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ESSAYS ON ASYMMETRIC AUCTIONS WITH RESALE

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF ECONOMICS

BY

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Abstract

This study investigates asymmetric auctions with resale using controlled laboratory experiments. In the first essay titled "Auctions with Resale: An Experimental Study", we study the bidding behavior in first price asymmetric auctions followed by resale markets wherein bargaining power varies from seller to buyer. Building upon current literature, we posit a revenue-efficiency trade-off between the resale regimes with either the seller (Monopoly resale) or the buyer (Monopsony resale) has all bargaining power. The results imply a symmetrization of bids for both the bidders under both regimes. Using controlled experiments that mimic the theoretical setting, we find support for higher bidding under the monopoly resale regime with similar efficiency levels across the two resale regimes. Then we employ quantile regression analysis by controlling for certain bidder specific and auction specific characteristics to provide limited evidence for symmetrization.

The second essay, "Bargaining in Auctions with Resale", extends the analysis to a double auction (DA) framework in the resale stage that gives both, buyer and seller equal bargaining power. The theoretical results indicate that the equilibrium bidding functions and the resale prices under the DA regime fall in between those from the monopoly and monopsony regimes and the bid-symmetrization property continues to hold in this case as earlier. After running experiments similar to earlier setup, we do not find much support for symmetrization. However, there is limited evidence for a transition of average bids and resale prices across regimes.

The final essay, "Emission Trading Schemes as Auctions with Resale", reviews emission trading schemes (ETS) as auctions with resale and examines the results from RGGI (Regional Greenhouse Gas Initiative, an ongoing ETS in the United States) in the light of previous analysis. The trend of RGGI allowance prices indicates a scenario closer to monopsony resale regime.

Chapter 1

Introduction

Auctions are among the oldest institutions governing economic transactions. The principal aim of any general auction procedure is to award a commodity to the bidder who values it the most. Traditionally, auctions have been used to sell antiques and collectibles. Use of auctions in the sales of government debt by central banks as well as in government procurement contracts is seen as a routine practice. The scope of objects sold via auctions has been expanding over the years. Today it ranges from something as abstract as an electromagnetic spectrum or a right to emit certain pollutants to professional players in an international cricket league[1]. This ever-widening scope and volume of transactions under auctions coupled with numerous and varied procedures in which they are carried out, have made them an exciting subject of inquiry. One such interesting but relatively less studied aspect is the presence of a resale opportunity and how it affects the bidding behavior in an auction. Most of the standard results in auction theory take the absence of resale following an auction for granted. However, we do see objects being resold after an auction on a number of occasions, even at times when resale is prohibited.

For instance, the 3G spectrum license auctions in UK generated a record revenue of over £22 billion (about $35 billion) for the 5 licenses[2] offered for sale in the year 2000. Although the resale of the licenses was prohibited by the government, telecommunication companies found ways to circumvent this restriction. TIW, a US-Canadian firm that acquired the most prized license 'A' for over £4.38 billion, was initially backed (and eventually purchased) by a Hong Kong conglomerate, Hutchison Whampoa, whose core businesses include telecommunications. Further,

[1]Professional cricket players are auctioned off to various teams in the Indian Premier League (IPL), see http://timesofindia.indiatimes.com/sports/cricket/ipl-2012/List-of-Players-in-2012-IPL-Auction/articleshow/11699930.cms

[2]http://news.bbc.co.uk/2/hi/business/727831.stm

when NTL - a cable company backed by France Telecom dropped out of the auction, it didn't stop France Telecom from acquiring *Orange Telecom*, who won license 'E' for about £4 billion at the auction. Another successful bidder, British Telecom, won license 'C' through a wholly owned subsidiary and floated it on the stock market to sell. This example clearly shows the ability of firms to anticipate post-auction resale and (in this case) bid higher to claim the resulting common surplus.

Another potential application of auctions with resale can be found in the electricity markets. The deregulation of electricity industry has resulted in separating the activities of generation, transmission and distribution of electricity, traditionally done by a monolith firm. Subsequently, this separation of activities led to the creation of wholesale and retail markets for electricity. The players in wholesale market include generators, retailers as well as other financial intermediaries who specialize in transmission and distribution only. Many of the established wholesale power markets today in the US (PJM, New England, ERCOT[3]) employ auctions to sell electricity wherein some of the participants are retailers who bid only for the sake of resale to end-users.

Despite their growing importance, auctions with resale have received attention very recently in terms of theoretical and empirical literature. Bikhchandani and Huang (1989) formulated the market of US Treasury Bills (TB) as auctions with resale and compared expected revenues from having primary market as a discriminatory auction versus a uniform price auction. They derived sufficient conditions under which the expected revenues are higher for the uniform price auctions. In a related study, Hortascu and Kastl (2008) examined the effects of information gain about rival bids on the bidding behavior using data from Canadian Treasury Bill auctions. They consider whether bid updating by a dealer (third party bidder) differs on the basis of a private value component or the common value one. Since

[3]Please see http://www.ferc.gov/market-oversight/mkt-electric/overview.asp.

there are no resale considerations involved in a private value setting, the updating is restricted to the distribution of residual supply. On the other hand, information about rival bids leads to updating the value of the object itself under a common value setting. The empirical results indicate that the auction data from 3-months T-Bill market support the private values model (implying lesser resale considerations) whereas the data from 12-months T-Bill market fail to support the private values model (implying higher resale considerations).

In a series of theoretical papers (1999, 2000, 2003), Haile established that a resale opportunity adds a *common value* element to an otherwise private value auction. Haile (2001) provided empirical evidence for the effect of a resale market on bidder's willingness to pay in a study of auctions of timber contracts by the US Forest Service. He used a policy change that restricted resale to find bidder valuations of timber contracts to be higher before the policy change. For a large class of items (e.g. antiques, wines, books, paintings, confiscated automobiles, real estate etc.) sold in auctions, a majority of the participants are the 'dealers', who specialize in reselling the items won during those auctions. Market for real estate (especially, in the light of recent property bubble in US) can be thought of as providing ample opportunities to these dealers/middlemen to profit from resale. Bose and Deltas (2007) examined the role of such a 'middleman', someone with no use value participating in an auction with resale. They find that the presence of middleman can prevent bidders with higher valuation from entering initial auction. Similarly, Garatt and Troger (2006) specify a 'speculator', who can limit the access to bidders if active in primary auctions followed by resale.

Asymmetry among bidders can more than often be cited as a reason for post-auction resale. Asymmetries can occur on account different dimensions - information advantage, market size, experience etc. Pagnozzi (2007) considered English auctions with resale involving a weak-strong pair of bidders where the bidders' values are

distributed asymmetrically. He finds that the prospect of resale leads to relatively aggressive bidding by the weak type bidder, and thus higher revenue for the initial seller. Further, it is shown that a strong type bidder may be better off by letting the weak bidder win the initial auction at a relatively low price and purchasing the item in the resale market.

There have been very few experimental studies (List, 2004; Georganas and Kagel, 2011; Georganas, 2011) that focus on auctions with resale opportunities. Their major focus has been on comparing bidding behavior between resale and no-resale scenarios to understand the effect of resale on auctions. As theoretical literature establishes links (See, Cheng and Tan, 2008; Lebrun, 2010) between different types of resale market structures and its impact on bidding behavior, there is a need to verify those results using experimental setting. This study seeks to fill this gap.

The purpose of this study is to investigate the effects of bargaining power in the resale stage on the bidding behavior in the first stage of auctions. This study builds upon recent theoretical advances[4] in the literature and provides experimental results that could be helpful in understanding the workings of real-world markets such as markets of CO_2 allowances.

In the first essay titled "Auctions with Resale[5]: An Experimental Study", we analyze the bidding behavior in first price asymmetric auctions followed by resale markets, wherein bargaining power lies entirely either with the seller or the buyer. We extend the theoretical results of Hafalir and Krishna (2008) to a setting where the buyer has all the bargaining power (called as a monopsony resale regime) and find that the bidders will bid lower compared to the case where the seller has all the bargaining power (termed as a monopoly resale regime). Further, we also find that the efficiency (in the sense of the object ending up with the party valuing it the most) is higher under the monopsony regime. Finally, the results indicate

[4]Hafalir and Krishna (2008), Cheng and Tan (2008)

[5]This chapter is based on a paper written jointly with Georgia Kosmopoulou.

equivalence of bid distributions for the bidders, i.e., both the bidders bidding in identical manner (bid-symmetrization) in equilibrium under both regimes. Using controlled experiments that mimic the theoretical setting, we find support for higher bidding under the monopoly resale regime with similar efficiency levels across the two resale regimes. Then we employ quantile regression approach by controlling for certain bidder specific and auction specific characteristics to provide limited evidence for symmetrization under the monopsony resale.

The second essay, "Bargaining in Auctions with Resale", extends our investigation to include a double auction (DA) framework in the resale stage. i.e. both, buyer and seller in the resale stage can make offers and the trade ensues if buyer's offer is higher than or equal to the seller's offer. The trading price in this case equals the average of the two offers. Our theoretical results indicate that the equilibrium bidding functions and the resale prices under the DA regime fall in between those from the monopoly and monopsony regimes. The symmetrization property continues to hold in this case as earlier. Our experimental results indicate that the average bids and prices under the DA are found to be closer in magnitude to the ones under the monopsony regime. We analyze the bidding by different bidder-specific characteristics such as gender, risk attitude, major and previous participation but do not find evidence for symmetrization.

In the final essay, "Emission Trading Schemes as Auctions with Resale", we review emission trading schemes (ETS) as auctions with resale and focus on one of the real world ETS, Regional Greenhouse Gas Initiative (RGGI) that came into effect from January 2009. We discuss how the structure of an ETS fits in the framework of auctions with resale by describing the primary and secondary markets followed by an analysis of the allowance auction results held in the first phase of RGGI. The behavior of clearing prices for the auctions held in the RGGI indicates a shift from a seller's market to a buyer's market over the course of three years.

Chapter 2

Auctions with Resale: An Experimental Study

2.1 Introduction

This chapter[1] compares bidding behavior across first price asymmetric private value auctions with resale opportunities presented in seller's and buyer's markets and offers experimental evidence on bidding behavior and resource allocation.

Standard results in auction theory presume mostly the absence of resale options. However, forward looking bidders, having a chance to resell in a secondary market, bid differently than bidders in a single auction setting. In fact, the sale prices of government owned assets or public resources are often determined by resale opportunities. Examples include spectrum license auctions and the ensuing sale of telecommunication companies in the last decade and, more recently, sales of right to emit pollutants, especially greenhouse gases. The structure of a secondary market for emission permits, for instance, can have a significant effect on initial bidding behavior in established Emission Trading Schemes (ETSs or cap and trade schemes) and how they impact initial as well as final allocative efficiency. The applicability of this framework extends to housing markets, real estate sales and (re-)allocation of common pool or common property resources. Examples include fisheries, wildlife preserves and surface water resources (White, 2006).

When the option to resell in a secondary market exists, bidders take this option into account and adjust their bids in the primary auction market. Adding a resale opportunity introduces a *common value* element to an otherwise private value auction (Haile, 1999). If the winner of an auction has all the bargaining power in the resale market (in what we call a monopoly resale regime), there will be a speculative interest in acquiring the item at the auction stage knowing there is a chance to resell

[1]This chapter is based on a coauthored paper with Georgia Kosmopoulou.

it (Hafalir and Krishna, 2008). On the other hand, if the loser of the auction has all the bargaining power in the resale market (in a monopsony resale regime), such an interest does not exist and the common value at the auction stage is restricted. Thus we expect more aggressive bidding in a monopoly resale regime than in a monopsony resale regime. In both cases, the common value created by the resale opportunity leads to a symmetrization of bids; in equilibrium, bidders behave as if they compete in a symmetric auction for a common value whose size is determined by the structure of the resale market. Both first stage bids and resale prices are expected to be higher under the monopoly resale regime leading to greater efficiency losses.

In this chapter, we investigate the relationship between revenue and efficiency using controlled experiments that mimic the theory. We consider an initial auction taking place between two bidders drawing their values from asymmetric supports. We find higher bids on average in a monopoly resale regime than in a monopsony resale regime. Interim efficiency, measured in terms of the proportion of efficient outcomes realized at the conclusion of the auction stage, is the same across regimes but higher in magnitude than predicted. Final efficiency becomes higher for the monopsony resale regime when bidder asymmetries are more pronounced. In the monopoly resale regime, large asymmetries in the value distributions across bidders lead to statistically significant differences in the bid distributions, which is consistent with other experimental work (see Georganas and Kagel 2011). In the monopsony resale regime, however, controlling for bidder and auction heterogeneity, we provide some evidence in support of bid symmetrization for values in the middle range.

The rest of this chapter is structured as follows. The next subsection reviews related literature. Section 2.2 presents the theoretical framework followed by equilibrium bid and (ex-ante) efficiency predictions. Section 2.3 describes the experimental design. Section 2.4 presents the main results and related discussion. The

final section offers concluding remarks.

2.1.1 Related Literature and Motivation

Haile's (1999) theoretical paper is among the earliest to analyze auctions with resale as a two stage game. Using the first price, second price and English auction settings, he shows that valuations are determined endogenously when forward looking bidders take into account the possibility of resale in a secondary market. The resale market structure determines the size of common surplus to be extracted in an initial auction. Hence, the revenue at the auction stage depends on the resale market structure and the information linkage between primary and secondary markets.

Haile (2001) tests empirically this result using data on U.S. Forest Service timber sales. Using a structural empirical model and taking into account unobserved heterogeneity and bids by opponents, he finds evidence that bids are higher with a 'high' resale seller effect (high likelihood of selling in a resale market) and a 'low' resale buyer effect (low likelihood of purchasing in a resale market).

Haile (2003) extends these ideas in a theoretical paper that emphasizes this informational linkage between markets. He constructs a two stage game, using three auction formats (first price, second price and English auctions) in the first stage and two auction formats (optimal and English) in the second stage to show the effect of a resale market on equilibrium bidding strategies.

More recently, Hafalir and Krishna (2008, 2009) and Cheng and Tan (2008) have studied market efficiency and revenue generation in independent private value (IPV) auctions with resale. These papers consider two types of bidders with asymmetric value distributions. Hafalir and Krishna focused on the revenue ranking between first and second price auctions with resale. One of the major insights from this work is the symmetrization property. Given the resale market structure, for every first price asymmetric auction there is an equivalent first price symmetric auction.

Asymmetric bidders behave as if they are competing in a symmetric auction for a common surplus determined by the nature of resale competition. In equilibrium, their bidding distributions are the same for those two auctions.

Cheng and Tan have established a similar bid-equivalence between an asymmetric first price IPV auction with resale and a first price common value auction with a suitably chosen common value function that reflects the transaction price. Using a discrete distribution example, they have shown a revenue-efficiency trade-off when the resale market has a monopoly/monopsony structure. Efficiency is the highest when the resale market is a buyer's market (i.e. a monopsony), while revenue is higher when the resale market is a seller's market (i.e. a monopoly). This ties in with Haile's (2003) result on surplus extraction.

On the experimental front, there have been very few related studies. Mueller et al. (2002) report experimental evidence on revenue and efficiency effects under the monopoly/monopsony structures using a double auction setting. They find average prices rising under monopoly and falling under monopsony with relatively no impact on efficiency compared to the competitive case. In their experiments, the subjects are assigned the tradable coupons before the double auctions begin. Hence, their setting effectively has only one stage.

Lange et al. (2004) build upon Haile (2003) and provide experimental support for the result that bids are higher in auctions with resale than those without, emphasizing the common value element. Their setup is a two stage game with the second stage market structured in some experiments as an English Auction and in others as an Optimal Auction. Players decide on the bids only during the first stage. The second stage allocation is automated and hence, players do not make any decisions at this stage.

Georganas and Kagel's (2011) study is the closest to ours. Their study also builds upon Hafalir and Krishna (2008) but their focus is on a comparison of bid-

ding behavior across resale and no resale scenarios. The resale scenario is in fact the monopoly resale regime. Our study incorporates two stages, consisting of an initial auction followed by a resale stage structured as monopoly/monopsony market. The theoretical framework is built upon the model by Hafalir and Krishna (2008). We perform experiments and compare observed patterns of behavior to theoretical predictions.

Our motivation comes from our interest in studying and predicting the effectiveness of Emission Trading Schemes. ETSs are seen as a successful market based approach to handle the issue of pollutants and their ill-effects including climate change. It is of interest to ask to what extent the existence of a secondary market and its structure have a significant effect on initial bidding behavior in ETSs, as well as how it will impact both initial and final allocative efficiency when in the near future, more stringent caps will generate higher demand in the secondary market. Some of the emission allowance futures and option contract trades are carried out via the over the counter (OTC) exchange through bilateral negotiations. There have been speculations about possible market concentrations in the event of an international cap and trade system. It is suggested that the US will be a dominant buyer and the countries from Former Soviet Bloc would be dominant suppliers of pollution permits under Annex I of Kyoto protocol (Nordhaus and Boyer, 1998).[2] This might give enormous leverage to the supplier countries to exercise their monopoly power and drive up allowance prices.

