARY OF MAIN FINDINGS

In this chapter, I summarize the important findings of the analysis. I review chapter 6 for summary of qualitative analysis and inspect chapter 7 to summarize the quantitative part of the analysis. In the last section 8.3 of this chapter, I synthesize results of final models and resolve the hypotheses set in the chapter 1.

8.1 SUMMARY OF THE QUALITATIVE PART

The results of all auction treatments were different from each other. Generally, the treatments allowing for communication among players scored better in all experimental parameters than their non-collusive counterparts. Comparison of basic formats without the communication channel shows that both formats are statistically identical in terms of efficiencies (although SMR performs slightly better), total prices paid by the bidders and total revenues. However, there arises a serious difference in the average final profits gained by the players of those treatments. Generally, lower number of goods was sold in the basic treatments since the competition drove prices to higher levels and weaker players were therefore forced to fall behind. The difference between SMR a SMRBP may be caused by the fact that facilitating exposure risk problem by allowing for package bidding can further decrease the total number of goods sold in the package-bidding format. While bidding on packages of goods the weaker players, who were outperformed by stronger ones, do not buy any goods at all rather than to buy only a subset of goods they would be interested in. This decreases total quantities sold in the basic package-bidding format with respect to basic SMR and therefore affects the average of final profits in a negative manner. Lower total quantities and seller revenues supports the results already introduced by Banks, Olson et al. (2003).

Bringing the two basic formats against their collusive examples favours resolutely the collusive treatments. While allowing for communication, the players developed collusive agreements and did not let the prices went up. By splitting the goods in stakes, they were able to buy more goods altogether and increase their profits substantially. Even though for lower prices, with more goods sold higher revenues for the auctioneer occurred. An interesting fact about the efficiency could be tracked while comparing basic with collusive treatments. The relative efficiency was actually increased by the lower competition among players since those were able to split the goods more accurately and therefore reach allocation that is more efficient.

Comparing SMR and SMRPB formats with communication allowed generally favours the SMR without package bidding. There were many situations when allowing for combinatorial bidding on packages broke collusion. The players usually set a collusive agreement on splitting the goods in some way favourable for all. However, many tried to divert from these agreements in an attempt to win more and gain higher profits. Prices were gradually rising as the agreements were broken and weaker players again fell behind. Overall fewer units of goods were sold on average in the SMRPB with collusion than in the SMR with collusion. Total prices were therefore lower and so were the revenues for the seller.

8.1.1 Other Sources of Variation in the Experiment

Not only treatment-specific differences were influencing the results of the experiment. There were also other factors affecting outcomes common to all treatments, such as actual parameter setting of goods or player types. The most beneficial type of goods in terms of private valuations was good A followed by good B. On contrary, goods C and D had zero or negative additional value for all players. The possible efficiency gain was highest for good B with respect to its efficiency per unit and low activity cost per unit. Moreover, not all players were of the same strength. The second player had only a limited chance to outplay others in terms of final profits due to the parameter setting. There appeared significant differences in achieved efficiency among individual player types. The first player had statistically higher rate of average cumulative efficiency (by 6 %, i.e. 2,5 times more) and final profit (by 49%) than others did. Reverse situation stands for the third player since her average cumulative efficiency was significantly lower (by -6 %, i.e. 7 times less) together with total price paid (by -24,7%); in other words the third player have bought less goods on average.

8.2 SUMMARY OF THE QUANTITATIVE PART

There are several factors influencing relative efficiency of auctions in our particular case. Table 25 provides the summary of actual and predicted behaviour of regression variables. The discussion of results in this section is based on two model specifications, both estimated by the robust regression method. First specification excludes variables for player types; the second includes them into the model. Let us first discuss what have these two specifications in common.

Table 25: Summary of predicted and actual behaviour of regression variables[49]

		Expectations		*Real Behaviour* no p-types		with p-types	
VARIABLE	**LABEL**	**Signif**	**Sign**	**Signif**	**Sign**	**Signif**	**Sign**
SMR	SMR dummy	yes	-	yes	+	no	
SMRPB	SMRPB dummy						
SMR_chat	SMR & chat	yes	+	yes	+		
SMRPB_chat	SMRPB & chat	yes	+	no		no	
chat	chat	yes	+	yes	+	no	
player_type	player type	yes				yes	-
final_profit	final profit within treatment	yes	+	yes	+	yes	+
q_a	q winner	yes	+	no		no	
q_b	q winner	yes	+	yes	+	yes	+
q_c	q winner	yes	+	yes	+	yes	+
q_d	q winner	yes	+	yes	+	yes	+
p_total	total price of all goods	no					
p_a	price a within round	yes	-				
p_b	price b within round	yes	-				
p_c	price c within round	yes	-				
p_d	price d within round	yes	-				
vp_a_diff	valuation - price diff	yes	+				
vp_b_diff	valuation - price diff	yes	+	yes	+	yes	+
vp_c_diff	valuation - price diff	yes	+	no		no	
vp_d_diff	valuation - price diff	yes	+				
control_time	control questions time	yes	-	no		no	
female	female	yes	-				
age	age	no					
cr	Czech native speaker	yes	+	no		no	
edu_quality	highest edu	no					
edu_years	length of university edu	no					
edu_economics	economics edu 1-5	no					
edu_math	math edu 1-5	no		yes	-	yes	-
edu_statistics	statistics edu 1-5	no		no		no	
edu_econometrics	econometrics edu 1-5	no					
experience	experimental exp	yes	+	no		no	

[49] Variables with blank cells were either not included or excluded out of the model. The SMRPB is a complementary dummy variable for SMR, i.e. significant with the same size and inverse direction. The estimations of interaction for variables SMR & chat and SMRPB & chat were run in the separate model in the section A.3.3.2 in the appendix.

8.2.1 Model Differences

The main differences in both models lie in their different specifications, which causes the crucial variables to change their behaviour. Introducing the dummy variables for player types shifts statistical significance from the dummies for auction format and communication channel to those variables controlling for player types. Let us first deal with both models separately. The model without player types has significant both *SMR* and *chat* variables with positive impact on relative efficiency. The actual usage of SMR auction format increases, ceteris paribus, the rate of relative efficiency on average by 0.035 percentage points. Presence of communication window in the auction interface increases, ceteris paribus, the rate of relative efficiency on average by 0.05 percentage points. Slightly disturbing fact is that these two coefficients actually quite differ from those estimated by the same model and the robust standard errors method; the other coefficients are on the other hand, comparable.

When we consider the model with variables controlling for player types, the significance of both *SMR* and *chat* variables disappear (even though the robust standard errors method of estimation produces at least the *SMR* variable significant on 5% level). However, two out of three player type variables are highly significant. If the observation is taken out of the population of player types one, it decreases, ceteris paribus, the relative efficiency on average by -0.086 percentage points. If, on the other hand, is the observation taken out of the population of second player types, it decreases, ceteris paribus, the relative efficiency on average by -0.064 percentage points.

Taken both model specifications altogether, there is a strong difference between the estimates of auction format and presence of communication channel. Considering only the second model with player type variables, it seems that a lot of variation in relative efficiency was in the experiment caused by its player type parametric setting rather than by the experimental design, i.e. auction format or allowing for communication. However, additional analysis in sections 0 and especially 6.3 showed that there are differences between treatments that do not depend only on the specification of player type. I therefore consider the model without player types of no less importance for the analysis.

8.3 RESOLVING THE HYPOTHESES

In the first wave of treatments without communication, the degree of competition was higher than in the collusive treatments. Even though I have employed setting with high complementarities among goods, the combinatorial SMRPB format scored generally worse in efficiency, which is in contrary to Brunner, Goeree et al. (2010). Prices reached the competitive levels closely, weaker bidders fell behind the players with higher valuations. The revenues for the auctioneer were generally low due to high competition, which favoured only strong bidders. Fewer goods were sold and the higher prices could not compensate the losses. Surpluses of bidders resulted at low or even negative levels. The SMRPB format resolved the exposure risk problem. Winners curse was observed in both auction formats.