[2]In the climate change conference of 2011, held in Durban, South Africa, the countries of the EU and a number of other developed countries have signed up to a second commitment period of the Kyoto Protocol, that ends in 2013. This will ensure that there is still some form of legally binding treaty in place to cut carbon emission before the new agreement made by 190 participating countries including the US, China and India takes effect at the end of 2020 (Gray, 2011).

2.2 Theoretical Framework

Two risk-neutral bidders are participating in a first-price independent private value sealed bid auction. After the conclusion of the auction the winner has the opportunity to participate in a monopoly (monopsony) resale market. The winner (loser) of the first stage auction can make a take-it-or-leave-it offer to sell (buy) the object to (from) the same opponent. Both bidders' values are drawn from independent uniform distributions with different supports. The weak bidder's value is an independent and identically distributed (iid) draw from U[0, a_w] wherein a_w is set at 10 in all experimental sessions that follow. The strong bidder's value is an iid draw from U[0, a_s] wherein a_s takes on the values 20 and 40 in two treatments of the experiment. We refer to the former treatment as S20 and the latter as S40.

Bidding distributions and the type of resale regime are common knowledge among the players. Players only know their own values and their own bids during the course of the game. They do not learn the private values or bids of their opponents.

Consider the auction followed by a resale market with monopoly power. This implies that the winner of the first auction has all the bargaining power in the secondary market. We first state the problem in general terms using $F(.)$ as the cumulative density function.

The problem for a bidder j winning the primary auction with a bid b is to determine an optimal price p that maximizes the revenue function R_j

$$\max_p R_j = [F_i(\phi_i(b)) - F_i(p)]p + F_i(p)v_j$$

where ϕ is the inverse bidding function. The first term is the expected payoff from selling in the second stage. The term in the bracket is the probability that the price

is less than or equal to the opponent's value. The second term in this expression is the expected payoff of bidder i when the price exceeds the opponent's value and there is no trade.

Consequently, the problem for bidder j choosing the optimal bid in the primary auction market can be stated as

$$\max_b \Pi_j = R_j(p, b) - F_i(\phi_i(b))b$$

where the first term is the expected revenue from the resale stage and the second term is the cost to bidder j.

Similarly, consider the auction followed by a resale market with monopsony power. The loser of the first auction has all the bargaining power in the secondary market. The problem for bidder j losing the primary auction with a bid b is to determine an optimal price r that maximizes the following resale profit function S_j

$$\max_r S_j = [F_i(r) - F_i(\phi_i(b))](v_j - r).$$

The term in brackets is the probability of trade, which is determined by the resale price being greater than or equal to the opponent's value. Hence, $S_j(r, b)$ represents the maximum expected revenue received from the resale stage by bidder j.

The problem for bidder j choosing the optimal bid in the primary auction market is then

$$\max_b \Pi_j = F_i(\phi_i(b))(v_j - b) + S_j(r, b)$$

where $F_i(\phi_i(b))$ is the probability of winning in the first stage.

The equilibrium bidding functions for each regime under the assumption of uniform distribution of values are described in Table 2.1 where again, a_s and a_w are the upper bounds of the strong and weak bidder's support respectively and v_i is

the value for individual bidder i. The bid functions for the monopoly resale regime follow directly from Hafalir and Krishna (2008) using the symmetrization property. The results under the monopsony resale are derived along the same lines but require some elucidation.[3] The weak bidder's value distribution sets an upper bound for the pricing distribution in the secondary market. The highest price offered by the strong bidder in the resale market should not exceed the upper bound of the weak bidder's value distribution. Following Lebrun (2010), the equilibrium bid function for the monopsony resale is defined over two intervals. For the first part, it is exactly the same as that in the monopoly resale regime. However, note that the bid and the resale price can never exceed the weak bidder's highest value. Hence for bids greater than $\frac{a_w}{2}$, the optimal price is merely a_w. Once the resale price bound is known, we can derive equilibrium bidding strategies for each player. The bidding functions are monotonic, continuous and increasing.

Table 2.1: Equilibrium bidding functions

	Monopoly Resale	Monopsony Resale	
Strong Bidder	$\frac{a_s + a_w}{4a_s} v_s$	$\frac{a_s + a_w}{4a_s} v_s$	$\forall\ 0 \leq v_s \leq \frac{2a_w a_s}{a_w + a_s}$
		$a_w - \frac{a_s a_w^2}{v_s(a_s + a_w)}$	$\forall\ \frac{2a_w a_s}{a_w + a_s} \leq v_s \leq a_s$
Weak Bidder	$\frac{a_s + a_w}{4a_w} v_w$	$\frac{a_s + a_w}{4a_w} v_w$	$\forall\ 0 \leq v_w \leq \frac{2a_w^2}{a_w + a_s}$
		$a_w - \frac{a_w^3}{v_w(a_s + a_w)}$	$\forall\ \frac{2a_w^2}{a_w + a_s} \leq v_w \leq a_w$

The optimal price in each regime depends on the inverse bidding functions $\phi_i(b)$ and $\phi_j(b)$. The price function is $p = 2b$ in the monopoly resale regime. Under the monopsony resale regime, the price function is $r = 2b$ for bids less than or equal to $\frac{a_w}{2}$ and $r = a_w$ for bids exceeding $\frac{a_w}{2}$. In our setup, resale happens invariably from weak to strong bidders. Note that the resale price distribution under the monopsony resale regime can not exceed the weak bidder's value distribution. On

[3]Please see the appendix A.1 for a complete derivation.

the other hand, the resale price distribution lies halfway between the strong and weak bidder's value distributions under the monopoly resale regime.

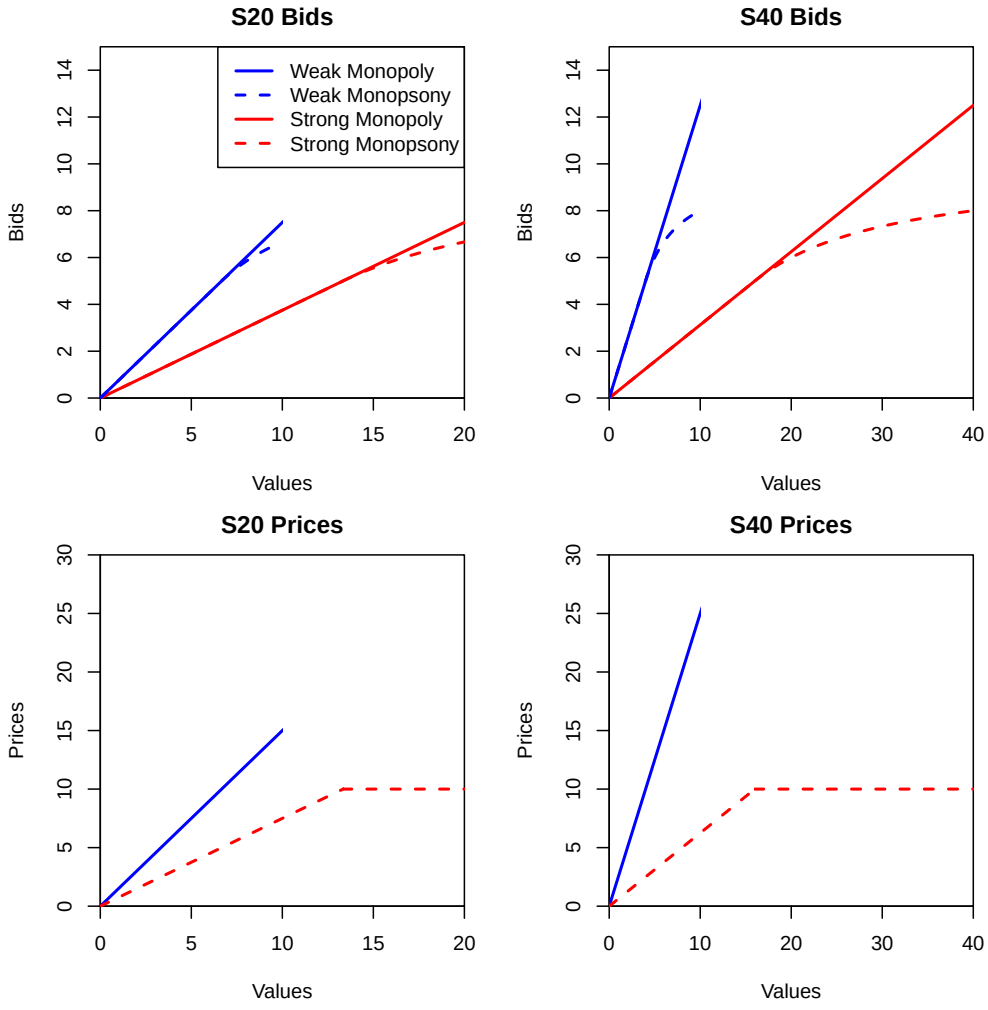

Figure 2.1: Theoretical bids and resale prices offered by values

In Figure 2.1, we present theoretical bids and resale prices as functions of values under both treatments. The solid lines represent bids in the upper panels and prices in the lower panels under the monopoly resale regime, and the dashed lines represent bids/prices under the monopsony resale regime. This allows a visual comparison of the relationship between the bidding and pricing functions of strong and weak bidders in the S20 and S40 treatments. Note that the equilibrium bids for weak and strong type bidders are in proportion to the ratio of their value distribution. i.e.

the weak bidder bids twice as much as the strong bidder in the S20 treatment and four times as much in the S40 treatment for both regimes, as shown in the top two panels of Figure 2.1.

These strategies lead to the following testable predictions (TP):

TP1. The bid distributions for weak and strong bidders are identical under each regime (Symmetrization property).

TP2. For any given set of asymmetric value distributions, equilibrium bids are higher under the monopoly resale regime than under the monopsony resale regime.

TP3. Resale prices are higher under the monopoly resale regime than under the monopsony resale regime.

The lower two panels of Figure 2.1 present the price as a function of the value of the bidder making an offer at the resale stage. This difference in prices leads to differential efficiency effects across regimes. We consider allocative efficiency and measure it as the ratio of the number of outcomes where the person with the highest value ends up owning the commodity to the total number of outcomes. In theory, we have the same interim efficiency under both regimes (i.e. the same number of mis-allocated outcomes at the end of the auction stage). However, there is higher efficiency at the end of the resale stage under the monopsony resale regime. This is due to the certainty of trade in cases when the strong bidder quotes a resale price of a_w to the weak bidder after losing the auction. The sure trade property mentioned in Hafalir and Krishna (2008) ensures more trades in the monopsony regime with a quote of a_w. Further, the higher the asymmetry among bidder distributions, the starker the efficiency effects become. As the variance of the strong bidder's value distribution increases relative to the weak bidder's distribution, more trades are realized under monopsony resale than under monopoly resale. As a result, we have:

TP4. There is a revenue-efficiency trade-off between the two regimes. i.e. the monopoly resale regime leads to higher auction revenue on average but lower final

efficiency, whereas the monopsony resale regime leads to lower auction revenue but higher final efficiency.[4]

2.3 Experimental Design

Our experimental design incorporates the details of this theory. We have two types of bidders and two resale regimes. Since our focus is on understanding bidding behavior across resale regimes, we kept the player types constant throughout the course of a session. Instructions were distributed to subjects at the beginning of each session. There were 40 rounds in each session divided equally between the monopoly and monopsony resale regimes. The software[5] was developed using z-Tree (Fishbacher, 2007).

Players received 65 *ruchmas* (our experimental currency) as the show up fee that was used as initial capital in the S20 treatment. For the S40 treatment, players received 100 ruchmas to account for a larger disparity in the value distributions of bidders. The conversion rate was 1\$ = 13 ruchmas. At the beginning of every session, instructions were read to the players accompanied by a Power Point presentation.[6]

There were two practice rounds followed by twenty rounds played for cash under each regime. Valuations were drawn randomly for each round. The players were reminded of their types at the beginning of each round. Each player was matched with an opponent of the other type, and the matching was changed randomly from one round to another. The information revealed was in line with the theoretical model. Each player knew his own type and own private value. At the end of the auction, each player was informed whether he won or not. In the second stage that

[4]Cheng and Tan (2008) were the first to provide evidence of this tradeoff using discrete type distributions.

[5]z-Tree screen shots of experiment and code can be found in appendix A.4

[6]Please see appendix A.3 for instructions.

followed immediately, the winning (losing) player had an opportunity to make a take-it-or-leave-it offer to sell (buy) to (from) the same opponent under monopoly (monopsony) resale treatment. If the player did not want to sell (buy), he was advised to quote a price of 9999 (0) ruchmas. Each round concluded with the final payoff displayed to each player depending on the outcome. The resale rules and players' value distributions were common knowledge. We did not provide the players with a history of their bidding or earlier prices, since we wanted them to treat each round independently as much as possible. The instructions emphasized that each draw of value was separate. After two practice rounds and twenty paid rounds of monopoly resale treatment, players were informed about the change in resale treatment. This was followed by another two practice rounds and twenty paid rounds of monopsony resale treatment. A brief questionnaire followed that asked the players about some demographic information related to their major, previous experience participating in auctions, risk preferences and gender.[7] The player's ending balance was shown on the screen at the end of the questionnaire. This concluded a typical session. Players received their earnings in *Sooner Sense* credit on their university identity cards, which could be used for purchases around campus. The players were recruited from the undergraduate and graduate student population at the University of Oklahoma, Norman campus. For the S20 treatment, the number of subjects per session varied from 4 to 12 with a total of 68 participants. For the S40 treatment, the number of subjects per session ranged between 6 and 12 with a total of 54 participants.

[7]Please see appendix A.2 for the questionnaire.

2.4 Results And Discussion

2.4.1 Summary statistics: Participant Sample

In table 2.2, we present summary statistics of the participants from both treatments based on the questionnaire mentioned in the previous section.

Table 2.2: Summary statistics: Participant sample

	S20 Treatment	S40 Treatment
Gender		
Male	41	42
Female	27	12
Academic Level		
Undergraduate	56	42
Graduate	12	12
Major/Area of Study		
Physical Sciences	3	1
Engineering	12	16
Humanities	2	0
Social Sciences	22	14
Business and Finance	25	21
Life Sciences	3	1
Health Sciences	1	1
Attitude toward risk		
Risk Neutral	20	14
Risk Averse	40	35
Risk Loving	8	5
Previous participation in real life auctions		
Yes	28	22
No	40	32
Previous participation in auction experiments		
Yes	5	2
No	63	52
Total participants	68	54

Our participants were predominantly male undergraduates as seen in the table. A majority of them were from Business/Finance, Social Sciences and Engineering disciplines. About sixty percent of all participants characterized themselves as risk

averse while twenty eight percent seem to be risk neutral. More than forty percent of all participants had participated previously in real life auctions but only six percent had participated in an auction experiment.

2.4.2 Descriptive Statistics: Bids

In Table 2.3, we show some of the descriptive statistics from the S20 and S40 treatments.

Table 2.3: Descriptive statistics

S20 Treatment				
Monopoly Resale				
Rounds	N	Average	Std dev	Max
1-20	1348	5.729 (3.764)	3.410	20 (7.5)
11-20	678	5.626 (3.758)	3.283	17.76 (7.5)
Monopsony Resale				
1-20	1358	5.101 (3.690)	2.838	15.09 (6.67)
11-20	678	5.034 (3.740)	2.736	15.00 (6.67)
S40 Treatment				
Monopoly Resale				
Rounds	N	Average	Std dev	Max
1-20	1080	8.48 (6.137)	7.376	40 (12.50)
11-20	540	7.786 (6.392)	6.584	39 (12.50)
Monopsony Resale				
1-20	1080	6.345 (5.209)	5.13	34.00 (8.00)
11-20	540	6.043 (5.08)	4.778	30.88 (8.00)

Theoretical predictions are in brackets.

As seen from the table, the average bids and standard deviations are higher under the monopoly resale regime than under the monopsony resale regime. While bidding in rounds 11-20 is isolated to examine more experienced bidders, the qualitative results remain the same across.[8]

We also provide a non-parametric test to compare bid distributions across bidder types under each regime and test **TP2**. We employ the Mann-Whitney test under

[8]We compare average and median bids by player types to find, once again, evidence of higher bidding under monopoly resale than under monopsony resale.

the null of equality of bid distributions for the two regimes to test for difference in the location across the two samples. For both treatments, we reject the null at $p < 0.01$ (S20: z-value = 4.405, N = 1348 and S40: z-value = 6.433, N= 1080). The estimated probabilities of bids under monopoly resale exceeding those under monopsony resale are 0.549 and 0.580 respectively under the two treatments. Given the results of this test, the prediction that average bids are higher under the monopoly resale regime than the monopsony resale regime is borne out.