The second weave of treatments introduced communication. Many cases of coordinated collusion appeared during the experiment in which prices remained very low or even at the upset base. This fact confirms results of (Valley et al., 1996) in the case of double oral auction. There were also cases in which some bidders tried to break the agreement with others. Such cases were occasionally successful, resulting in overall decrease in efficiency. Generally, no or very little competition among bidders was present. There was no shift in distribution of rents from auctioneer revenues to bidders’ surpluses; the observed patter demonstrated raising surpluses and revenues at the same time. With lower competition within the treatments with communication channel, more goods for lower prices were sold. The higher quantities more than compensated lower prices.

There was the evidence that allowing for combinatorial bidding in the SMRPB format breaks collusion. Some players tried to divert from the collusive agreement in the package-bidding format in an attempt to win more and gain higher profits. Prices were gradually rising as the agreements were broken and weaker players fell behind resulting in almost competitive situations. The package-bidding format therefore increased competition. The communication had positive impact on efficiency in both auction formats. Players were able to make an agreement and split goods at stakes among themselves. Successful collusive agreements resulted in better allocation of goods among players and therefore higher efficiencies.

Table 12 summarizes the results of partial hypotheses *within formats* and setting *without and with communication allowed* in the auction. Table 27 summarizes the results of partial hypotheses *between formats* and setting *without and with communication allowed* in the auction. Original partial hypotheses are available in the section 4.4.

Table 26: Partial hypotheses within formats - Results

	SMR	&		SMR & Coll	SMRPB	&		SMRPB & Coll
Total Prices	P_{SMR}	$<$	***	P_{SMR}^{Coll}	P_{SMRPB}	$\leq$		P_{SMRPB}^{Coll}
Efficiency	E_{SMR}	$<$	***	E_{SMR}^{Coll}	E_{SMRPB}	$<$	***	E_{SMRPB}^{Coll}
Auctioneer's revenue	R_{SMR}	$<$	***	R_{SMR}^{Coll}	R_{SMRPB}	$<$		R_{SMRPB}^{Coll}
Bidders' surpluses	S_{SMR}	$<$	***	S_{SMR}^{Coll}	S_{SMRPB}	$<$	***	S_{SMRPB}^{Coll}

Table 27: Partial hypotheses between Formats - Results

	SMR	&		SMRPB	SMR & Coll	&		SMRPB & Coll
Total Prices	$\mathrm{P}_{\mathrm{SMR}}$	$=$		$\mathrm{P}_{\mathrm{SMRPB}}$	$\mathrm{P}_{\mathrm{SMR}}^{\mathrm{Coll}}$	$>$	***	$\mathrm{P}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$
Efficiency	$\mathrm{E}_{\mathrm{SMR}}$	$\geq$	**	$\mathrm{E}_{\mathrm{SMRPB}}$	$\mathrm{E}_{\mathrm{SMR}}^{\mathrm{Coll}}$	$>$	***	$\mathrm{E}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$
Auctioneer's revenue	$\mathrm{R}_{\mathrm{SMR}}$	$=$		$\mathrm{R}_{\mathrm{SMRPB}}$	$\mathrm{R}_{\mathrm{SMR}}^{\mathrm{Coll}}$	$>$	***	$\mathrm{R}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$
Bidders' surpluses	$\mathrm{S}_{\mathrm{SMR}}$	$>$	***	$\mathrm{S}_{\mathrm{SMRPB}}$	$\mathrm{S}_{\mathrm{SMR}}^{\mathrm{Coll}}$	$=$		$\mathrm{S}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$

Table 28: General hypotheses - Results

Null *H0*	Alternative *HA*	Final Null Result
$\mathrm{SMR} < SMRPB$	$\mathrm{SMR} > \mathrm{SMRPB}$	could not be rejected
$\mathrm{SMR\ Coll} < SMRPB\ Coll$	$\mathrm{SMR\ Coll} > \mathrm{SMRPB\ Coll}$	rejected
$\mathrm{SMR} > SMR\ Coll$	$\mathrm{SMR} < SMR\ Coll$	rejected
$\mathrm{SMRPB} > SMRPB\ Coll$	$\mathrm{SMRPB} < SMRPB\ Coll$	rejected
$\mathrm{E}_{\mathrm{SMR}} = \mathrm{E}_{\mathrm{SMR}}^{\mathrm{Coll}}$	$\mathrm{E}_{\mathrm{SMR}} \neq \mathrm{E}_{\mathrm{SMR}}^{\mathrm{Coll}}$	rejected
$\mathrm{E}_{\mathrm{SMRPB}} = \mathrm{E}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$	$\mathrm{E}_{\mathrm{SMRPB}} \neq \mathrm{E}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$	rejected
$\mathrm{E}_{\mathrm{SMR}}^{\mathrm{Coll}} = \mathrm{E}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$	$\mathrm{E}_{\mathrm{SMR}}^{\mathrm{Coll}} \neq \mathrm{E}_{\mathrm{SMRPB}}^{\mathrm{Coll}}$	rejected

Table 28 summarizes main hypotheses of the experiment and brings their results. Basic SMR auction overall performed at the approximately same level with its combinatorial counterpart basic SMRPB format. However, when allowing for communication, these two formats substantially differ. The SMR scored better in terms of efficiency and brought higher revenues to the seller with lower final prices and approximately the same surpluses of the bidders. Even though SMRPB can prevent collusion, generally, we can say that the SMR auction format scored better result in our experiment than the SMRPB. Both formats scored better while allowing for collusive behaviour of its participants. The overall results are presented from the experimental point of view and therefore do not consider socially inadmissible nature of collusion among players.

The experiment showed that when suspicion of potential collusion while preparing the auction is present, the policy makers should prefer simpler versions of auction formats. The design should be clear and simple in case of auctions with high numbers of items in order to allow for complete utilization of allocative potential of the auction formats. Complexities of combinatorial bidding mechanisms can make the decision problem of bidders difficult to process and therefore cause inefficiencies due to their inappropriate bidding strategies. For sure, the unacceptable nature of collusion makes the question more intricate. Even though this experiment demonstrated that allowing for combinatorial bidding could break the collusion, the merits of simple auction procedures outperform this knowledge. It would be much more beneficial to cope with the collusive practices at the institutional and legal levels and let the economic machines operate without disorder.

9 CONCLUSIONS

In this thesis, I studied the complex auction formats under the possibility of communication during the auction. I experimentally evaluated two Simultaneous multi-round auction formats with a communication channel facilitating potential collusion among participants. The experiment was put into the context of spectrum auctions held in the Czech Republic in 2012 and 2013, since these may serve as representative of simultaneous auctions with serious suspicion of collusion. The crucial parameter from the real auctions worth replicating lies in the suspicion of collusive behaviour of its incumbents and the structure of the market that can be found also in other countries and industries. Using the parameter setting of Czech Spectrum Auctions, I have continued in the direction of basic research.

The Simultaneous multi-round auction (SMR) format and its extension allowing for combinatorial bidding, the Simultaneous multi-round auction Package bidding (SMRPB) format, were investigated in four experimental treatments. There were two basic and two additional treatments introducing a possibility of collusion via a simple communication channel present in the design of the experiment. In each experimental treatment, four bidders participated in the auction for multiple heterogeneous types of goods. The total number of auctioned goods exceeded fifty in each auction. Communication in respective treatments was intermediated through a chat window in the auction interface; a simple self-enforced mechanism that does not require any additional procedures. Four fundamental variables are studied in the experiment: relative efficiencies of the auction formats, total price paid by the bidders, their final profits, and auctioneer revenue. An econometric model explaining relative efficiency of the auction is developed within this thesis.

The key results of this thesis can be summarized as follows. All auction treatments were different from each other. Allowing for communication in the auction resulted in generally better results in all experimental parameters. Lower amounts of goods were sold in basic treatments in comparison with treatments with communication; since the competition drove prices to higher levels and weaker players fell behind. This situation occurred in both basic SMR and SMRBP treatments resulting in substantially lower efficiencies, auctioneer revenues and bidder surpluses. The allocative mechanisms worked much better when bidders could split auctioned goods in a collusive agreement. However, there was some evidence in the experiment that combinatorial bidding on packages may break the collusion which confirms but do not strengthen the statement of (Kwasnica and Sherstyuk, 2013).