Bids as a function of values using box and whiskers plots for the S20 and S40 treatments are described in Figures 2.2 and 2.3 respectively. Graphs are separated

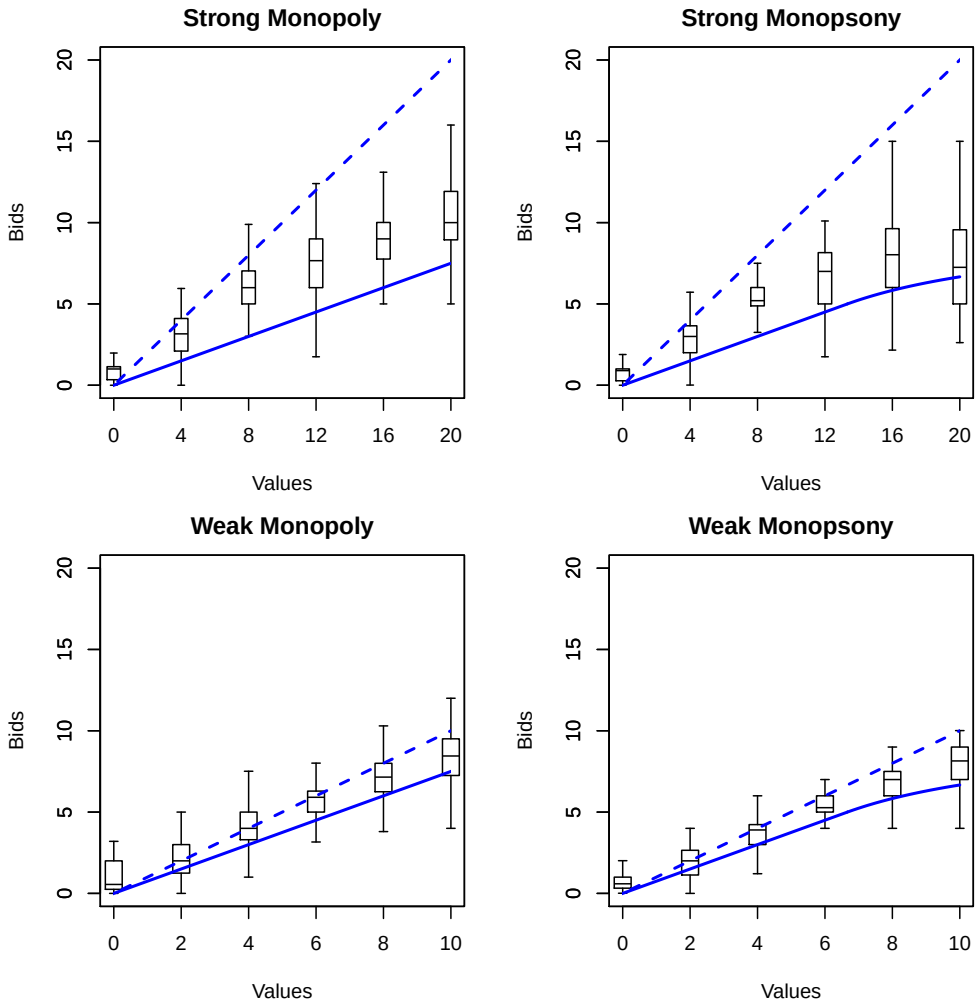

Figure 2.2: Box and whiskers plot of actual bids-S20 treatment

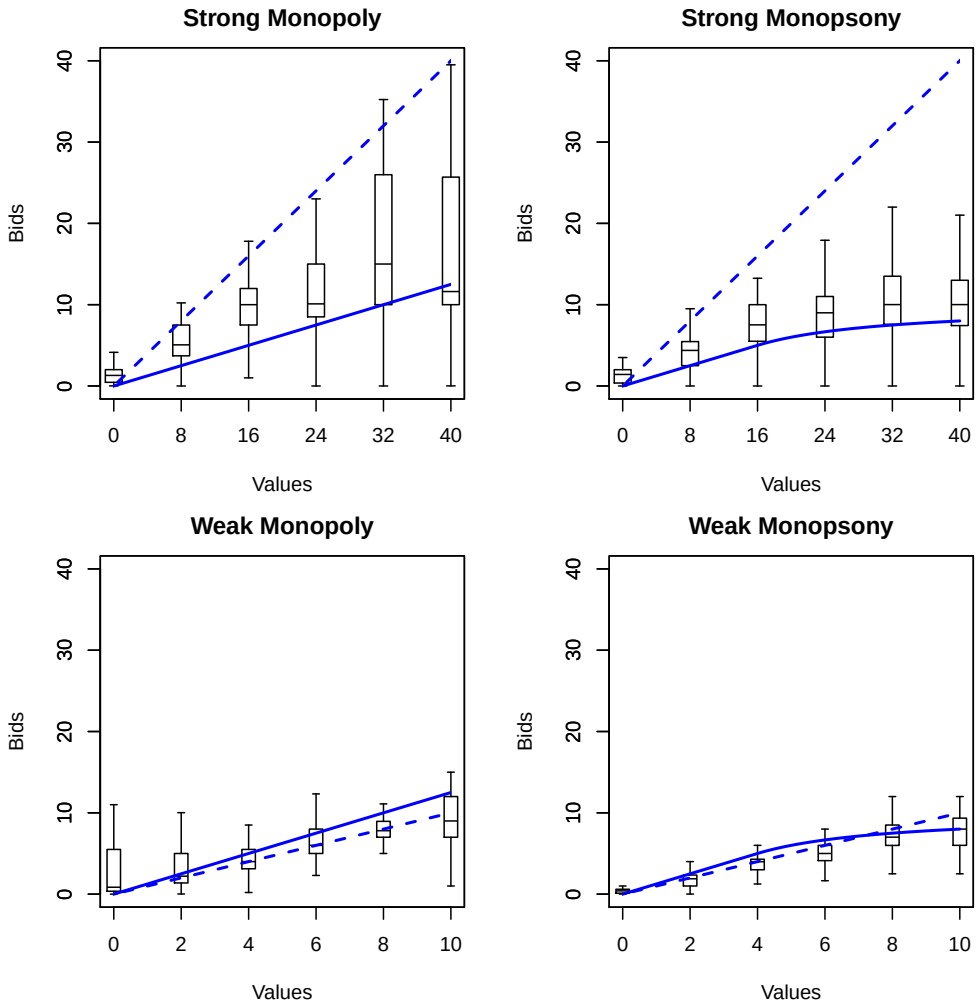

Figure 2.3: Box and whiskers plot of actual bids-S40 treatment

by bidder type and resale regime. The boxes represent the interquartile range and the whiskers extend up to the outermost data point within 1.5 times the interquartile range. The solid lines represent equilibrium bids, and the dashed lines indicate bidding one's value. Overall, the box plots are consistent with the descriptive statistics showing higher relative bids and greater dispersion for the monopoly resale regime and more so as the asymmetries intensify. Strong bidders bid on average above their equilibrium bids and shade their bids more at higher values. Since bidding higher than the weak bidder's highest equilibrium bid is a dominated strategy for the strong bidder, the observed pattern of bids tapering off for the strong bidder is

consistent with the previous studies (Gueth et al. 2005).

Overbidding compared to equilibrium level is a commonly observed phenomenon in the experimental literature (Kagel and Roth, 1995). It is also seen in these graphs, and it is more pronounced among strong bidders. Weak bidders tend to bid closer to their equilibrium bids except at the lower end of values under the monopoly resale regime.

2.4.3 Bid Shading under the Prospect of Resale

The equilibrium bidding strategies under a first price auction imply some degree of bid shading, calculated as $\frac{v_i - b_i}{v_i}$ for each bidder i. While the equilibrium bidding strategies under monopoly resale require a constant proportion of bid shading for both types of bidders, those under monopsony resale require a higher proportion of shading at higher values.

Table 2.4: Average degree of bid shading

Weak			Strong		
0-3.34	3.34-6.67	6.67-10	0-6.67	6.67-13.34	13.34-20
S20 Monopoly					
-3.15(0.25)	-0.05(0.25)	0.10(0.25)	0.17(0.62)	0.32(0.62)	0.42(0.62)
S20 Monopsony					
-2.95(0.25)	0.08(0.25)	0.15(0.28)	0.30(0.62)	0.37(0.62)	0.52(0.64)
0-4	4 - 7	7 - 10	0 - 16	16 - 28	28 - 40
S40 Monopoly					
-5.52 (-0.25)	-0.24(-0.25)	-0.13(-0.25)	0.10(0.69)	0.48(0.69)	0.50(0.69)
S40 Monopsony					
-0.59(-0.25)	0.12(-0.15)	0.11(0.10)	0.37(0.69)	0.59(0.71)	0.64(0.77)

In Table 2.4, we present the average degree of actual and predicted (in parentheses) bid shading under both resale regimes for the two treatments. The numbers in the first row represent value intervals for the weak and strong bidders. For the monopsony regime, the bidding strategies become non-linear (implying higher shading) for values greater than 6.67 in the S20 treatment and greater than 4 in

the S40 treatment. For the strong bidder, the relevant values are 13.34 and 16 for the two treatments, respectively. The value intervals are constructed to account for these cutoffs while splitting the remaining value intervals equally to achieve a reasonable spread. Weak bidders with lower values, on average, overbid under both resale regimes. Strong bidders, on average, do not overbid. Under monopsony resale, with only one exception, the empirical observations are both qualitatively and quantitatively closer to the equilibrium predictions than in the monopoly case.

2.4.4 Symmetrization of Bid Distributions

An important property of the equilibrium is the symmetrization of bid distributions under both regimes. Hafalir and Krishna (2008) have theoretically shown this symmetrization under the monopoly resale regime with the monopsony resale case outlined as an extension. The underlying idea is that both weak and strong bidders treat the auction with resale as equivalent to an auction without resale that has a common value component determined by the resale stage structure. Hence, we expect the bid distributions for weak and strong bidders within a given resale structure to be the same.

The kernel density estimates of bid distributions for weak and strong bidders under monopoly and monopsony regimes in the S20 and S40 treatments are depicted in Figure 2.4. The bidding distributions under monopoly resale for the S20 treatment (top-left panel) exhibit close similarities to those in Georganas and Kagel (2011).[9] The bid distributions for weak and strong bidders are much closer under the monopsony regime than under the monopoly regime (see the top-right panel). A possible reason for this could be the lack of speculative motive on the bidder's part in the first stage. The two bottom panels show kernel density estimates of

[9]Georganas and Kagel reject the symmetrization property for sufficiently large asymmetries similar to the level existing here in S20.

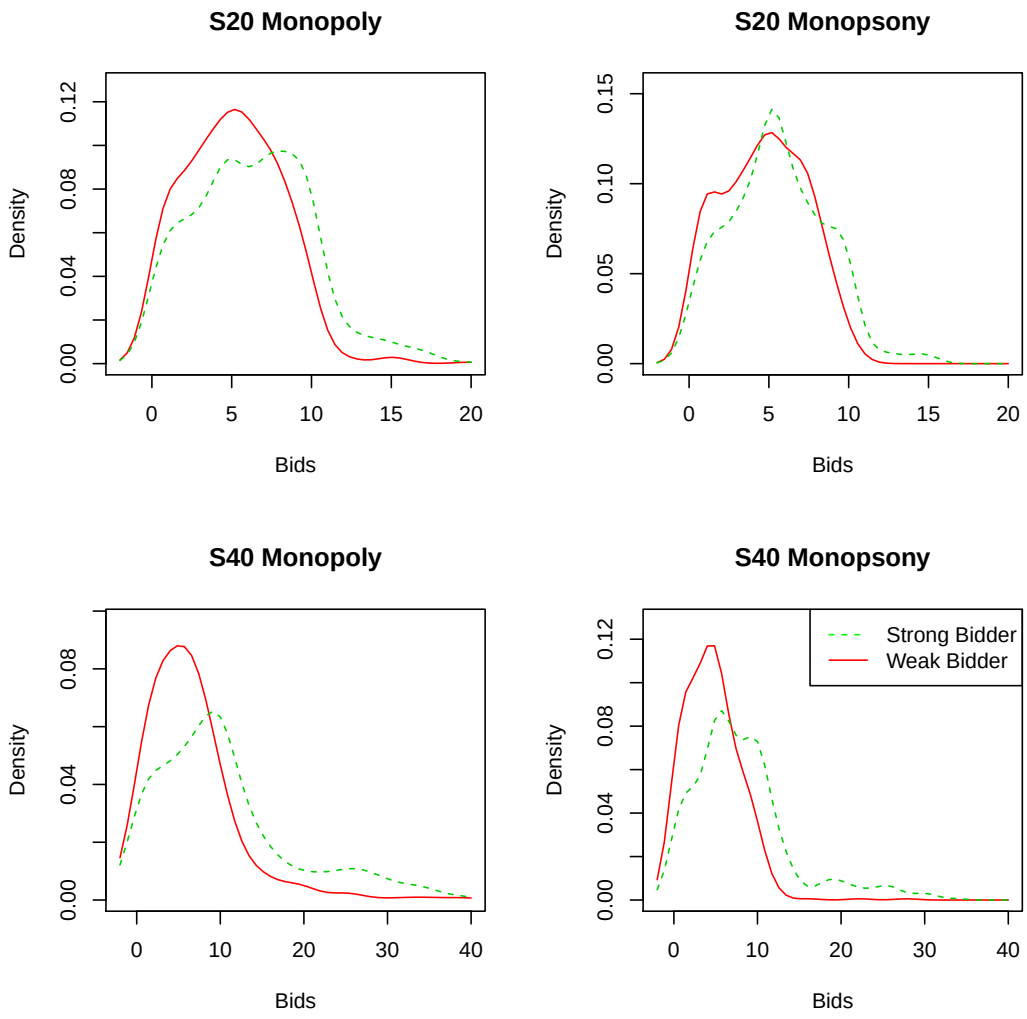

Figure 2.4: Kernel density estimates for bid distributions.

the bid distributions for the two bidder types under each regime for the S40 treatment. The bid distributions for weak and strong bidders appear quite distinct. A Kolmogorov-Smirnov (K-S) test provides formal evidence of differences in size, dispersion or central tendency. The test rejects the null of no difference between weak and strong type bidder distributions for both regimes and both treatments at a probability value less than one percent.[10]

The analysis so far has explored qualitative distributional differences without

[10]We tested the normalized (relative) bid distributions to control for differences in the theoretical distribution of bids. They yield similar results.

providing controls for bidder and auction heterogeneity. Next, we present a quantitative analysis that controls for unobserved heterogeneity among bidders and differences in auction and bidder measurable characteristics. We first perform mean level analysis and then apply quantile regression techniques to investigate how bidding aggressiveness varies for different values and types of bidders across the distribution. The basic econometric model of the relation between values and bids for both bidder types that is derived directly from the equilibrium strategies is

$$b_{iat} = \beta_1 v_{iat} + \beta_2 (v_{iat} \times A_i) + \mathbf{z}_{iat}^{'} \delta + \alpha_i + \epsilon_{iat} \tag{2.1}$$

where the unit of observation is a bid submitted by bidder i, in auction a, in round t. Our dependent variable is the bid b_{iat}. The value of the bidder i in auction a and round t is v_{iat}. A_i is an indicator variable that takes value 0 or 1 for a strong and weak type bidder, respectively. Hence, the coefficient β_2 measures the differential effect of values on bids between a weak and a strong bidder. The vector $\mathbf{z}$ contains a set of variables used to control for observed heterogeneity across bidders and auctions. They capture a bidder's attitude toward risk, his/her gender, academic level and previous participation in real life auctions. It includes indicators of the order of an auction in the experimental sequence, and the number of available bidders of each type in a session. The bidder specific fixed effects are represented by α_i. The coefficients of our interest are β_1 and β_2. As mentioned in section 2, weak bidders bid twice as much as strong bidders in the S20 treatment and four times as much in the S40 treatment. Hence, we expect $\beta_1 = \beta_2$ in the S20 treatment under each regime and $\beta_2 = 3\beta_1$ in the S40 treatment.