Results did not prove that the basic package-bidding format is significantly different from the SMR format. Allowing for combinatorial bidding did not bring higher efficiency in our parameter setting which is in contradiction to (Brunner et al., 2010) who claim that combinatorial bidding is more efficient. Generally, there is strength in simplicity of bidding languages in the SMR auction format. In comparison to its combinatorial SMRPB counterpart, the clear and simple design of SMR makes the decision problem of players easier and manageable. The inappropriate bidding strategies in complex combinatorial mechanisms do not allow for complete utilization of allocative potential of the auction formats and therefore cause inefficiencies. This result corresponds to that of Goeree and Holt (2010), who question combinatorial formats precisely because they are not computationally manageable for their participants, and of Bichler et al. (2013a), who suggest that with the number of licenses in stock exceeding 30 is the number of possible bidding combinations immense and makes the bidder optimization problem unacceptably difficult.

The policy recommendations resulting from this research are straightforward. When suspicion of potential collusion while preparing the auction is present, the policy makers should prefer simpler versions of auction formats, which bring higher efficiencies and revenues. This holds true especially for auctions with high volume of goods for sale. This statement is supported not only by this research, but also by Bichler et al. (2013b). Moreover, Bichler et al. (2013a) further state that even the efficiency of simple auction formats increases with high volumes of goods in stock. This result could not be confirmed for non-communication treatments in this research, but holds solid for the auction with the presence of communication. Its further scrutiny can be one of the possible extensions of this research.

The research presented in this thesis has several possible extensions. Resulting from the prior research (for example Brunner et al., 2010, Bichler et al., 2013b; and others) and also the experiments realized within this thesis, the performance of players in combinatorial auctions is highly dependent on their practice or experience. Controlling for the high complexity of scrutinized auction settings by adding treatments with the experienced subjects seems to be very meaningful. Second possible extension is the structural change in the communication pattern within the group of players, where the possibility of communication would be given to only a subset of subjects. An effect of new entrants to established collusion may be explored by such settings.

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Appendix A: Technical Appendix

A.1 DESCRIPTIVE STATISTICS OF VARIABLES

In the Table 29 on the next page, you can have a look at the summary statistics of all relevant variables in the dataset. There are observation identifiers and dummy variables present at the beginning of the table followed by the important auction parameters in the middle and participant sample descriptive variables at the end of the table. All variables in the first two categories have 288 observations which corresponds to 3 observations per one treatment; 24 subjects per one treatment; and 4 experimental treatments ($3 \cdot 24 \cdot 4 = 288$). The third category of participant sample descriptive variables has 96 observations corresponding to 24 subjects per one treatment and 4 experimental treatments ($24 \cdot 4 = 96$).

A.2 THE INITIAL MODEL

I have run the linear regressions for the initial model provided in the section 4.2.1. The model tries to explain the relative efficiencies of individual auctions (*e_r*) by the dummy variables for auction formats (*SMR*) and communication channel (*chat*); final profits (*π)* and total prices paid by the players (*P*); respective price vector (*p_a; p_b; p_c; p_d*); and quantity vector (*q_a; q_b; q_c; q_d*).

A.2.1 First estimates

The results of initial model estimates are provided in the Table 30. Severe problems with normality of residuals and more importantly with multicollinearity of predictors occur in this model. Normality is not required in order to obtain unbiased estimates of the regression coefficients, but the multicollinearity causes the regression coefficients become unstable[50] (Chen et al., 2003). Other assumptions of linear regression were verified.

[50] The normality of residuals was rejected by both visual examination of density plots and statistical tests. The p-value in Shapiro-Wilk W test for normal data resulted in 0.0000. Multicollinearity was checked by the *variance inflation factor;* Breusch-Pagan test for heteroskedasticity with null hypothesis of constant variance resulted with p-value equal to 0.62.

Table 29: Descriptive statistics of the relevant variables

Variable	Label	N	Mean	Std. Dev.	Min	Max
id_session	auction format	288	2.50	1.12	1	4
id_group	unique group id	288	36.50	20.82	1	72
id_subject	unique subject id	288	48.50	27.76	1	96
SMR	SMR dummy	288	0.50	0.50	0	1
SMRPB	SMRPB dummy	288	0.50	0.50	0	1
SMR_chat	SMR & chat	288	0.25	0.43	0	1
SMRPB_chat	SMRPB & chat	288	0.25	0.43	0	1
chat	chat	288	0.50	0.50	0	1
player_type	player type	288	2.50	1.12	1	4
final_profit	final profit within treatment	288	312.07	529.08	-1717.2	2269.9
q_a	q provisional winner	288	0.88	0.90	0	2
q_b	q provisional winner	288	2.20	3.63	0	22
q_c	q provisional winner	288	0.41	0.96	0	7
q_d	q provisional winner	288	1.08	1.81	0	9
p_total	total price of all goods	288	1868.97	1862.81	0	5368
p_a	price a within round	288	2157.36	368.80	1680	3080
p_b	price b within round	288	61.44	11.00	48	88
p_c	price c within round	288	255.38	50.49	180	360
p_d	price d within round	288	61.22	10.78	48	88
e	efficiency total	288	0.23	0.17	0	0.63
e_r	efficiency relative total	288	0.24	0.17	0	0.66
e_player	subject-specific eff.	288	0.058	0.077	0	0.439
rev	revenue for the seller	288	7475.89	3835.00	0	14944
unsold_total	unsold licenses total	288	34.72	12.46	10	53
vp_a_diff	valuation - price diff	288	309.36	379.22	-312	1314
vp_b_diff	valuation - price diff	288	11.19	11.48	-6	41
vp_c_diff	valuation - price diff	288	115.13	50.56	35	222
vp_d_diff	valuation - price diff	288	13.97	11.18	-2	45
control_time	control questions time	96	488.81	110.55	211	715
female	female	96	0.26	0.44	0	1
age	age	96	22.43	1.78	19	28
cr	Czech native speaker	96	0.74	0.44	0	1
edu_quality	highest edu	96	2.66	0.54	1	3
edu_years	length of university edu	96	3.28	1.30	2	7
edu_economics	economics edu 1-5	96	3.47	0.71	1	5
edu_math	math edu 1-5	96	3.29	0.59	2	5
edu_statistics	statistics edu 1-5	96	2.99	0.42	1	4
edu_econometrics	econometrics edu 1-5	96	2.23	1.09	1	4
experience	experimental exp	96	5.51	3.65	0	16

Table 30: Results of initial models of relative efficiency

VARIABLES	(1) Initial Model	(2) prices p_total	(3) prices q_a	(4) vp differences p_total	(5) vp differences q_a
SMR	0.0199 (0.0178)	0.0728*** (0.0174)	0.0721*** (0.0175)	0.0678*** (0.0181)	0.0671*** (0.0181)
chat	-0.0179 (0.0250)	0.0745*** (0.0200)	0.0744*** (0.0201)	0.0627*** (0.0229)	0.0624*** (0.0230)
final_profit	-6.05e-05** (2.67e-05)	6.92e-05*** (1.85e-05)	6.57e-05*** (1.98e-05)	6.29e-05*** (1.94e-05)	5.93e-05*** (2.07e-05)
p_total	-0.000129*** (3.46e-05)	-5.34e-06 (5.28e-06)		-5.22e-06 (5.28e-06)	
q_a	0.266*** (0.0717)		-0.00360 (0.0110)		-0.00351 (0.0110)
q_b	0.0195*** (0.00293)	0.0142*** (0.00223)	0.0137*** (0.00219)	0.0136*** (0.00228)	0.0132*** (0.00224)
q_c	0.0490*** (0.0116)	0.0203** (0.00855)	0.0179** (0.00821)	0.0194** (0.00860)	0.0170** (0.00825)
q_d	0.0235*** (0.00505)	0.0136*** (0.00445)	0.0126*** (0.00435)	0.0142*** (0.00447)	0.0132*** (0.00437)
p_a	-0.000379*** (7.26e-05)				
p_b	0.00890*** (0.00276)				
p_c	0.000476* (0.000253)	-0.000242 (0.000219)	-0.000262 (0.000218)		
p_d	-0.00432 (0.00272)				
vp_b_diff				0.00146 (0.00138)	0.00149 (0.00138)
vp_c_diff				0.000105 (0.000251)	0.000121 (0.000251)
Constant	0.593*** (0.116)	0.163** (0.0676)	0.166** (0.0677)	0.141*** (0.0398)	0.141*** (0.0399)
Observations	288	288	288	288	288
R-squared	0.593	0.499	0.498	0.501	0.500

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

A.2.1.1 Testing the model

The variance inflation factor of the initial model determined the variables for total price and quantity of good A as the most problematic (VIF above the level of 90) and prices A; B; D also indicating collinearity (VIF around 20)51. All three prices were correlated to each other and total price was correlated to quantity of good A. The highest share of goods A on total price seems obvious with respect to their valuations.

[51] The threshold for VIF indicating collinearity is 10 (Chen, X., P. Ender, et al. 2003).

Table 31: Correlation of collinear variables in initial model

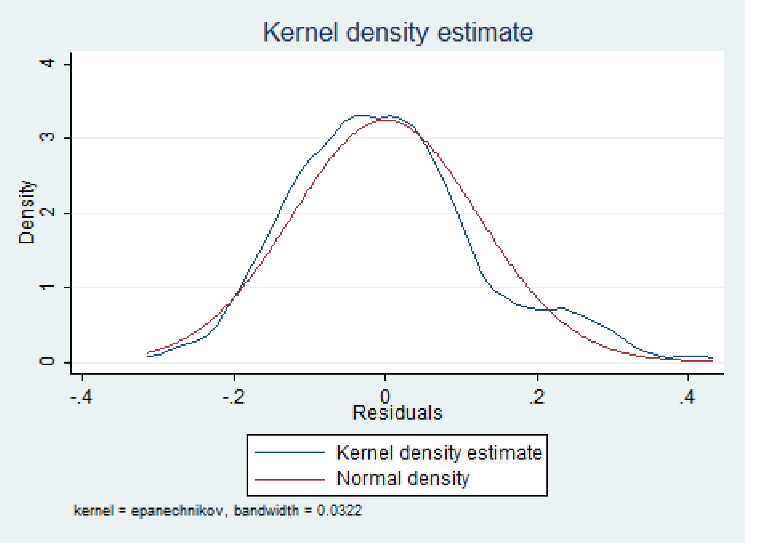
	q_a	p_total	p_b	p_d	p_a
q_a	1.0000				
p_total	0.9663	1.0000			
p_b	-0.4057	-0.2970	1.0000		
p_d	-0.4024	-0.2976	0.9628	1.0000	
p_a	-0.4152	-0.3045	0.9559	0.9392	1.0000

A series of partial F-tests for collinear variables rejected the null hypotheses that the coefficients of these variables would be zero at the same time in total, in pairs or individually (with exception of test for variable p_d). I have approached to gradual reduction of variables in sequence of *p_d; p_b; p_a;* and *p_total/q_a*. Since the correlation between *p_total* and q_a is above 96%, the elimination of either of them makes almost no difference. Both reduced models (with p_total and with q_total) have resulted in stabilization of multicollinearity problems[52]. Other assumptions remained fulfilled except for normality of residuals, which still seems to have heavy right tail. Since especially the tests for heteroskedasticity are very sensitive to assumption of normality of residuals, I have double-checked the normality by inter-quartile range test that assumes the symmetry of the distribution. There are no severe outliers, 2,43% of mild outliers (7 in total) and the distribution seems quite symmetric (inner fences: -0.3 and 0.28; outer fences: -0.52 and 0.5). There is a Kernel density plot of residuals provided in the Graph 4. Overall results of models with total price (2) and quantity of good A (3) are provided in the Table 30 on page 75.

All tests seem quite reasonable for the simplified models and their significance would be sufficient. However, performing two specification tests show that a specification error can occur in our models. Both link test for single-equation models and Ramsay reset test suggest that there are omitted variables in our models.

[52] The variance inflation factor of all variables does not exceed 2.3; Breusch-Pagan test p-value: 0.68 and 0.76 for models with q_a and p_total respectively.

Graph 4: Kernel density of residuals



A.2.2 Valuation-Price Differences

First alteration that should add an additional explanatory power to the models covers the valuations of individual players. The initial model does not embody player valuations for individual goods even though the economic rationality could suggest so. The decision of single player depends more on the difference of his valuations for each particular good and its respective price rather than on the price itself that is the same for all players in the group. I try to control for this by replacing prices[53] with variables *vp_x_diff;* where x stands for type of the good *a; b; c;* or *d.*

The initial analysis and its results were very similar to those in the section A.2.1. Two almost interchangeable models resulted from the analysis, this time with the difference of the variable capturing information about price b included into the model. All assumptions were clearly verified[54]. The additional variable, even though non-significant, improved the model slightly. Overall results of *vp_x_diff* model specifications with total price (4) and quantity of good A (5) are provided in the Table 30 on the page 75.

[53] The prices are replaced since they are highly correlated with differences. Correlation of all *vp_x_diff* variables and their respective prices exceeds 95%.

[54] The variance inflation factor of all variables does not exceed 4.7; Breusch-Pagan test p-values: 0.45 and 0.52 for models with q_a and p_total respectively. Normality of residuals was again rejected by the Shapiro-Wilk W test with very low p-value. Inter-quartile range test favours the second model with the variable q_a.

A.3 FURTHER MODEL ALTERATIONS

In this section, I am going to expand the model in an attempt to gain more explanatory power and reveal the relations among variables. Following the analysis in the section 6.3, I am going to control for the individual player types in the regression analysis and for the characteristics of participants of the experiment.

I am going to use the model with value-price differences from previous analysis; more precisely the "*vp-q_a*" specification introduced in the equation (4.3**)**. In contrast to the reduced models with simple prices, the value-price specification offer generally higher significance, especially on the intercept. This model is almost perfectly comparable to its twin, the "*vp-p_total*," but scored better in terms of assumption testing.

$$\begin{aligned} e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\ + \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \varepsilon \end{aligned} \quad (1.1)$$

A.3.1 Controlling for Player Types

In this section, I widen the inventory of variables by the dummies for individual player types. I include *pt_1*; *pt_2*; and *pt_3* for first three player types respectively. I intentionally omit the fourth player (due to the perfect collinearity) since there appears the least statistical difference between the mean efficiencies of the fourth player type and others in the Table 18. Equation (10.2**)** shows the respective specification of this model.

$$\begin{aligned} e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\ + \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \beta_{10} pt^1 + \beta_{11} pt^2 \\ + \beta_{12} pt^3 + \varepsilon \end{aligned} \quad (10.2)$$

The estimates of model (10.2**)** again improved the results slightly, even though the extent of changes is moving ahead at snail's pace rather than growing rapidly. The R-squared gained approximately 2 percentage points. Significance of first two player types is considerable, although for costs of lowered significance of *chat* and *q_a* variables. It seems from this model that a lot of variation in relative efficiency was caused by the player-type parametric setting of the experiment rather than by its original intention, i.e. the communication channel. Adding the explanatory power was exchanged for tiny worsening of the assumption testing results, even though the assumptions of the linear regression were again fulfilled.[55] Results of estimates of model (10.2**)** are provided in the Table 33 on page 81 under the label "*player types model*".

A.3.2 Controlling for Participant Characteristics

I am interested whether the participant characteristics have any potential impact on the relative efficiency of auctions and therefore I am going to control for these characteristics in this section of the data analysis. Table 29 shows in its bottom section all respective variables describing the participant sample size. Besides the common characteristics such as gender, age, nationality etc., I am going to examine the series of "*edu*" variables, which track subjective perception of adjusted education of participants expressed on 1-5 scale. An important variable capturing the experimental experience of subjects is *experience*. Following the propositions in the section 6.2.1, I also examine the variable *control_time*, which tracks the length of completing the control questionnaire at the beginning of the experiment. This variable, even though with a limited power, should capture the understanding of the experimental rules. I have noticed a clear pattern during the experiment itself: the faster completion of control questions the better understanding of the experiment. I am going to examine two kinds of models. First model (1.3**)** will try to explain the relative efficiency solely on the participant characteristics, the second model (1.5**)** will implement these characteristics into the specification (10.2**)**.