A simple quantile regression model allows us to investigate more systematically how the effect of key controls varies across the distribution of bids reducing the impact of outlier values. Since there is a differential effect by bidder type upon bids

Table 2.5: Mean level and quantile regression results for actual bids

	Quantiles			Mean Level
Variables	0.25	0.5	0.75	
Treatment S20 Monopoly Resale				
Value(β_1)	0.489*	0.534*	0.589*	0.505*
	(0.014)	(0.019)	(0.025)	(0.015)
Value × Weak Bidder Indicator	0.331*	0.323*	0.272*	0.213*
(β_2)	(0.023)	(0.025)	(0.032)	(0.033)
p-value from testing $H_0 : \beta_2 = \beta_1$	0.000	0.000	0.000	0.000
Treatment S20 Monopsony Resale				
Value(β_1)	0.394*	0.404*	0.443*	0.396*
	(0.019)	(0.021)	(0.032)	(0.013)
Value × Weak Bidder Indicator	0.401*	0.424*	0.389*	0.323*
(β_2)	(0.025)	(0.028)	(0.037)	(0.023)
p-value from testing $H_0 : \beta_2 = \beta_1$	0.858	0.658	0.417	0.028
Treatment S40 Monopoly Resale				
Value(β_1)	0.303*	0.346*	0.435*	0.427*
	(0.029)	(0.032)	(0.056)	(0.023)
Value × Weak Bidder Indicator	0.569*	0.546*	0.411*	0.393*
(β_2)	(0.041)	(0.047)	(0.074)	(0.079)
p-value from testing $H_0 : \beta_2 = 3\beta_1$	0.005	0.000	0.000	0.000
Treatment S40 Monopsony Resale				
Value(β_1)	0.200*	0.242*	0.267*	0.295*
	(0.022)	(0.023)	(0.022)	(0.015)
Value × Weak Bidder Indicator	0.578*	0.626*	0.596*	0.504*
(β_2)	(0.040)	(0.034)	(0.037)	(0.035)
p-value from testing $H_0 : \beta_2 = 3\beta_1$	0.810	0.315	0.030	0.000

Standard errors are in parentheses. * denotes statistically different from zero at 0.01 level of significance. N = 1348 for S20 Monopoly Resale, N = 1358 for Monopsony Resale. N = 1080 for S40 Monopoly Resale and S40 Monopsony Resale.

across the value distribution, the model can shed light on symmetrization (**TP1).** Following Koenker and Bassett (1978), Koenker (2005) and Lamarche (2006), we propose the following simple quantile regression model:

$$Q_{b_{iat}}(\tau|\mathbf{x}_{iat}) = \mathbf{x}_{iat}\gamma(\tau) \tag{2.2}$$

where $Q(.|.)$ is the τ-th conditional quantile function, $\gamma(\tau) = (\beta_1(\tau), \beta_2(\tau), \delta(\tau)')'$ is the vector of parameters and $\mathbf{x}_{iat} = [v_i, v_{iat} \times A_i, z'_{iat}]$ is the vector of covariates.

The quantile model is estimated via optimization by finding

$$\hat{\gamma}(\tau) = argmin \sum_i \sum_a \sum_t \rho_\tau(b_{iat} - x'_{iat}\gamma(\tau)) \tag{2.3}$$

where $\rho_\tau(u) = u(\tau - I(u < 0))$ is the quantile regression "check function." We restrict attention to three quantiles $\tau = \{0.25, 0.50, 0.75\}$.

In Table 2.5, we report mean level and quantile regression results for bids in the monopoly and monopsony regimes under the S20 and S40 treatments. Using F-tests of the difference in bidding intensity between strong and weak bidders under the two regimes, we test for symmetrization.[11] Notice that the results from mean level regressions lead to rejection of H_0 for all cases at a 5 percent level of significance. Outliers can impact significantly mean level regressions. However, the conditional quantile regression results based on the 0.25, 0.5 and 0.75 quantile estimates provide some support for symmetrization under the monopsony regime for the middle range values of the bid distribution, but not under monopoly resale.

[11] As mentioned earlier, the hypotheses tested are that $\beta_2 = \beta_1$ and $\beta_2 = 3\beta_1$ for the S20 and the S40 treatment respectively.

2.4.5 Resale Price Comparisons

According to **TP3**, we expect higher resale prices under the monopoly resale regime compared to the monopsony resale regime conditional on trade in the second stage. The disparity in resale prices can be perceived as an indication of speculative behavior on the part of the weak bidder under the monopoly resale regime.

The experimental data shows higher resale prices on average under monopoly resale as expected and provides support for **TP3**. For the S20 treatment, on average, the resale price is 33% higher under monopoly resale than under monopsony resale conditional upon trade in the resale stage (t = 5.168, N = 217, $p < 0.01$). For the S40 treatment, the average resale price conditional on trade at the resale stage is about 28% higher under monopoly resale than under monopsony resale (t = 3.187, N= 169, $p < 0.01$). We further employ Mann-Whitney tests to compare the equality of resale price distributions under monopoly and monopsony resale conditional upon trading at the resale stage. The null of equality of resale prices between monopoly and monopsony resale is rejected for both the S20 (z-value = 4.317, $p < 0.01$) and the S40 (z-value = 2.054, $p = 0.04$) treatments. Further, the estimated probabilities of the monopoly resale price exceeding the monopsony resale price are 0.670 and 0.592 respectively for the S20 and S40 treatments.

2.4.6 Efficiency Comparisons

We consider two definitions of efficiency. In the first definition, we use the ratio of number of outcomes, wherein a high value bidder wins to the total number of outcomes. In Table 2.6, we describe the interim (auction stage) and final (resale stage) efficiency comparisons for both treatments using data from all periods.[12] Interim efficiency is higher than predicted but almost equal across regimes for the

[12]The calculations for both tables using periods 11 - 20 are consistent with these numbers.

S20 treatment. The final efficiency levels are also similar with monopoly resale registering higher actual efficiency than predicted.

For the S40 treatment, interim efficiency for both regimes is much higher than predicted. Final efficiency for monopsony resale is relatively higher, providing support for **TP4** only in this case.

Table 2.6: Efficiency calculations - I

Efficiency (in percent)				
	Interim		Final	
	Predicted	Actual	Predicted	Actual
S20 Monopoly	75.00	80.71	87.50	90.80
S20 Monopsony	75.00	80.11	91.67	90.42
S40 Monopoly	62.50	77.03	81.25	87.96
S40 Monopsony	62.50	79.25	92.50	92.78

Table 2.7: Efficiency calculations - II

Efficiency (in percent)				
	Interim		Final	
	Predicted	Actual	Predicted	Actual
S20 Monopoly	91.67	91.37	97.56	96.40
S20 Monopsony	92.07	91.73	99.00	96.91
S40 Monopoly	79.70	85.66	93.25	93.64
S40 Monopsony	81.06	89.34	98.38	97.34

We also report efficiency calculations based on another widely used measure. This definition employs the average value of the ratio $\frac{v_i}{\max\{v_i, v_{-i}\}}$, where the numerator, v_i, is the owner's value at a given stage and the denominator is the maximum of the values of everyone else who is part of the market at that stage. Unlike the previous measure, which relies on the count of efficient versus inefficient outcomes, the current measure focuses on the average magnitude of lost surplus. In Table 2.7, we report the predicted and actual efficiencies based on this approach. Actual interim efficiencies for the S20 treatment are about the same across regimes and similar to the predictions. Actual final efficiencies are also similar in magnitude

for the two regimes but lower than predicted. For the S40 treatment, the observed interim efficiencies are higher than predicted and even more so for the monopsony resale. The observed final efficiencies are much closer to the predictions, implying a higher lost surplus under the monopoly resale compared to monopsony resale.

2.5 Conclusions

We derive equilibrium bidding distributions in an auction with monopsony resale and compare them to those derived in Hafalir and Krishna (2008) for auctions with monopoly resale. The shift of bargaining power from seller to buyer tends to reduce speculative tendencies on the bidder's part, leading to differential revenue and efficiency outcomes. Our experimental results show that bids are indeed higher under the monopoly resale regime than the monopsony resale regime across both treatments. The resale prices conditional on trade in the secondary market are higher under monopoly resale. The actual number of efficient outcomes (both interim and final) are higher than predicted. Our quantitative analysis, providing controls for bidder and auction level characteristics, offers some support to symmetrization only in the monopsony case.

Chapter 3

Bargaining in Auctions with Resale

This chapter continues the study of bidding behavior in first price private value asymmetric auctions followed by resale. This setup introduces equal bargaining power to buyer and seller in the resale stage resulting in equilibrium bidding and pricing functions to fall midway between those for the same setup under monopoly resale (seller's market) and monopsony resale (buyer's market) along with symmetrization of bids. Controlled experiments are employed that mimic the theoretical setup. This setup enables us to shed light on the workings of real world markets[1].

3.1 Introduction

Bilateral bargaining under incomplete information is one of the 'classic' economic problems. In a way, it represents the essence of a *market* at the most fundamental level, where two parties knowing their reservation values about a good are willing to make a trade. While a mutually beneficial trade may be possible in these circumstances, the individual parties have an incentive to hide their true valuations thereby precluding trade. Hence, there are serious limitations in designing a mechanism that would ensure honest revelation of preferences and ex-post efficient allocation without any external subsidy (Vickrey, 1961). Interestingly, the problem of efficiency is mitigated when the number of trading parties increases under a standard double auction framework (Satterthwaite and Williams, 1989, Williams, 1991). More than often, bargaining occurs in a secondary market preceded by a sale through a mechanism that invites broad participation such as an auction setting.

The empirical motivation to consider the second format comes from electricity

[1]A secondary market for emission trading is, for example, Chicago Climate Futures Exchange (CCFE) that operates as a double auction environment

markets, emission trading markets as well as markets for second-hand automobiles. For instance, the Regional Greenhouse Gas Initiative (RGGI), a recent emission trading scheme in the US[2] that has auctioned off emission allowances over last four years which have been trading on the Chicago Climate Exchange (CCX) via standard futures and options contracts. Auctions followed by resale opportunities have been receiving attention in theoretical and experimental literature following Haile's early works (1999, 2001, 2003). More recently, Hafalir and Krishna (2008) along with Cheng and Tan (2008) have established a theoretical framework that derives an equivalence between a first price private value asymmetric auction with resale and a first price symmetric auction without resale whose valuations are governed by the resale price structure. The upshot of this analysis is that the (asymmetric) bidders behave as if they are participating in a symmetric auction hence facilitating the derivation of equilibrium bidding strategies in the first stage. Georganas and Kagel (2011) provide experimental evidence on bidding behavior between resale and no resale regime and provide some evidence for symmetrization under a monopoly resale regime (where the seller has all the bargaining power in the resale stage). Jog and Kosmopoulou (2012) extend the analysis to a monopsony resale regime (where the buyer has all the bargaining power in the resale stage) based on this framework using controlled experiments and find evidence for higher first stage bidding under monopoly resale compared to monopsony resale.

In this chapter, we extend the analysis further to negotiations that allow a balance in bargaining power and settings that are representing a broader set of markets. Specifically, we have an asymmetric first price auction between a pair of weak-strong bidders followed by a double auction resale between the same bidders. Thus, the buyer and seller in the resale stage have equal bargaining power. We employ two treatments involving different distributional supports in order to be

[2]Please see www.rggi.org for details

consistent with our earlier results as well as provide a robustness check on the theoretical results. Overall, we find the average bids and efficiency values under double auction resale leaning toward the empirical results from monopsony resale case.

In the next subsection, we review related literature. It is followed by laying out the theoretical framework and derivation of equilibrium bidding functions under double auction resale regime. Section 3.3 delineates the experimental design with special reference to innovations in the instructions. Descriptive statistics and main results are summarized in section 3.4. The last section offers concluding remarks.

3.1.1 Related Literature

Chatterjee and Samuelson (1983) studied bilateral bargaining under incomplete information with single buyer and seller having private values drawn from a commonly known distribution and derived linear equilibrium bidding strategies. In this setup, trade takes place if buyer's offer is greater than or equal to the seller's offer at a price P $= kb + (1 - k)s$, where b and s are respectively buyer's and seller's offer. The parameter k lies between [0,1] and dictates the bargaining rule. Using uniform distribution of values the authors show that $k = 0.5$ leads to the highest probability of trade as well as the maximum sum of profits for both parties (ex-ante). This 'split-the-difference' bargaining rule is optimal in a limited sense in that it is a 'second-best' solution given the informational constraints of this setup.

A more comprehensive treatment of bilateral bargaining is by Myerson and Satterthwaite (1983), where they derive the set of allocation mechanisms that possess two important properties, viz. (Bayesian) incentive compatibility and individual rationality. They show that for such mechanisms to be ex-post efficient, outside subsidies are inevitable. Multiple equlibria based on players' beliefs are examined in Satterthwaite and Williams (1989) and Leininger et al. (1989) with each equilib-

rium leading to a different level of efficiency. Radner and Schotter (1989) provide experimental evidence for 'linear' bidding strategies in bilateral bargaining under incomplete information. They find that with experience, outside equilibria (such as a 'step-function' equlibria) can be supported.

Maskin and Riley (2000) investigate private value asymmetric auctions and derive equilibrium bidding strategies for a pair of 'weak-strong' bidders. They find that the expected revenue under the first price sealed bid auction may be higher or lower than English auction, thus voiding the revenue equivalence. The weak-type bidder bids more aggressively in equilibrium and prefers a sealed bid auction to open auction. Hafalir and Krishna (2008) add a resale stage to this setup of sealed bid asymmetric auction and show that the two stage asymmetric auction is equivalent to a single stage symmetric auction whose valuations are governed by the resale stage.

Cheng and Tan (2008) reach similar conclusions by a slightly different approach. They find equivalence between an asymmetric private values auction with resale and a single stage common value auction without resale wherein the common value is determined by the resale stage. Despite their different approach, the equilibrium bidding functions match up with those from Hafalir and Krishna (2008). Cheng and Tan further employ Chatterjee and Samuelson's (1983) linear equilibrium in the resale stage to find bidding strategies in asymmetric auctions with resale where the resale stage is a k-double auction between the buyer and the seller. We build on this model to derive explicit bidding strategies under $\frac{1}{2}$-double auctions resale setting for the two bidder types as described in the next section.

3.2 Theoretical Framework

Two risk-neutral bidders participate in a first-price independent private value sealed bid auction. The auction is followed by a resale between the same bidders. The bidder winning (losing) the auction can make an offer to sell (buy). Trade takes place if the buyer's offer is at least as high as the seller's offer. Trading price is halfway between the offers. If buyer's offer is less than seller's offer, there is no trade in the resale stage and the first stage winner keeps the object. Both bidders' values are drawn from independent uniform distributions with different supports. The weak bidder's value is an independent and identically distributed (iid) draw from U[0, a_w] wherein a_w is set at 10 in all experimental sessions that follow. The strong bidder's value is an iid draw from U[0, a_s] wherein a_s takes on values 20 and 40 in two treatments of the experiment. We refer to the former treatment as S20 and the latter as S40 for the remainder of this paper. Bidding distributions and the type of resale regime are common knowledge among the players. Players only know their own values and their own bids during the course of the game. They do not learn the private values or bids of their opponents.

Under these settings, the resale takes place invariably from a weak to strong bidder (Hafalir and Krishna, 2008). Following Cheng and Tan (2008), we first find the (linear) resale price functions by by solving the maximization problems for a weak bidder (seller) and a strong bidder (buyer) in the second stage. Having known the resale price function [p(b)], we can derive the first stage bidding strategies as the solutions that satisfy the following system of differential equations[3] with appropriate boundary conditions:

$$\frac{d}{db} ln F_k[\phi_k(b)] = \frac{1}{p(b) - b} \qquad \forall k = s, w.$$

[3]Please see the appendix B.1 for a detailed derivation.

where $\phi_k(.)$ is the equilibrium inverse bidding function for player k.

Under the assumption of uniform distribution of values, the equilibrium bidding strategies $b_i(v_i)$ for each bidder i as functions of their values are as follows:

$$\begin{aligned} b_w(v_w) &= \frac{a_s + a_w}{4a_w} v_w && v_w \in \left[0, \frac{a_w(a_s + 3a_w)}{3a_s + a_w}\right] \\ &= \frac{a_s + 3a_w}{8a_w}\left[10 + \frac{v_w}{2} - \frac{(15a_w + 5a_s)a_w}{(3a_s + a_w)v_w}\right] && v_w \in \left[\frac{a_w(a_s + 3a_w)}{3a_s + a_w}, a_w\right], \end{aligned}$$

$$\begin{aligned} b_s(v_s) &= \frac{a_s + a_w}{4a_s} v_s && v_s \in \left[0, \frac{a_s(a_s + 3a_w)}{3a_s + a_w}\right] \\ &= \frac{a_s + 3a_w}{8a_w}\left[10 + \frac{v_s a_w}{2a_s} - \frac{(15a_w + 5a_s)a_s}{(3a_s + a_w)v_s}\right] && v_s \in \left[\frac{a_s(a_s + 3a_w)}{3a_s + a_w}, a_s\right]. \end{aligned}$$

where a_s and a_w are the upper bounds of strong and weak bidder's value distributions respectively. The resulting equilibrium bidding and pricing functions are depicted in figure 3.1. Note that in all cases, the bidding strategies for both bidder types are proportional to the ratio of their value distributions, i.e., for a given value, the weak bidder bids twice as much as the strong bidder under the S20 treatment and four times under the S40 treatment for all regimes.

To put in perspective the bidding functions across various resale regimes, we present in figure 3.2, the theoretical bidding functions under all three resale regimes for S40 treatment. As we can see the equilibrium bidding strategies are overlapping for the weak and strong bidders over the first half of the value distribution. For the rest of the value distribution, we see bids under the monopoly resale regime to be highest and those under the monopsony resale regime to be the lowest ones with bids under the double auction regime falling in between the two.

This leads us to the following testable predictions (TP):

TP1. The average first stage bids and (resale) prices under the double auctions resale regime lie in between those under monopoly and monopsony resale regimes.

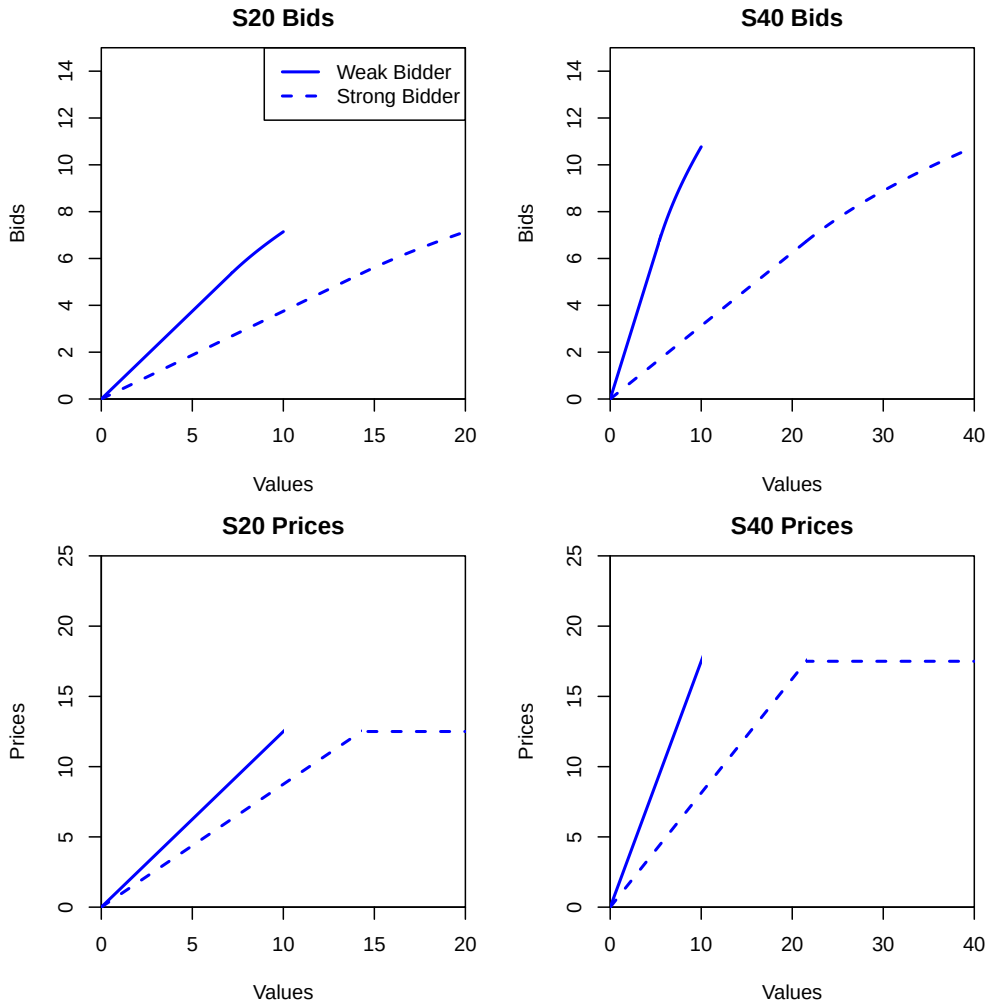

Figure 3.1: Theoretical bids and resale prices offered by values

TP2. (Symmetrization property). The bid distributions for weak and strong bidders are identical under double auction resale regime.

This follows from the idea that the weak and strong bidders behave as if they are looking after the common 'prize' determined by the double auction mechanism in the resale stage. Hence the bidding distributions (as in the monopoly and monopsony regimes) look the same for both types in spite of the asymmetry in the value distributions.

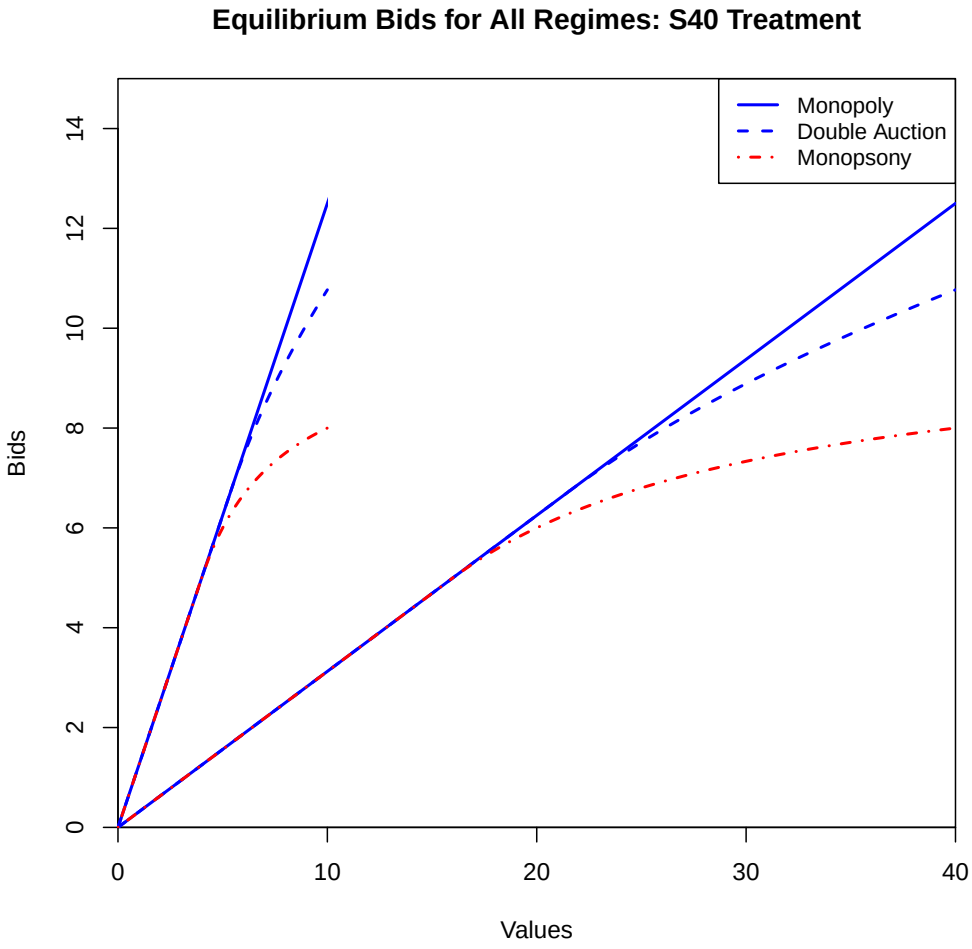

Figure 3.2: Theoretical bids for all resale regimes under S40 treatment

3.3 Experimental Design

Our experimental design closely follows the theoretical setup. We have two types of bidders and two treatments as specified earlier. The software[4] was developed using z-Tree (Fishbacher, 2007).

Players received 100 *ruchmas* (our experimental currency) that was used as initial endowment in both treatments. The conversion rate was 1$ = 7 ruchmas for the S20 treatment. For the S40 treatment, the conversion rate was 1$ = 11

[4]Please see appendix B.4 for the code and screen shots of the experiment.

ruchmas to account for larger disparity among the players' value distributions. This ensured that the final payoffs were similar for all players in each treatment. At the beginning of every session, instructions were distributed and read aloud to the players accompanied by a Power Point presentation.

We would like to point out here the use of graphical examples and schematics in our instructions is a new feature introduced to facilitate the information for the participants. Drafting instructions for experimental subjects often poses a unique quandary for the experimenter. While one wants the subjects to understand the rules perfectly in order to participate, care has to be taken so as not to lead subjects in any particular direction. Some of the popular solutions are using unusually large numbers to generate contrived examples or ask subjects to answer a questionnaire[5] that ensures whether the subject has understood the rules. We use graphical examples to illustrate the procedure[6] thereby avoiding any numbers. The schematics are an attempt to provide handy and concise explanation of instructions. Informal correspondence with participants indicated that they were able to comprehend the instructions better because of graphs and schematics.

In a typical session, there were two practice rounds[7] followed by forty rounds played for cash. One half of the total participants in a session began as a strong(weak) type. The player types were switched after twenty rounds. i.e., If a player started as a strong type for the first twenty rounds, he was changed to a weak type for the last twenty rounds and vice-versa. Valuations were randomly drawn for each round. The players were reminded of their types at the beginning of each round. Each player was matched with an opponent of the other type and the matching was changed randomly from one round to another. The information revealed was in line with the theoretical model. Each player knew his own type and own private value.

[5]For instance, veconlab software by Charles Holt
[6]Instructions can be found in appendix B.3
[7]S40 treatment had 4 practice rounds

At the end of the auction stage, each player was informed whether he won or not. In the second stage that followed immediately, both players had an opportunity to make an offer to sell (buy) to (from) the same opponent. If the player did not want to resell (buy), he was advised to quote a price of 21(0) ruchmas [41(0) in S40 treatment]. Trade took place if the buyer's offer was at least as high as the seller's offer. In the case of a trade, the trading price was a simple average of the two offers. If there was no trade in the second stage, the first stage winner kept the item. Each round concluded with the final payoff and trading price (if trade went through) displayed to each player depending on the particular outcome. The resale rules and players' value distributions were common knowledge. We did not provide the players with a history of their bidding or earlier prices since we wanted them to treat each round as much independently as possible. After two practice rounds and the initial twenty rounds for cash, players were informed about the change in types for the remaining twenty rounds. A brief questionnaire followed that asked the players about some demographic information related to their major, previous experience in auction participation, risk preferences, native language and gender[8]. A player's ending balance was shown on the screen at the end of the questionnaire. This concluded a typical session. Players received their earnings in *sooner sense* credit on their university identity cards that could be used for purchases around campus. The players were recruited from the graduate and undergraduate student population at the University of Oklahoma, Norman campus. The number of players per session varied from 4 to 12 with a total of 50 participants in six sessions for the S20 treatment. For the S40 treatment, the number of players per session ranged from 4 to 14 with a total of 46 players in six sessions.

[8]Please see appendix B.2 for the questionnaire

3.4 Results And Discussion

3.4.1 Descriptive Statistics: Bids

In table 3.1, we present the descriptive statistics[9] for both bidder types under each treatment. Strong bidders bid, on average, higher than the weak bidders under

Table 3.1: Descriptive statistics: Bids

S20 Treatment				
Strong Bidder				
Rounds	N	Average	Std dev	Max
1-20	999	5.935 (3.750)	3.410	19.29 (7.14)
11-20	500	5.716 (3.707)	3.794	18.92 (7.14)
Weak Bidder				
1-20	999	4.210 (3.690)	2.701	20.00 (7.14)
11-20	500	4.025 (3.740)	2.543	15.00 (7.14)
S40 Treatment				
Strong Bidder				
Rounds	N	Average	Std dev	Max
1-20	920	8.965 (5.590)	6.301	39.00 (10.76)
11-20	460	8.414 (5.692)	5.911	38.09 (10.76)
Weak Bidder				
1-20	920	4.998 (6.123)	3.561	35.00 (10.76)
11-20	460	4.818 (6.092)	3.522	35.00 (10.76)

Theoretical predictions are in brackets.

both treatments. Further, the strong bidders' bids exhibit higher variation than weak bidders' bids. The difference is more pronounced under the S40 treatment. While weak bidders are expected to bid on average higher than the strong bidders for the S40 treatment, the actual average bids are lower for the weak bidders. Thus, the strong bidders overbid under both treatments but the weak bidders overbid only for the S20 treatment. We can cite two broad reasons to explain this bidding behavior, viz. strong bidders looking to acquire the item right at the bidding stage thus

[9]We isolate rounds 11-20 to focus on more experienced bidders. However, the quantitative results are similar for the full and restricted sample.

avoiding taking chances at the resale stage and weak bidders' aversion to potential losses by bidding higher in the first stage and failing to trade in the resale stage. The latter is more evident in the S40 treatment and hence the weak bidders actually underbid for the S40 treatment. Overall, there were lesser number of actual trades in the resale stage under both treatments which is consistent with the above bidding behavior. We compared the bidding distributions for weak and strong bidders under

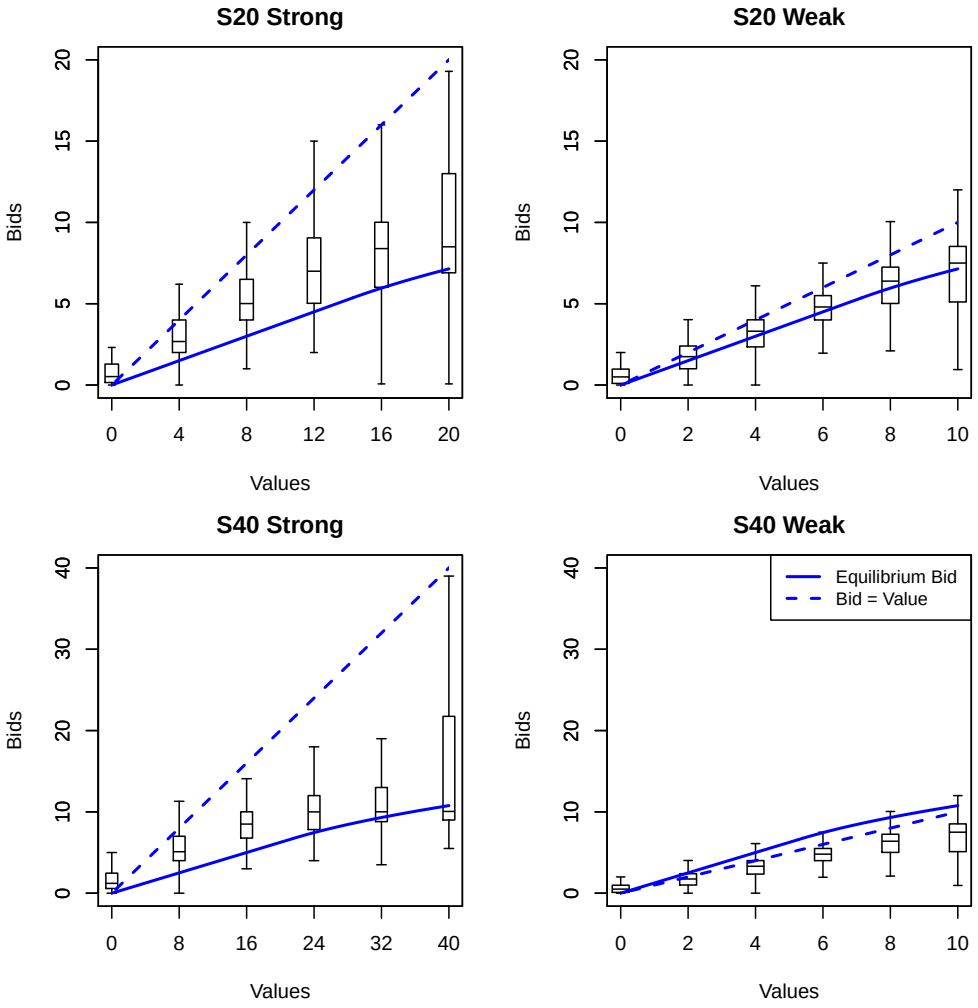

Figure 3.3: Box plots of actual bids

each treatment using a Kolmogorov-Smirnoff (K-S) test. The null of equality of distributions is rejected at 1 percent probability for both cases resulting in rejection of symmetrization prediction (**TP2**).