A.3.2.1 Participant Sample Characteristics

The model utilized in this section is provided in the equation (1.3**)**. It consists of relative efficiency as the dependent variable and participant sample characteristics as explanatory variables. Results of model (1.3**)** estimates are provided in the Table 32.

$$\begin{aligned} e_r = \alpha + \gamma_1 time^{control} &+ \gamma_2 female + \gamma_3 age + \gamma_4 cr \\ &+ \gamma_5\ edu^{quality} + \gamma_6 edu^{years} + \gamma_7 edu^{economics} \\ &+ \gamma_8 \mathrm{edu}^{\mathrm{math}} + \gamma_9 edu^{statistics} \\ &+ \gamma_{10} edu^{econometrics} + \gamma_{11} exp + \varepsilon \end{aligned} \tag{1.3}$$

[55] The mean VIF was 2.31, while the maximum of 6.26 reaches the variable vp_b_diff; Breusch pagan p value 0.5087; Inter quartile range test remains at the same level as in the previous cases.

The explanatory power of this model is not great[56]. Its R-squared reaches only the 0.118 level. However, this model can and does provide some additional useful knowledge to the analysis. There are five statistically significant variables in this model: time needed for completion of control questions (*control_time*); Czech nationality (*cr*); mathematical education (*edu_math*); statistical education (*edu_statistics*) and experience in economic experiments (*experience*). These significant variables serve as proxies for participant characteristics in the following model specifications.

Table 32: Model of relative efficiency on participant characteristics

VARIABLES	Coefficient	Standard errors
control_time	-0.000185*	(0.000103)
female	0.0149	(0.0240)
age	0.0124	(0.00952)
cr	0.0681***	(0.0238)
edu_quality	-0.00931	(0.0313)
edu_years	-0.0105	(0.0164)
edu_economics	0.0177	(0.0162)
edu_math	-0.0483**	(0.0199)
edu_statistics	0.0536*	(0.0276)
edu_econometrics	-0.0126	(0.0110)
experience	0.00508*	(0.00286)
Constant	-0.00441	(0.243)
Observations	288	
R-squared	0.118	

Note: *** p<0.01, ** p<0.05, * p<0.1

A.3.2.2 Two Resulting Model Specifications

Following the specifications in sections A.2.2; A.3.1; and A.3.2.1, I construct the two complete model specifications of the relative auction efficiency. The first model, provided in the equation (1.4**)**, encompasses specification without player types, but with sampling participant characteristics. The second model, provided in the equation (1.5**)**, encompasses specification with player types together with sampling participant characteristics. Results of both specifications estimates are displayed in the Table 33 on page 81.

[56] All assumptions of linear regressions were verified. The mean of the variance inflation factor was 1.92, while the maximum of 4.71 reaches the variable edu_years; Breusch pagan p value 0.2935;

Table 33: Results of second round models of relative efficiency

VARIABLES	(1) vp differences q_a	(2) player types model	(3) vp differences with p-chars	(4) all at once model
SMR	0.0671***	0.0571***	0.0616***	0.0497***
	(0.0181)	(0.0181)	(0.0184)	(0.0183)
chat	0.0624***	0.0341	0.0599***	0.0290
	(0.0230)	(0.0241)	(0.0229)	(0.0240)
final_profit	5.93e-05***	5.61e-05***	6.35e-05***	5.96e-05***
	(2.07e-05)	(2.07e-05)	(2.10e-05)	(2.09e-05)
q_a	-0.00351	-0.00917	-0.00574	-0.0105
	(0.0110)	(0.0112)	(0.0109)	(0.0111)
q_b	0.0132***	0.0159***	0.0126***	0.0154***
	(0.00224)	(0.00233)	(0.00225)	(0.00233)
q_c	0.0170**	0.0208**	0.0168**	0.0200**
	(0.00825)	(0.00818)	(0.00823)	(0.00812)
q_d	0.0132***	0.00893*	0.0141***	0.00911**
	(0.00437)	(0.00457)	(0.00439)	(0.00458)
vp_b_diff	0.00149	0.00424***	0.00117	0.00398**
	(0.00138)	(0.00158)	(0.00138)	(0.00156)
vp_c_diff	0.000121	-0.000141	0.000158	-9.73e-05
	(0.000251)	(0.000257)	(0.000253)	(0.000258)
pt_1		-0.0848***		-0.0870***
		(0.0248)		(0.0249)
pt_2		-0.0558**		-0.0642***
		(0.0238)		(0.0238)
pt_3		-0.0138		-0.0129
		(0.0211)		(0.0208)
control_time			-3.26e-05	-3.97e-05
			(7.44e-05)	(7.30e-05)
cr			0.0260	0.0194
			(0.0176)	(0.0174)
edu_math			-0.0338**	-0.0383***
			(0.0142)	(0.0142)
edu_statistics			0.0317*	0.0388**
			(0.0188)	(0.0186)
experience			-0.00105	-0.000136
			(0.00211)	(0.00209)
Constant	0.141***	0.203***	0.166**	0.231***
	(0.0399)	(0.0443)	(0.0718)	(0.0747)
Observations	288	288	288	288
R-squared	0.500	0.522	0.521	0.545

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

$$
\begin{aligned}
e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \ \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\
+ \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \ \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \gamma_1 time^{control} + \gamma_2 cr \\
+ \gamma_3 \mathrm{edu}^{\mathrm{math}} + \ \gamma_4 edu^{statistics} + \ \gamma_5 exp + \varepsilon
\end{aligned} \tag{1.4}
$$

$$
\begin{aligned}
e_r = \alpha + \beta_1 SMR + \beta_2 chat + \beta_3 \pi + \beta_4 q_a + \ \beta_5 q_b + \beta_6 q_c + \beta_7 q_d \\
+ \beta_8 vp_{\mathrm{b}}^{\mathrm{diff}} + \ \beta_9 vp_{\mathrm{b}}^{\mathrm{diff}} + \beta_{10} pt^1 + \ \beta_{11} pt^2 \\
+ \ \beta_{12} pt^3 + \gamma_1 time^{control} + \gamma_2 cr + \gamma_3 \mathrm{edu}^{\mathrm{math}} \\
+ \ \gamma_4 edu^{statistics} + \ \gamma_5 exp + \varepsilon
\end{aligned} \tag{1.5}
$$

Both models differ in accordance to the previous analysis. The model with vp_differences and participant characteristics has several already earlier significant variables, mainly SMR and chat. Participant characteristics added significance to mathematical and statistical education. Adding control variables for player types into the “all at once” model put importance to the first and second player types, losing the significance on chat variable at the same time. The second model has slightly better coefficient of determination, which raised again about two percentage points to 54%. However, adding the variables into the “all at once” model was sacrificed by a slight decrease in results of testing the linear regression assumptions.[57]

A.3.3 Additional Model Analysis

A.3.3.1 Modelling Individual Treatments

It is not subject of this thesis to model all treatments independently on each other. It is however a very interesting research question. For the sake of simplicity, I assume that our final model resulting from the abovementioned analysis will fit well for all four experimental treatments taken separately. The estimates however, with only 72 observations each, have a limited explanatory power since a lot of power has been lost due to the reduction of data sample. The detailed analysis of all cases separately is therefore an opportunity for further research scrutiny. The results of the estimates of individual treatments are provided in the Table 34.

[57] All assumptions of linear regressions were verified. First model: the mean VIF was 1.85, while the maximum of 4.78 reached the variable vp_b_diff; Breusch pagan p-value: 0.5254. Second Model: the mean VIF was 2.04, while the maximum of 6.31 reached the variable vp_b_diff; Breusch pagan p-value: 0.7043.

Table 34: Results of individual treatments and interactions

VARIABLES	(1) SMR	(2) SMR Collusion	(3) SMRPB	(4) SMRPB Collusion	(5) Interactions
SMR					-0.00437
					(0.0248)
SMR_chat					0.0947***
					(0.0274)
SMRPB_chat					-0.0223
					(0.0246)
final_profit	8.47e-05	3.06e-07	3.76e-05	3.76e-05	7.05e-05***
	(6.25e-05)	(4.40e-05)	(2.97e-05)	(2.97e-05)	(1.87e-05)
q_a	-0.0192	-0.000513	-0.00787	-0.00787	-0.0137
	(0.0210)	(0.0256)	(0.0209)	(0.0209)	(0.0105)
q_b	0.0233***	0.00637	0.0140***	0.0140***	0.0147***
	(0.00400)	(0.00506)	(0.00402)	(0.00402)	(0.00210)
q_c	-0.0666	0.00506	0.0237	0.0237	0.0197***
	(0.0407)	(0.0103)	(0.0149)	(0.0149)	(0.00637)
q_d	0.00426	0.00432	-0.00244	-0.00244	0.00719
	(0.00882)	(0.0144)	(0.0108)	(0.0108)	(0.00528)
vp_b_diff	0.00281	0.0391***	-0.00177	-0.00177	0.00310**
	(0.00214)	(0.00739)	(0.00352)	(0.00352)	(0.00153)
vp_c_diff	-7.94e-05	2.84e-05	0.000116	0.000116	5.21e-05
	(0.000330)	(0.00106)	(0.000408)	(0.000408)	(0.000220)
pt_1	-0.110**	-0.292***	-0.0210	-0.0210	-0.0787***
	(0.0509)	(0.0750)	(0.0474)	(0.0474)	(0.0223)
pt_2	-0.0704	-0.258***	-0.0169	-0.0169	-0.0572**
	(0.0684)	(0.0748)	(0.0504)	(0.0504)	(0.0223)
pt_3	-0.0227	-0.0328	-0.0342	-0.0342	-0.0120
	(0.0572)	(0.0433)	(0.0365)	(0.0365)	(0.0227)
control_time	0.000134	-0.000338*	0.000225	0.000225	-6.82e-06
	(0.000256)	(0.000195)	(0.000153)	(0.000153)	(7.98e-05)
cr	0.0253	0.0406	0.00834	0.00834	0.0253
	(0.0592)	(0.0390)	(0.0336)	(0.0336)	(0.0181)
edu_math	-0.0749***	-0.0306	0.00528	0.00528	-0.0331**
	(0.0269)	(0.0309)	(0.0395)	(0.0395)	(0.0131)
edu_statistics	-0.0496	0.0383	0.0142	0.0142	0.0349**
	(0.0325)	(0.0451)	(0.0468)	(0.0468)	(0.0165)
experience	-0.0164***	0.000332	0.00193	0.00193	-0.00172
	(0.00520)	(0.00554)	(0.00370)	(0.00370)	(0.00211)
Constant	0.644***	0.563***	-0.0652	-0.0652	0.243***
	(0.165)	(0.146)	(0.177)	(0.177)	(0.0624)
Observations	72	72	72	72	288
R-squared	0.475	0.604	0.223	0.223	0.569

Note: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

A.3.3.2 The Interactions

It would be inadequate to assume that no interaction between our dummy variables for auction format and presence of chat interface occurs. I therefore construct two interaction variables SMR & chat (*SMR_chat*) and SMRPB & chat (*SMRPB_chat*) to discover interrelation effects of those variables. When I run the model with interactions, only the variables for SMR & chat is significant[58]. I have used the option with robust standard errors for estimating the model. The coefficient of SMR & chat has a positive sign, which suggests that there is an important positive relation between the auction format and presence of communication channel. The results of the interaction estimate are provided in the Table 34.

[58] Assumptions of both models were properly verified. First model: the mean VIF was 1.93, while the maximum of 5.2 reached the variable vp_b_diff; Cameron & Trivedi's decomposition of IM-test p-value: 0.8794. Second Model: the mean VIF was 1.8, while the maximum of 4.33 reached the variable vp_b_diff; Cameron & Trivedi's decomposition of IM-test p-value: 0.8567.

Appendix B: Instructions

The original instructions were written in Czech. This is an English translation. The instructions were divided into three parts: (I) the introduction in section B.1; (II) general instructions common to all treatments in section B.2; and (III) treatment-specific supplement for respective treatments insection B.3.

B.1 INTRODUCTION

Welcome to the Laboratory of Experimental Economics. My name is Jindřich Matoušek and my colleague's name is Lubomír Cingl. Thank you for participating in today's experiment.

Please, place all your belongings away so we can have your full attention.

In the course of the experiment please do not talk to other participants, do not drink water and shut down your mobile phones. Violation of these rules would cause immediate exclusion from the experiment without any payment.

You cannot lose any money in this experiment. You will be given 100 CZK for coming on time. This 150CZK and any money that you earn during the experiment will be paid to you, privately in cash, at the end of the experiment. Average expected payment in today's experiment is 400CZK and the average length of the experiment is 2 hours. The length of the experiment depends on the speed of participants, therefore please be patient.

All amounts in this experiment will be given in the Experimental Currency Units (ECU). The exchange rate to Czech Crowns is one CZK for three ECUs.

You can make notes for enclosed sheet of paper. By the control questions placed at the beginning, we only want to make sure you understand the experiment; you will not be excluded nor discriminated in any manner because of them.

Please note that you commit yourself to participation in the whole experiment and if you leave before the end, you receive no payment at all. For your participation on the experiment, we need you to sign the consent form. Please take the consent form provided on a separate sheet of paper, read it and when you sign it, raise your hand and the experimenters will collect them. If you are not willing to participate and not sign the consent form, please leave the experiment now and your participation fee of 100 CZK will be paid to you.

If you have any question now or during the experiment, please raise your hand and we will answer it in private.

B.2 GENERAL INSTRUCTIONS

THE EXPERIMENT

The experiment will involve a series of auctions. Each auction will consist of multiple rounds.

In each auction, you will be competing with others for a set of multiple goods, which will contain various types and quantities. There are several important rules in this auction that encompasses (i) the way you can bid for the goods; (ii) provisional winners in each round of the auction; (iii) your eligibility; and (iv) possibility of bid withdrawal. These rules are not trivial but crucial for your participation in the auction and also for you payoff from the experiment. Therefore, please, devote to them an utmost attention.

Each auction will have an indefinite number of rounds, which depends on decisions of its participants.

Let us explain individual rules of the auction more closely.

INDIVIDUAL AUCTION ROUNDS

Each auction will consist of series of preliminary not exactly determined number of auction rounds. Each round has a time limit in which you have to submit your bid. After each round, the system will evaluate all submitted bids and show the round summary. This process repeats until the auction ends.

GROUPS AND BIDDERS

At the beginning of each auction, you will be randomly assigned to a group of four bidders (you and 3 others). Within these groups, you will be competing in all rounds of this auction. After this auction will end, you will be randomly assigned to the new group of four bidders.

GOODS FOR SALE

In each group of four players, four types of goods labelled A, B, C, and D, will be auctioned off. Each type of the good is offered in multiple homogenous units. You can submit bids for as many units of each goods type and for as many types as you want to. You will submit bids by adding the units into your bidding basket.

PRICES AND VALUES OF GOODS

Each type of the good A; B; C; a D offered for sale has different upset price. The price of each goods type can increase gradually throughout the auction, in case that an offer was placed to this type in the previous auction round. Each increase will be realized in volume of 20% of the upset price of a respective good type. If an offer was not placed, price of the good remains the same. The price of a good within each type will be always the same for all units.

Each player will have different valuations for all types of goods. Your total personal value for each type of the good will be known only to you.

The total valuation of each type of the good consists of two components: common value and private value component of the good. Total valuation is then the sum of these two components.

Each unit of the good has its own common value, which is identical for all units of the good. No bidder has the precise information about this common value. Each bidder receives only her private estimate of the common value determined by the random draw. The estimate of the common value is for each player drawn separately, but always out of the same interval.

Each player is further informed about her own private valuation of the good, which she receives upon each unit bought in the auction. The private value is typically different for each player and is determined by the random draw from the interval in range of ± 10% of the common value component (which you do not know, but which is the same for all players); i.e.:

$$\mathbf{PVC} \in < -0{,}1 \cdot CVC\, ;\, +0{,}1 \cdot CVC >.$$

Even though your private component can be negative, your total value of each type of the good is always positive.

Following table summarizes your knowledge of each type of the good in the auction:

PVC	$\mathbf{PVC} \in < -0{,}1 \cdot CVC\, ;\, +0{,}1 \cdot CVC >$
CVC	Estimate
Total information	PVC + Estimate of CVC

EXAMPLE:

Private value component PVC	20
Estimate of CVC	300
Total signal	$\text{PVC} + \text{Estimate of CVC} = \mathbf{320}$

COMPLEMENTARITIES OF GOODS

All types of goods offered in the auction are complements. It means that a set of multiple goods containing more types (A; B; C; or D) has higher value than each type separately; thus winning of more than one type of goods at once gives you the advantage of higher profit.