In figure 3.3, we present the box plots for bids by player types under both treatments for different blocks of values. The horizontal lines inside the boxes represent median and the edges of boxes represent the middle fifty percent of observations. The whiskers extend to the most extreme point within 1.5 times the edges of a box. The solid lines are equilibrium bids and the dotted lines represent values equal to bids. Figure 3.3 confirms the above story as we see overbidding in all but one case, i.e., the weak type bidder in the S40 treatment. Notice also that the weak type bidders bid much closer to predictions under the S20 treatment. While the strong types overbid in general, their bids come closer to predictions for values around 30 under the S40 treatment.

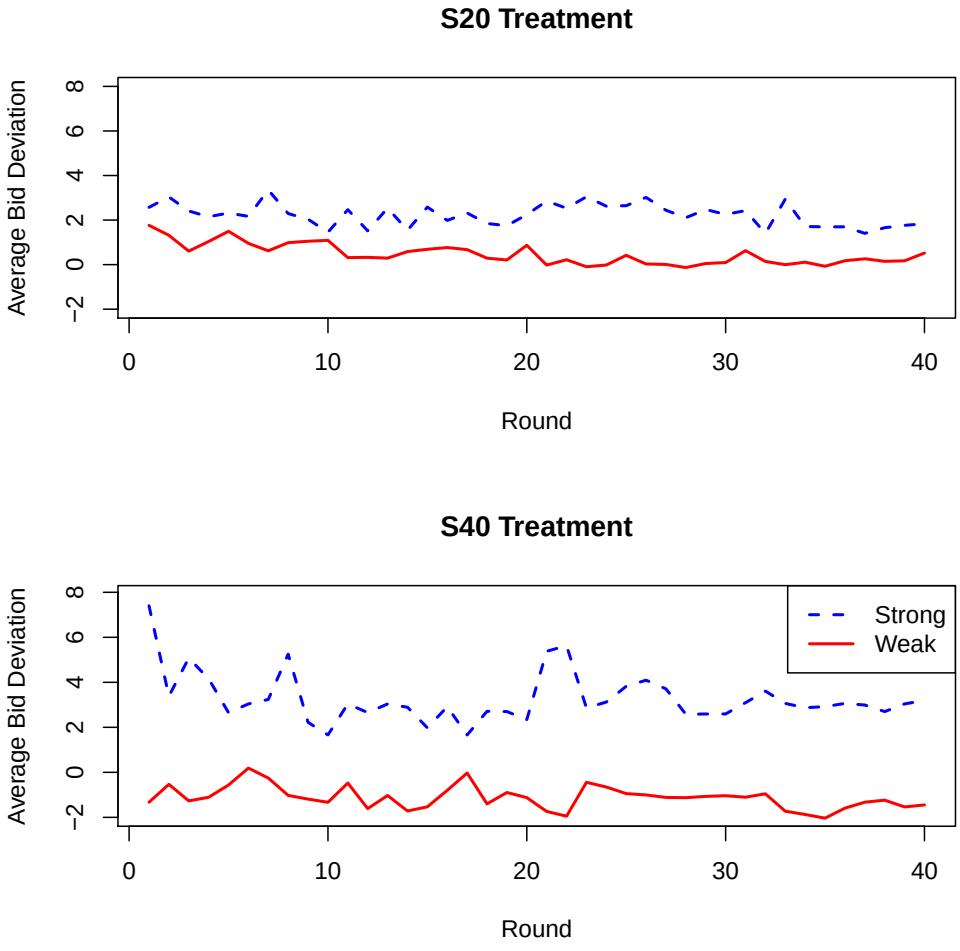

Figure 3.4: Average bid deviations across rounds

In figure 3.4, we present average bid deviations[10] over auction rounds for both the treatments. It corroborates our findings from the box plots as we see the strong bidder, on average, overbidding in both treatments. Overbidding is more pronounced in the S40 treatment. Notice a small spike around round 21 in the bid deviations indicating the switch in type. As for the weak bidder, the average bid deviations hover around zero in the S20 treatment implying bids closer to predictions. For the S40 treatment, the average bid deviations remain below zero for a majority of rounds indicating underbidding.

3.4.2 Descriptive statistics: Participant Sample

As mentioned in the earlier section, all the experimental participants answered a brief questionnaire following the auction game. We present below summary statistics of the participants in the S20 and S40 treatments. Overall, the majority of participants were male undergraduates from the disciplines of Engineering and Business/Finance. A majority were risk averse or risk neutral. About two thirds of participants in the S20 treatment had not previously participated in a real life auction whereas same proportion of participants in the S40 treatment had participated in a real life (including on-line) auction. When it came to the participation in an auction experiment, this experiment was the first experience for almost all. Lastly, about one third of participants' native language was different than English.

We compare bids by various demographic characteristics of the participants for the two regimes. Specifically, we present box plots (Figure 3.5 through 3.11) of actual bids by gender, previous participation, attitudes toward risk for both treatments and by major (Business and Finance vs. Other) for S20[11] treatment. For all the box plots, solid lines indicate equilibrium bids whereas dotted lines indicate

[10] Calculated as actual bid - predicted bid

[11] As seen in table 3.2, there aren't enough participants majoring in Business and Finance for the S40 treatment. Thus, we compare bids by major only for the S20 treatment

Table 3.2: Summary Statistics: Participant sample

	S20 Treatment	S40 Treatment
Gender		
Male	35	28
Female	15	18
Academic Level		
Undergraduate	46	35
Graduate	4	11
Major/Area of Study		
Physical Sciences	0	3
Engineering	14	11
Humanities	1	2
Social Sciences	5	9
Business and Finance	30	12
Life Sciences	0	7
Chemistry	0	2
Attitude toward risk		
Risk Neutral	15	15
Risk Averse	29	21
Risk Loving	6	10
Previous participation in real life auctions		
Yes	22	27
No	28	19
Previous participation in auction experiment		
Yes	2	3
No	48	43
English is participant's native language		
Yes	34	27
No	16	19
Total participants	50	46

bidding one's value.

Figures 3.5 and 3.6 compare bids by gender and bidder type for the S20 and S40 treatments respectively. For the S20 treatment, especially at higher value intervals, female participants seem to bid higher than their male counterparts under both types. For the S40 treatment, there isn't much difference in the bidding behavior with one exception. Male bidders with strong type overbid at values above 36 compared to the female bidders of the same type.

Figures 3.7 and 3.8 display the box plots for bids by type and by previous participation for the S20 and S40 treatment respectively. In the S20 treatment, bidders with no previous experience in auctions have more dispersed bids at higher values for both, weak and strong types. On the other hand, strong type bidders in the S40 treatment with previous experience bid higher exhibiting more variance than those without experience.

The next set of figures, figure 3.9 and 3.10 describe the bids under both treatments by player type and the reported attitude toward risk. RN stands for risk neutral whereas RA implies risk averse bidders. Generally speaking, risk averseness leads to overbidding (see, Holt, 1980; Harris and Raviv, 1981; Riley and Samuelson, 1981; Krishna, 2002) in first price private value auctions, as a risk-averse bidder puts more value on winning than a risk-neutral bidder. However, there is ambiguity in the effect of risk aversion in first price common value auctions (Levin et. al, 1996). While the importance of winning leads one to bid higher as in private value framework, the possibility of negative profits on winning pushes risk-averse bidders to bid lower. The final effect on bidding depends on which of the two forces prevails. The comparison of box-plots of RA-RN bidders by bidder type is reflective of this ambiguity. The weak types seem to bid similarly whether they are RN/RA implying a cancellation of the two forces mentioned above. For the strong types, the latter factor dominates leading to relatively lower bids for RA bidders than RN bidders.

Lastly, we compare bids for participants by reported major of study depicted in figure 3.11. We isolate the participants with Business/Finance as their major from the participants with all other majors. For the weak type bidders, we do not find any significant differences by their major. However, the strong type bidders with business and finance as major bid higher displaying a larger variation in their bids compared to the strong type bidders from other majors.