If you win one type of good (in an arbitrary quantity), your profit is equal to the value of this good. However, if you win more than one type of goods at once, your profit will raise according to following formula:

$$\boldsymbol{valuation} = [\mathbf{1} + \mathbf{0{,}1}\ \cdot (\boldsymbol{X} - \mathbf{1})] \cdot \boldsymbol{sum\ of\ \ valuations\ of\ goods\ won}\ ,$$

where X stands for the number of goods types acquired. Thus:

1 type – value is equal to the valuation of goods;

2 types – value raises by 10% of the valuation of goods;

3 types – value raises by 20% of the valuation of goods;

4 types – value raises by 30% of the valuation of goods.

EXAMPLE:

Total value of the good of type A is 300, of type B is 100.

If a player wins good A, her profit is 300.

If a player wins good B, her profit is 100.

If a player wins goods A and B, her profit is 1,1*(300+100) = 1,1*400 = 440.

PROVISIONAL WINNERS

The system automatically process all submitted bids when the auction round is finished. In the auction round summary you will be informed if and for how many units of goods are you currently the provisional winner. A situation that more than one player submits the same bid can occur in the course of the auction round. If the sum of such bids in your group exceeds the number of goods sold in the auction, the system determines the winner of given units randomly, since the price is the same for all players. You therefore do not have to win complete set of goods on which you have submitted your bid.

After the time limit runs out or when each player submits her bid a new auction round occurs.

You will win precisely such goods in the last auction round for which you are currently the provisional winner. Only the final offers out of the last auction round are used for calculation of auction profits and therefore your real payoff out of the experiment.

THE RULE OF ELIGIBILITY

Each participant of the auction has a certain number of activity points at disposal, which represent her eligibility for submitting the bids in the auction. The activity points determine the maximum number of goods on which a player is able to submit bids.

Each unit of the good costs a certain number of activity points. Your total bid cannot exceed your current level of activity points.

The number of your activity points can decrease during the auction, since it depends on your behaviour in previous auction rounds. In each round, you will gain as much of activity points as you have used in the previous one. If you will submit a bid in a given round with total activity cost lower than it is your current level of activity at your disposal, your eligibility for subsequent rounds will diminish – your number of activity points will fall.

There is no way of acquiring the activity points back throughout the auction, nor to acquire more of them.

EXAMPLE:

You have 10 points of activity in a given auction round at your disposal. One unit of good A costs 3 activity points, one unit of good B costs 1 activity point.

If you will submit a bid for 3 units of good A and for 1 unit of good B in a given round, you will pay 10 activity points in total (3x3+1x1), by which you will use up your activity for this round. You will have 10 points of activity at your disposal in a subsequent round of the auction.

If you will submit a bid for 2 units of good A and for 2 units of good B in a given round, you will pay 8 activity points in total (2x3+2x1). You will have 8 points of activity at your disposal in a subsequent round of the auction.

WITHDRAWING WINNING BIDS

There can emerge a situation during the course of an auction, in which you will win in some auction round only a subset of goods on which you have placed your bid. You can therefore win only a subset of goods for a price, which exceeds the actual value of the goods.

If such situation becomes true, you have the possibility to withdraw your provisionally winning bid. The bid withdrawal is available always during the auction round summary. You can withdraw your bid for as many goods (both types and units), by which you are currently the provisional winner.

The possibility of bid withdrawal is limited in its volume. In particular, each bidder can use the right for withdrawal in at most two auction rounds, without any reference to the number of withdrawing goods in each particular round. However, the number of activity points for subsequent round will be appropriately decreased during each bid withdrawal by the sum of activity points for all respective withdrawn bids.

FINAL AUCTION ROUND

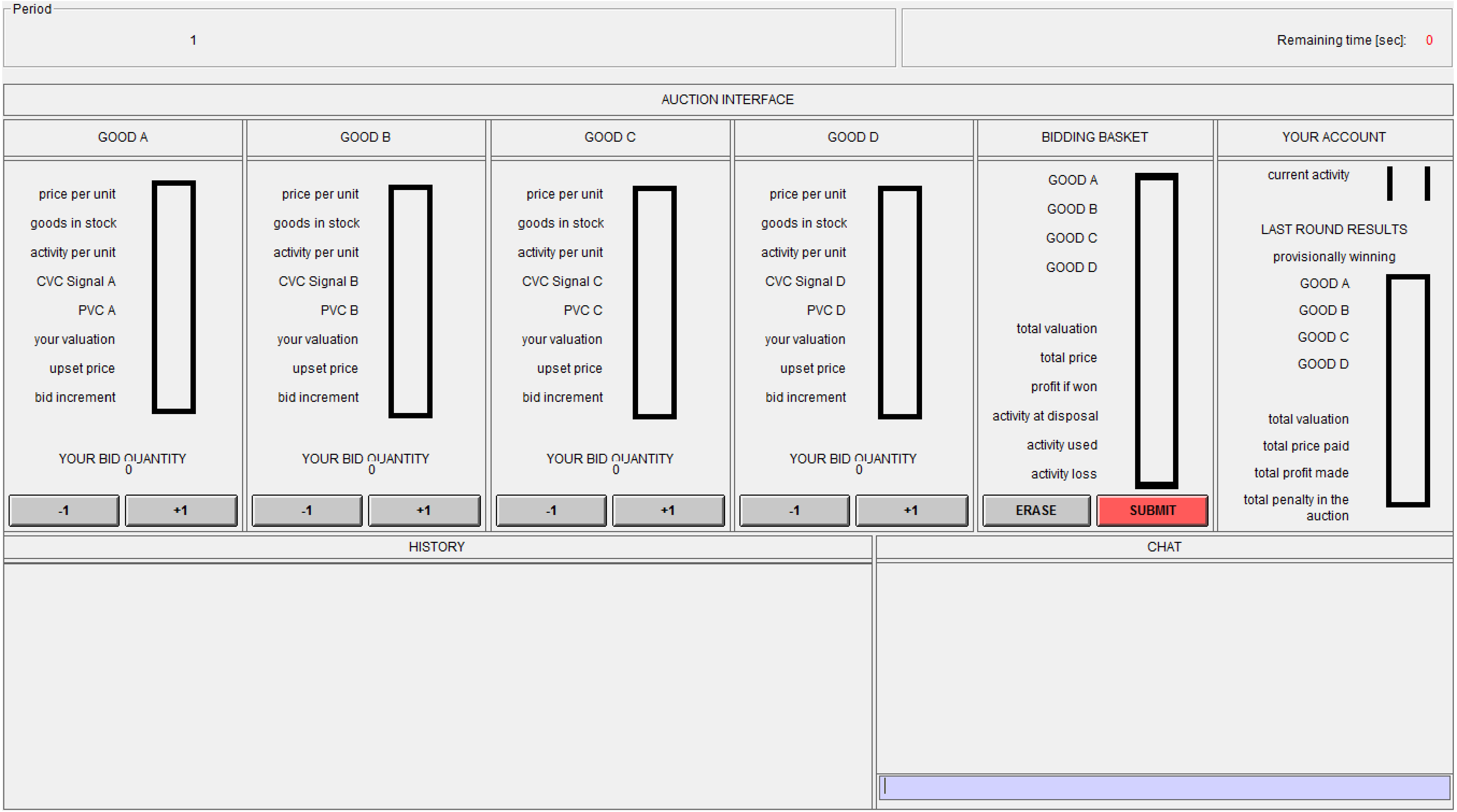
A final auction round arise when no participant submits an additional bid on any good. Technically this situation means that all four participants in a group submit a bid for "empty bidding basket." The auction ends by this situation.

If you submit an empty bidding basket in some auction round during the course of the auction, your activity will fall to zero. You will not be able to participate in the auction any further. Submit therefore an empty bidding basket only in the situation when you will wish to terminate your participation in the auction.

HISTORY

There is a history box present during the whole auction in the bottom left corner of the auction interface. For each player there is displayed the number of individual types of goods in this box for which this player was a provisional winner in a given auction round. The history is for the saving of space displayed by shortcuts (1-A; 1-B; 1-C; 1-D; 2-A; 2-B; etc.). Shortcut „1-A“ means „player 1 – good A;“ shortcut „2-B“ means „player 2 – good B“ etc.