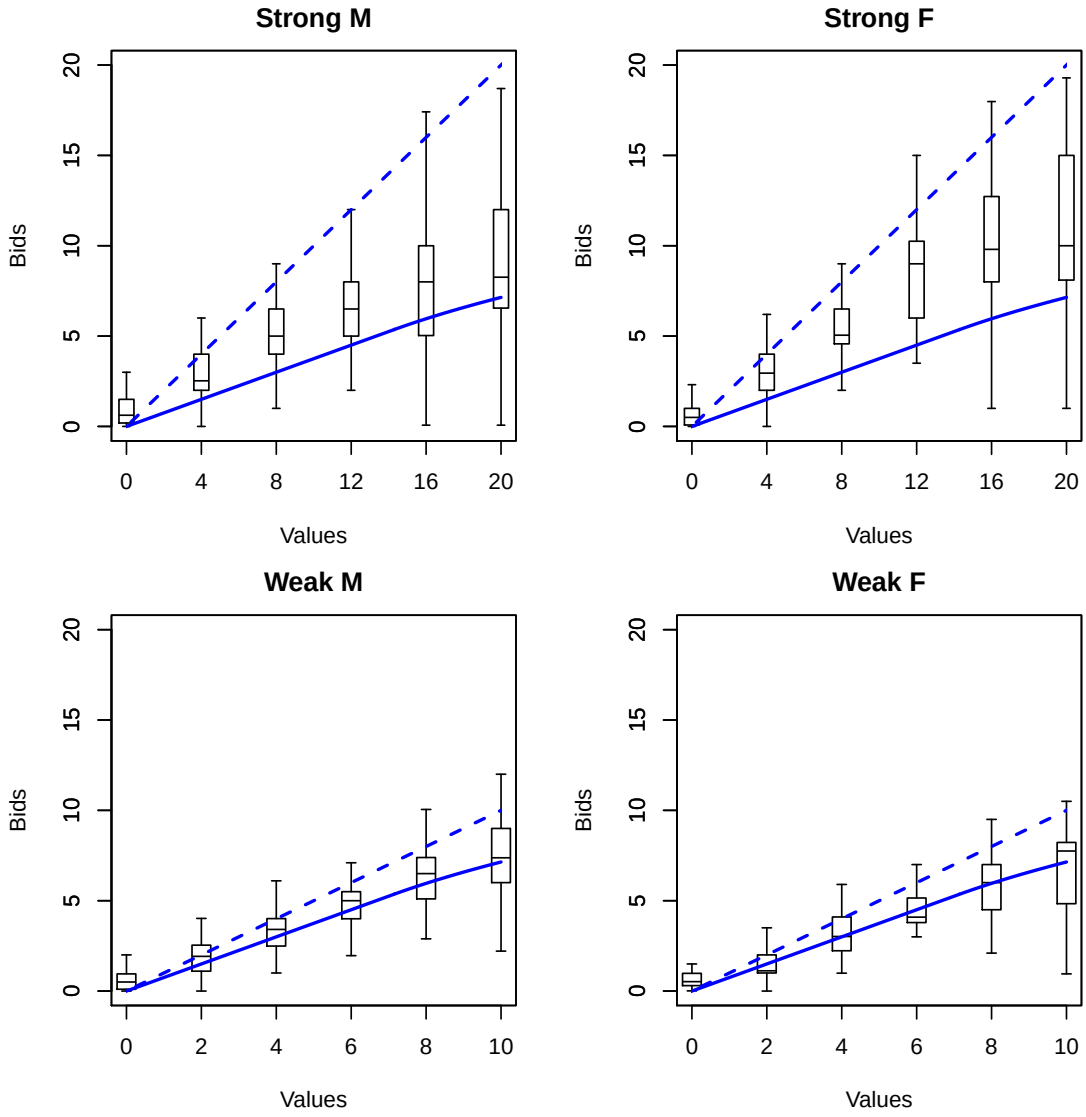

Figure 3.5: Box plots of actual bids by gender: S20 Treatment

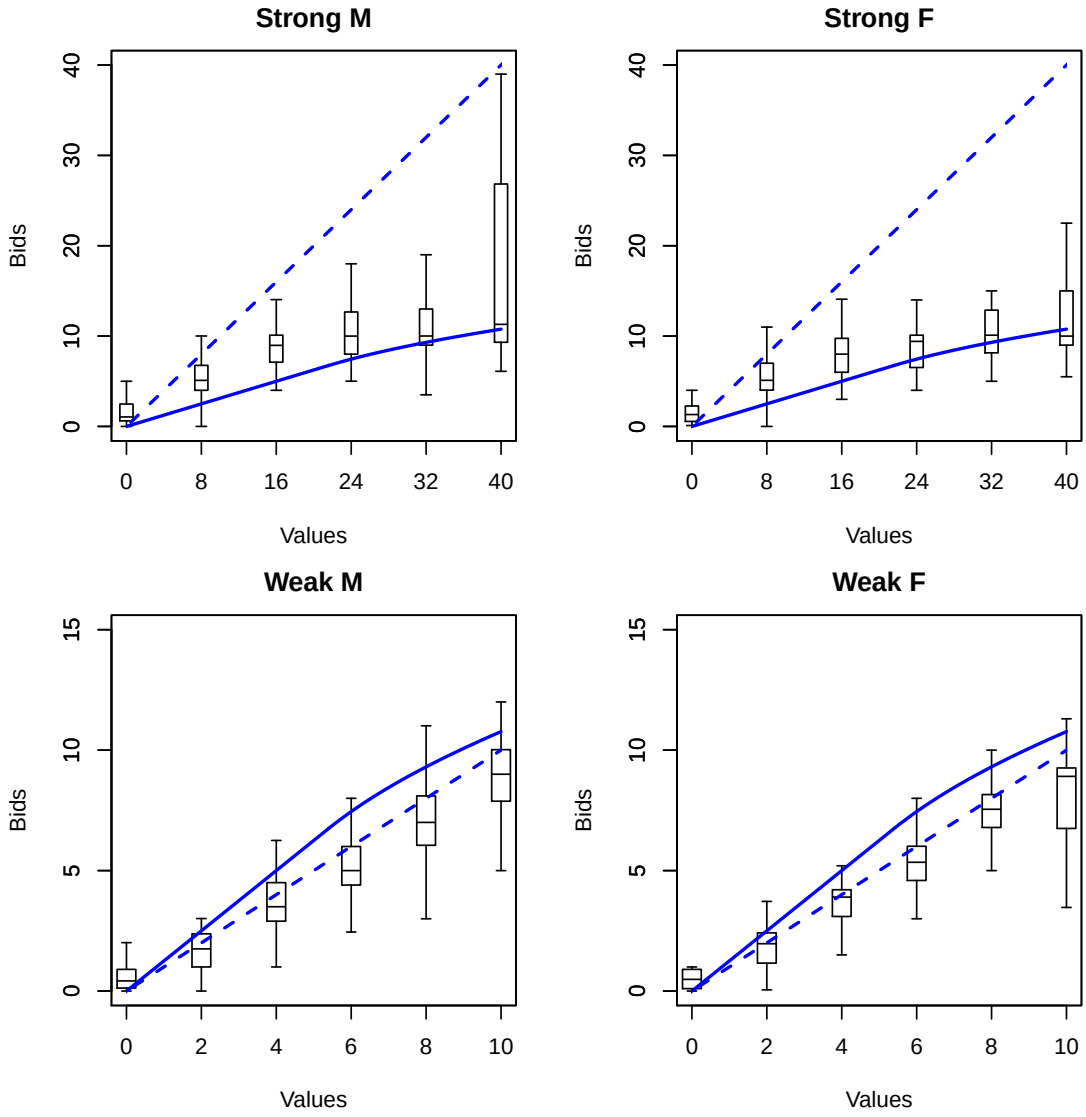

Figure 3.6: Box plots of actual bids by gender: S40 Treatment

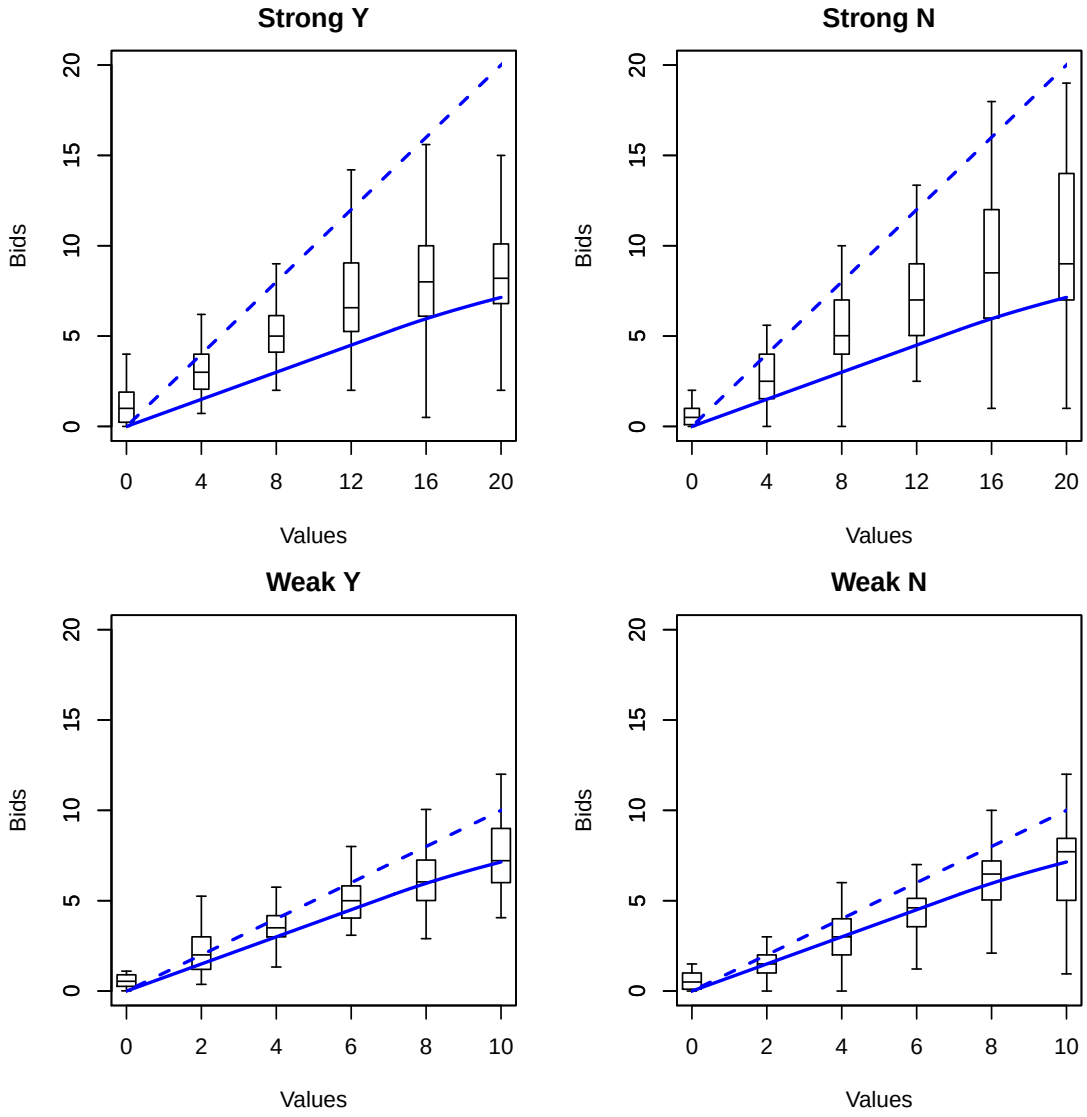

Figure 3.7: Box plots of actual bids by previous participation: S20 Treatment

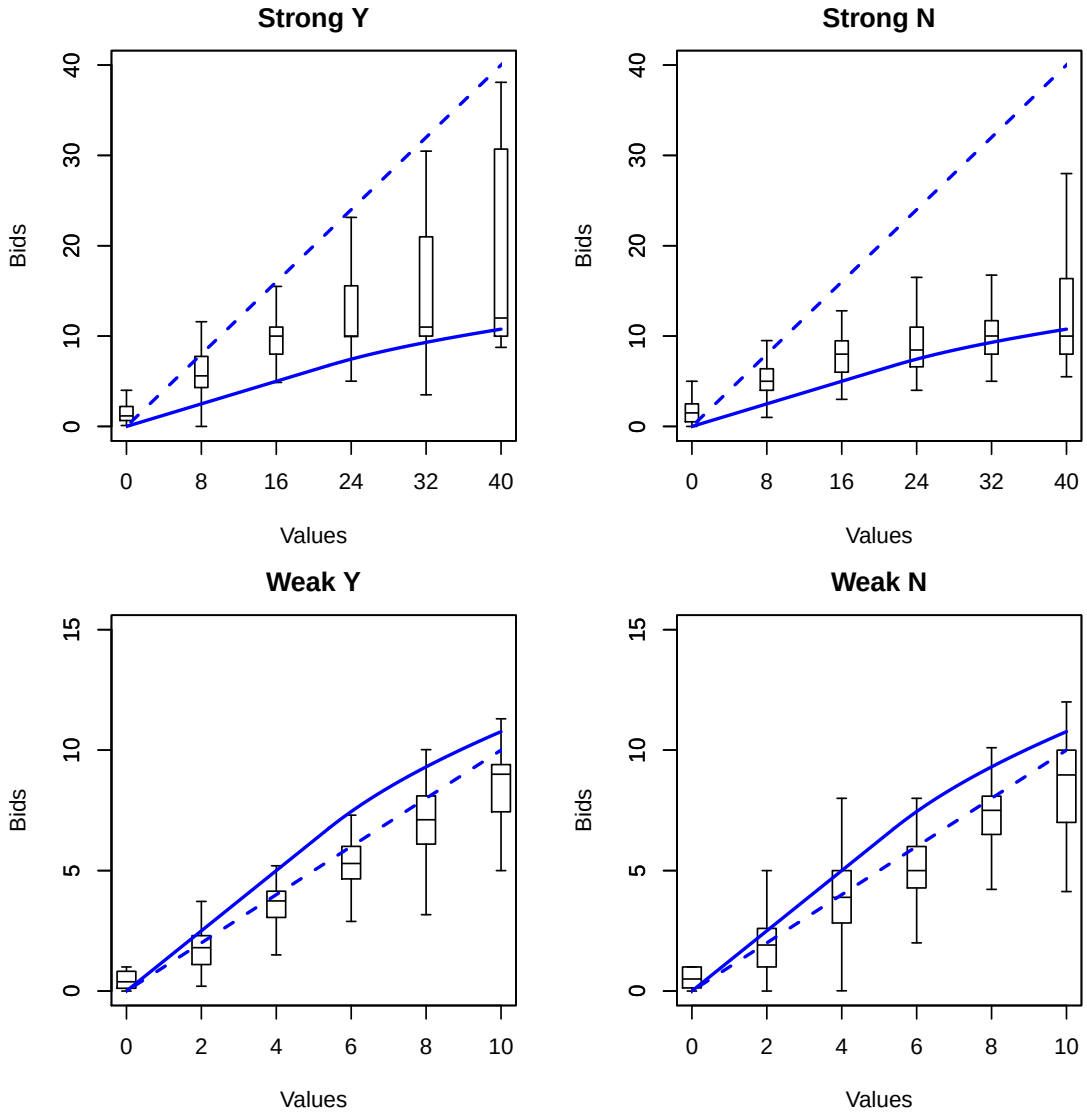

Figure 3.8: Box plots of actual bids by previous participation: S20 Treatment

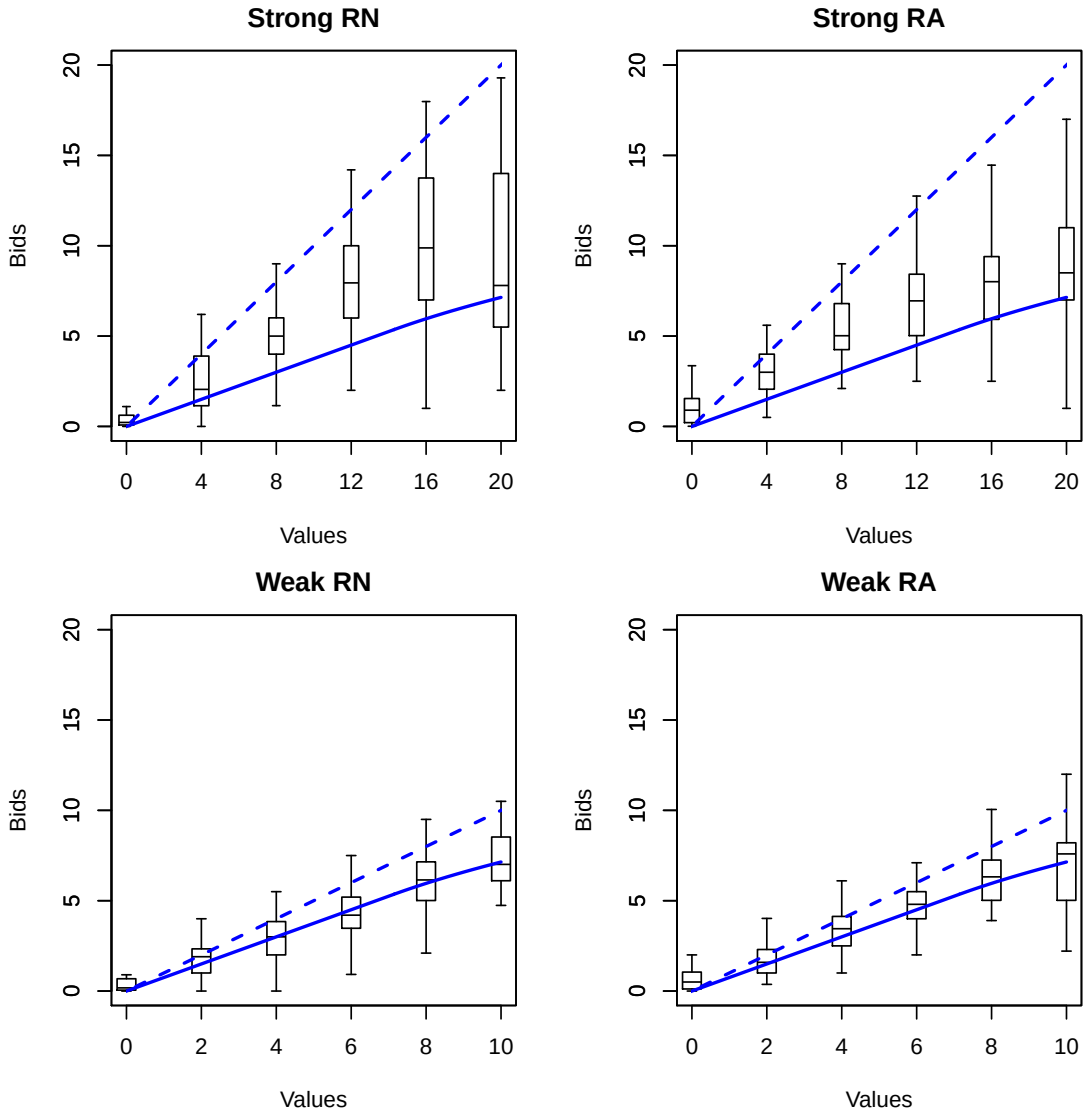

Figure 3.9: Box plots of actual bids by risk attitudes: S20 Treatment

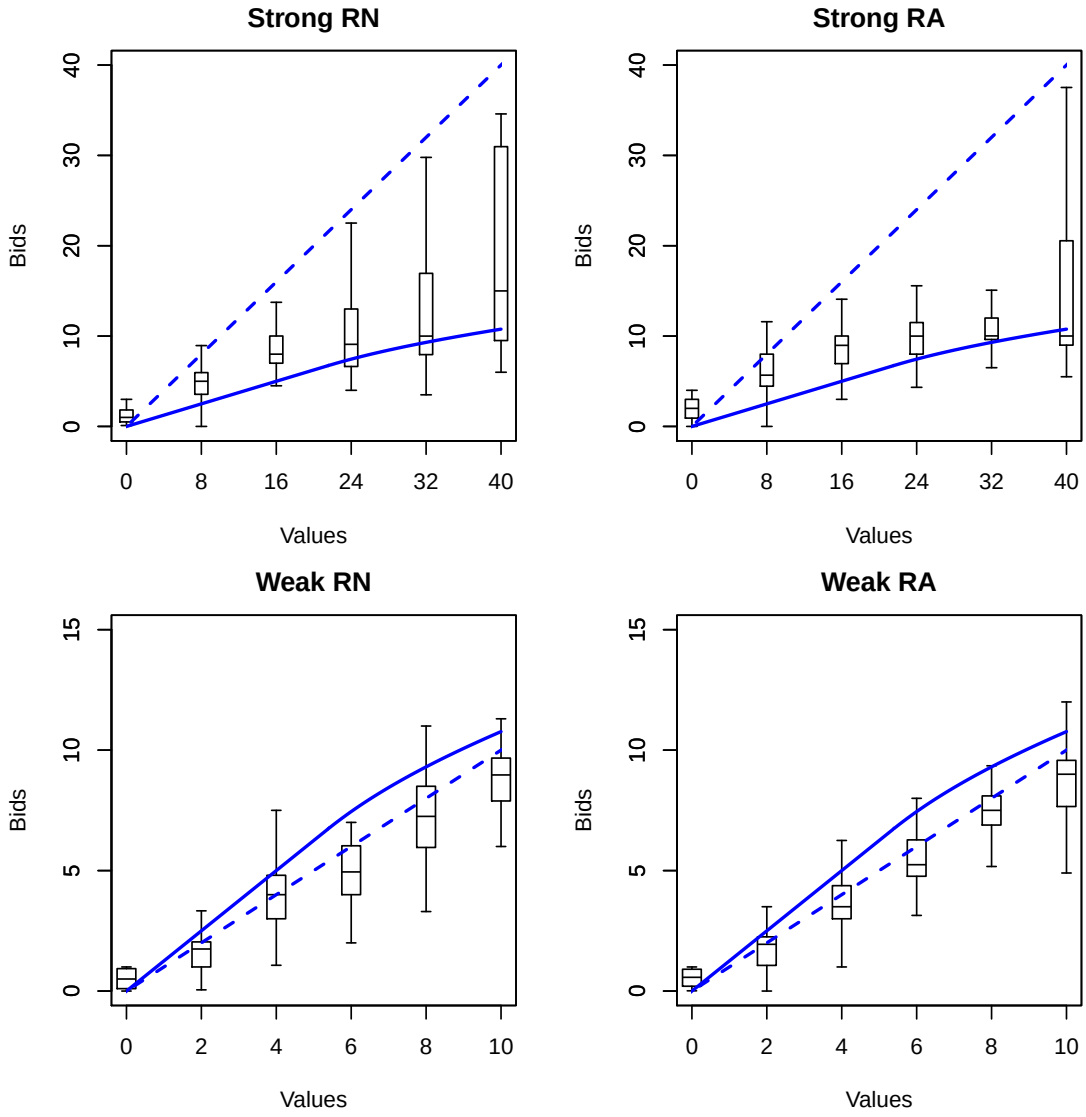

Figure 3.10: Box plots of actual bids by risk attitudes: S40 Treatment

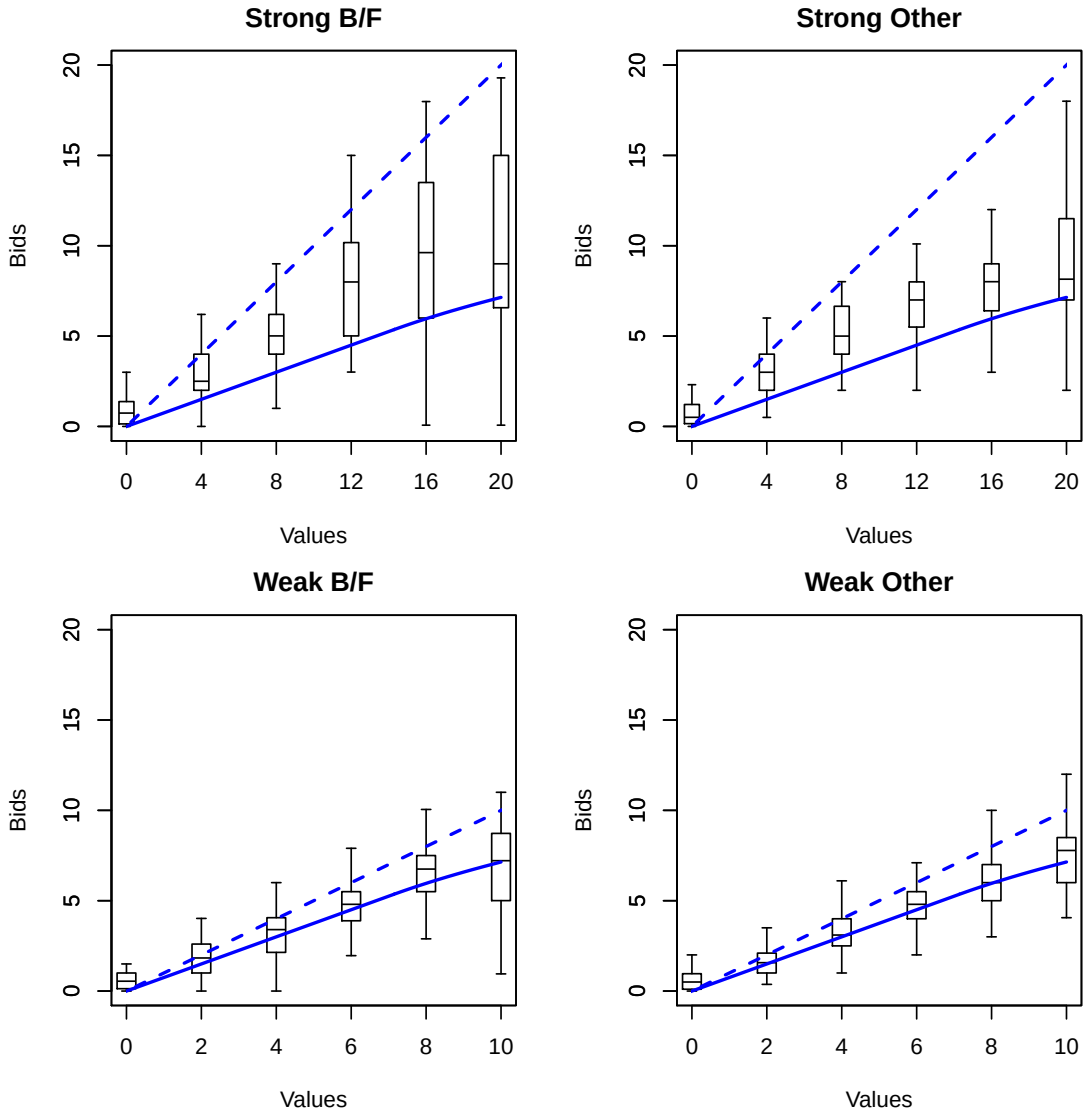

Figure 3.11: Box plots of actual bids by major of study: S20 Treatment

3.4.3 Key Statistics Across Resale Regimes

In table 3.3, we present the comparison[12] of key statistics that provides evidence to test **TP1**. The statistics include average (first-stage) bids, average resale (second stage) prices (conditional on trade in second stage) and two measures of interim (first stage) and final efficiencies. While the first two statistics are obvious, the efficiency measures require elucidation.