Figure 1: The auction interface



YOUR PROFIT AND EARNINGS FROM THE EXPERIMENT

At the end of the auction your earnings for this auction are determined. Your profit will be equal to the total value of the licenses you won at the end of the auction (i.e. in the final round of the auction), minus the total cost you paid for them. Thus:

$$\boxed{Profit = total\ value\ of\ the\ goods\ won - price\ paid\ for\ all\ licenses\ won}$$

Your final earnings will depend on one of the auctions realized in this experiment. This auction will be determined randomly at the end of the experiment.

SUMMARY

i) The experiment will consist of series of auctions. First auction is a trial and will not influence your payoff from the experiment. Each auction will consist of series of preliminary not exactly determined number of auction rounds. A final auction round arise when no participant submits an additional bid on any good.

ii) You will submit your bids by adding the units of goods into your bidding basket.

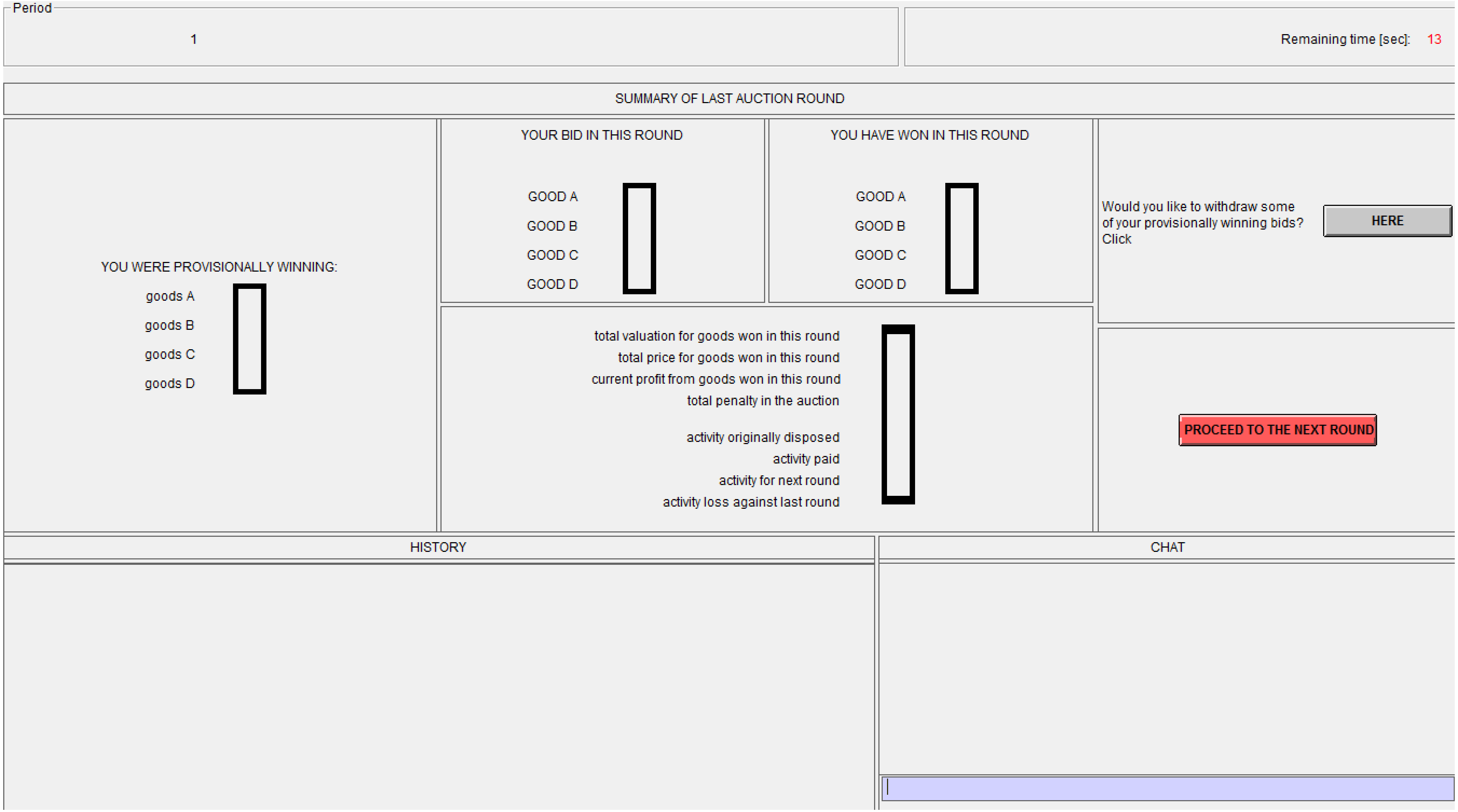
iii) The price of a particular type of the good can rise during the auction if there will be positive demand for this good. Your payoff from the experiment will depend on your ability to win the desired goods but also on chance and the abilities of others.

iv) The provisional winning bids are announced after each auction round. However, these do not affect the final profit from the auction until they became final winning bids at the last round of the auction.

v) The rule of eligibility says in principal that you cannot wait with the bid submission to the end of the final rounds of the auction. If you want to win your desired portion of goods in the auction, you have to submit bids already from the beginning.

vi) During the course of the auction, but not at its end, you will have the possibility to renounce of your provisionally winning bid. This possibility will however be limited.

Figure 2: Summary of the auction round



vii) Individual valuations of goods are for each player determined randomly. It consists of common and private value component of the good, where the private component is known individually to all bidders. Common value component is on the other hand not known and the players have only a private signal about its value.

viii) Your profit out of each auction will be determined only on the situation from the final auction round and will be equal to the difference of total value of goods you have won and total price of your final bidding basket. Only one of the auctions realized today will be chosen for your payoff at the end of the experiment.

B.3 TREATMENT-SPECIFIC SUPPLEMENTS

The treatment-specific supplements to the instructions were presented to the participants in the following sequence. There were three basic parts of the supplement: (i) notice; (ii) communication window; and (iii) set of goods as a package. Following table summarizes which parts were presented in which treatment. There was a simple one-sentence introduction "treatment specific supplement introduction" present at the beginning in all treatments.

	Notice	**Communication window**	**Set of goods as a package**
SMR Basic	✓	X	X
SMR Collusion	✓	✓	X
SMRPB Basic	✓	X	✓
SMRPB Collusion	✓	✓	✓

TREATMENT-SPECIFIC SUPPLEMENT INTRODUCTION

Hereby presented additional rules were not stated in the online questionnaire.

NOTICE

i) Price of the goods is gradually rising throughout the auction (in case the offers are placed to this type of a good). If you will not be able to find an optimal situation with positive profit in any round and you will incur a loss, it is highly improbable that you would find such a situation in subsequent rounds.

ii) If you will incur a loss out of the auction used for the calculation of your payoff from the experiment, it will appear on that payoff. Potential loss will be adequately subtracted from your payment for timely arrival. We therefore strongly recommend not submitting bids that can incur in losses.

iii) If you will submit a bid in any round, your bidding basket will reset and assigns freshly again according to your new offer. It is not possible to add some goods into your existing bidding basket. You always have to submit an offer for complete set of desired goods.

iv) Your task in the experiment is to gain positive profit at the end of each auction, not to maintain your full level of activity points.

COMMUNICATION WINDOW

There will be a communication window present in the bottom right corner of the auction interface. You can send whatever messages to other participants in your group through this window. Such messages will be visible only to the players in your own group. The communication window will also be displayed for two minutes before each auction.

SET OF GOODS AS A PACKAGE

You will be bidding for a set of goods of your preference in each round of today's auctions. The system will handle this set a one compact package. Your bid will be either accepted as a package or refused a package; you will therefore win complete set you were bidding for or nothing.

At the end of each auction round, the system processes all bid packages submitted in the current auction round and display information about the provisionally winning bids of this round. The processing runs based on the package with highest price. Even the players who did not submitted an offer with the highest price, but their offer was after the processing stage and determination of other provisionally winning bids still available from the perspective of the quantity can become the provisional winners of their packages.