Under the first measure of efficiency, we consider the ratio of instances where a person with higher valuation wins the auction stage to the total number of auction instances to arrive at interim efficiency (IE-1). Final efficiency under this measure (FE-1) consists of the ratio of instances where the person with high valuation ends up owning the item at the end of the resale stage to total number of auctions.

Another popular measure of efficiency that we consider gives an account of surplus lost in terms of value instead of mere number of instances. Under this measure, the interim efficiency (IE-2) is the average value of the ratio of first stage winner's value to the maximum of the two players' values. Similarly, final efficiency (FE-2) is the average value of the ratio of the value of item's owner at the end of the second stage to the maximum of the two players' values.

As seen in table 3.3, the average bids and resale prices for DA regime are slightly lower than both, the monopoly and monopsony resale regimes in the S20 treatment. For the S40 treatment, while the average bids and resale prices for DA are in between those from the monopoly and monopsony regimes the DA values are closer to monopsony values in all cases. It indicates greater bargaining power exploited by the buyer even though the DA offers equal bargaining power in theory to buyer and seller in the resale stage.

With regards to efficiency measures, we observe relatively higher interim effi-

[12]Values for monopoly and monopsony resale regime are reported in Jog and Kosmopoulou (2012)

Table 3.3: Comparison of key statistics across resale regimes

Statistic	Monopoly S20	DA S20	Monopsony S20
Avg Bid (all rounds)	5.73	5.07	5.10
Avg Bid (Last 10 Rounds)	5.62	4.87	5.03
Avg Resale Price	8.51	6.70	6.78
Actual Interim Eff. (IE-1)	80.71	82.28	80.11
Actual Final Eff.(FE-1)	90.80	86.88	90.42
Actual Interim Eff.(IE-2)	91.37	92.83	91.73
Actual Final Eff.(FE-2)	96.40	96.57	96.91
Statistic	Monopoly S40	DA S40	Monopsony S40
Avg Bid (all rounds)	8.48	6.98	6.34
Avg Bid (Last 10 Rounds)	7.78	6.61	6.04
Avg Resale Price	10.88	9.46	8.17
Actual Interim Eff. (IE-1)	77.03	86.19	79.25
Actual Final Eff. (FE-1)	87.96	91.30	92.78
Actual Interim Eff. (IE-2)	85.66	92.87	89.34
Actual Final Eff.(FE-2)	93.64	95.76	97.34

DA: Double auction. All the efficiency values are in percent.

ciency under the DA compared to the monopoly and monopsony regimes for both treatments. It is true for both efficiency measures, IE-1 and IE-2 under both treatments. This is consistent with the analysis of bidding behavior where we observed the inclination of strong bidders towards acquiring the item by overbidding in the initial stage and avoid any trade in the resale stage. The final efficiency values (FE-1) for both treatments indicate relatively lower amount of trades in the resale stage. Final efficiency values in terms of lost surplus (FE-2) for the DA fall in between its monopoly and monopsony counterparts for the S20 and S40 treatments providing a smoother transition across regimes. The upshot of this analysis is that we have limited evidence for supporting **TP1**. While the resale prices for both treatments and average bids for the S40 treatment under the DA regime fall between those under monopoly and monopsony resale, the average bids for the S20 treatment do not. Further, the DA values for bids and prices are relatively closer to monopsony values precluding a very smooth transition[13] as expected.

[13]We intend to carry out a few more sessions to generate more data points.

3.4.4 Bid Shading Across Resale Regimes

Next, we compare the extent of bid shading across the three resale regimes. In a first price auction, equilibrium bidding strategy implies some form of reduction or *shading* of bids from one's value (unlike the second price auction where bidding one's value is the dominant strategy). It follows from the description of equilibrium bidding strategies (figure 3.2) under the three resale regimes that the amount of bid shading[14] is identical under the three regimes for values in the first half of the value distribution of each bidder. Thereafter, the amount of bid shading under the DA lies between the monopoly and monopsony resale regimes for the rest of the value distribution for each bidder.

We present a comparison of average bid shading under the three resale regimes in table 3.4 by bidder types. The value intervals for each bidder in bold type are created to provide comparable sizes that divide the value distribution as equally as possible and account for non-linear part of equilibrium bidding strategies. The upper panel of the table presents results for the S20 treatment and the lower panel describes the same for the S40 treatment under all regimes. Overall, we find the average bid shading is increasing as expected across the value intervals for all three regimes with just two exceptions. While the average bid shading is higher for the weak bidder under the DA regime compared to the other two for the S20 treatment, it is closer to monopsony regime for the S40 treatment. In fact, notice that the amount of average bid shading remains almost same for the last two value intervals under the monopsony and DA regimes. Strong bidder, on average, never overbids under all regimes. For lower value interval (0-6.67), the strong bidder bids much closer to value leading to a much lower shading of bids than predicted under the DA regime for the S20 treatment. Apart from that case, we find the average bid shading

[14]Bid shading is defined as $\frac{v_i - b_i}{v_i}$ for a bidder $i$with value v_i and equilibrium bid b_i

Table 3.4: Bid shading across resale regimes

Weak Bidder			Strong Bidder		
0-3.34	**3.34-6.67**	**6.67-10**	**0-6.67**	**6.67-13.34**	**13.34-20**
S20 Monopoly					
-3.15(0.25)	-0.05(0.25)	0.10(0.25)	0.17(0.62)	0.32(0.62)	0.42(0.62)
S20 Monopsony					
-2.95(0.25)	0.08(0.25)	0.15(0.28)	0.30(0.62)	0.37(0.62)	0.52(0.64)
S20 Double auctions					
0-3.34	**3.34-7.14**	**7.14-10**	**0-6.67**	**6.67-14.28**	**14.28-20**
-1.73(0.25)	0.16(0.25)	0.21(0.26)	0.09(0.62)	0.36(0.62)	0.46(0.63)
Weak Bidder			Strong Bidder		
0-4	**4 - 7**	**7 - 10**	**0 - 16**	**16 - 28**	**28 - 40**
S40 Monopoly					
-5.52 (-0.25)	-0.24(-0.25)	-0.13(-0.25)	0.10(0.69)	0.48(0.69)	0.50(0.69)
S40 Monopsony					
-0.59(-0.25)	0.12(-0.15)	0.11(0.10)	0.37(0.69)	0.59(0.71)	0.64(0.77)
S40 Double auctions					
0-5.38	**5.38-7.5**	**7.5-10**	**0-21.5**	**21.5-30**	**30-40**
-0.68(-0.25)	0.09(-0.22)	0.08(-0.12)	0.24(0.69)	0.57(0.693)	0.60(0.71)

Theoretical predictions are in brackets.

under DA falling between its monopoly and monopsony counterparts. But the bid shading under DA is much closer to monopsony than the monopoly regime once again indicating the prevalence of buyer's bargaining power under the DA regime.

3.5 Conclusions

This chapter continued the study of bidding behavior under asymmetric auctions with resale by introducing a double auction framework in the resale stage where both, buyer and seller make offers. Following Cheng and Tan (2008), we derived equilibrium bidding and pricing functions for two bidders with values distributed uniformly over asymmetric intervals. While the theoretical predictions indicate

average bids and prices to fall between those from the monopoly and monopsony resale regime implying a smooth transition, the experimental evidence so far, does not support it. The resale prices for both treatments as well as average bids under the S40 treatment for the DA fall in between the monopoly and monopsony values. However, the bids and prices under the DA are closer to the monopsony values implying relatively a bit more bargaining power for the buyers in resale stage. These trends are consistent with the amount of average bid shading by each bidder. Strong bidders bid much higher than predictions leading to higher interim efficiencies and less number of trades in the resale stage.

Chapter 4

Emission Trading Schemes as Auctions with Resale

This chapter reviews emission trading schemes (ETS) as auctions with resale with particular reference to the Regional Greenhouse Gas Initiative (RGGI), one of the largest cap-and-trade schemes in the US. We hope to use the theoretical and experimental investigation of auctions with resale from the previous analysis to provide insights in understanding the workings of these schemes.

4.1 Background

Climate change is at the center of recent developments in energy and economic policy in the US. The principal cause of global warming is considered to be emissions of gases like Carbon Dioxide (CO_2), Methane (CH_4) and few others, collectively called as Greenhouse Gases (GHG). Fossil fuel consumption and electricity generation are two of the most polluting activities that contribute to GHG emissions.

In the last two decades, emission trading schemes (also known as cap-and-trade schemes) are seen to be a preferred choice over the traditional command and control approach to GHG emissions. The command and control approach emphasizes on regulating the firm/entity responsible for pollution at the source level followed by periodic inspections. Under this approach, the affected entity does not have much say in the process of reducing pollution nor any incentive to do more than what the regulator asks for. On the other hand, an emissions trading scheme (ETS henceforth) involves setting up specific performance targets (a Cap) for a specific class of emitters by a central agency and allocating emission permits to the affected entities. The emission permits are freely tradable among the entities; hence the market decides the best course of compliance strategies while the central agency keeps a strict record of total emissions. The main appeal of an ETS is the flexibility it

offers to affected sources to manage their emissions which is lacking in the command and control approach.

The Acid Rain Program (ARP) and Regional Greenhouse Gas Initiative (RGGI) in the United States, European Union Emission Trading Scheme (EUETS) are some of the most notable recent ETS from the last two decades. The major entities covered under these ETS are power plants that use fossil fuels for electricity generation. Most recently, the state of California has announced[1] a cap and trade scheme that is expected to cover major sources of GHG emissions in the state such as refineries, power plants, industrial facilities, and transportation fuels.

A typical ETS is characterized by two components: A primary market which allocates the allowances/permits to the entities in the first place and a secondary market where the entities trade the permits among themselves. Let us briefly describe the two components.

4.1.1 Primary Market

There are two ways in which the initial allowances are allocated to the affected entities. The first is called 'Grandfathering' where an entity receives emission permits free of charge, based on some measure of its past performance. A small part of the allowances may be auctioned off to kick off the market and ensure liquidity from time to time. The ARP and EUETS have employed this approach. Alternatively, the majority/all of the initial allowances can be auctioned off so that the interested entities have to bid for them. Countries in EUETS like UK have shown their inclination towards the auction allocation in the recent years. RGGI, which came into effect starting January 2009, has been auctioning off all allowances on a quarterly basis.

The issue of the method of initial allocation has been in discussion from quite

[1] http://www.arb.ca.gov/cc/capandtrade/capandtrade.htm

some time now (Cramton and Kerr, 2002). The grandfathering scheme is criticized on the basis of 'windfall profits' made by the affected entities. Although the entities like power companies get the allowances for free under grandfathering, they (the allowances) do have a market value and hence an opportunity cost. Hence, the companies treat the allowances as assets on their balance sheets and account for their 'usage' over time to justify an increase the price of final product. This phenomenon has been observed in the EUETS. It led to turn the public opinion at large against the ETS.

On the contrary, RGGI auctions in the United States have been contributing a sizable amount of revenue to the governments of the participating states. This revenue is used for strategic investments in the power sector to stimulate innovations as well as protect the consumers from possible excessive power prices. To quote RGGI, "States sell nearly all emission allowances through auctions and invest proceeds in consumer benefits: Energy efficiency, renewable energy, and other clean energy technologies. RGGI will spur innovation in the clean energy economy and create green jobs in each state."

4.1.2 Secondary Market

The secondary market helps to provide liquidity to the affected entities across the compliance period with respect to allowances. The method of primary allocation may be a one-time (grandfathering) or periodical (auctions) and hence it may contain fairly long time intervals between successive occurrences. The secondary market provides a platform to transact emission permits and allows entities to choose their plans with respect to the production process. i.e. they can buy/sell their share of allowances according to their need as well as the market direction. In other words, the prices in the secondary market provide correct incentives to the entities in managing their resources regarding future investments. Typically, the allowances are

traded on organized exchanges or through bilateral arrangements (also called over the counter or OTC) via standard financial products like futures and options. The trades occurred in the secondary market are notified to the central agency keeping a tab on all the allowances in the scheme through a registry. Having described the nature of two markets in an ETS; we describe the Regional Greenhouse Gas Initiative to get a sense of how an ETS has worked in the real world.

4.2 RGGI

The Regional Greenhouse Gas Initiative is the first mandatory ETS in the US that limits CO2 emissions from electric power generators using fossil fuels. The participating states[2] are Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont as seen in the following figure. RGGI covers about 225 fossil fuel-fired electric power plants of 25 megawatts (MW) or greater in size from the above region. The program consists of two three-year compliance periods. The first compliance period began on January 1st, 2009 and ended on December 31st, 2011. The second compliance period runs from January 1st, 2012 through December 31st, 2014. The emission levels are capped to 2009 level and then will be lowered 2.5 percent each year starting in 2014 to achieve a total of 10 percent reduction by 2018. The method of initial allocation for RGGI is primarily through quarterly auctions held in the months of March, June, September and December of each year. The auction format is single-round, uniform-price, sealed bid auction with a reserve price that is indexed to inflation. The participating power plants can use allowances issued by any participating state in the program to comply with its individual state program. The allowances have no expiration date and are bankable for use in future.

[2]New Jersey left the program in December 2011. It is not a part of the second control period.



Figure 4.1: RGGI: Participating states

The secondary market for RGGI allowances consists of trading the actual allowances and its financial derivatives via standard futures, forwards and options contracts. These transactions are either on a *public* exchange such as Chicago Climate Futures Exchange (CCFE) or *over the counter* (OTC) when they are not traded on a public exchange but negotiated between two interested parties directly.

4.3 Overview of RGGI Results

There have been sixteen auctions so far for the RGGI CO_2 allowances. In Table 4.1, we present the amount of allowances offered, percentage of offered allowances sold along with the clearing and reserve prices for each auction.

Table 4.1: RGGI allowance auctions: Overview

Auction	Control period	Allowances Offered	Allowances % Sold	Clearing price($)	Reserve price($)
1	1	12,565,387	100.00	3.07	1.86
2	1	31,505,898	100.00	3.38	1.86
3	1	31,513,765	100.00	3.51	1.86
	2	2,175,513	100.00	3.05	1.86
4	1	30,887,620	100.00	3.23	1.86
	2	2,172,540	100.00	2.06	1.86
5	1	28,408,945	100.00	2.19	1.86
	2	2,172,540	100.00	1.87	1.86
6	1	28,591,698	100.00	2.05	1.86
	2	2,172,540	73.60	1.86	1.86
7	1	40,612,408	100.00	2.07	1.86
	2	2,137,992	97.80	1.86	1.86
8	1	40,685,585	100.00	1.88	1.86
	2	2,137,993	100.00	1.86	1.86
9	1	45,595,968	75.46	1.86	1.86
	2	2,137,992	61.37	1.86	1.86
10	1	43,173,648	57.34	1.86	1.86
	2	2,137,991	54.82	1.86	1.86
11	1	41,995,813	100.00	1.89	1.89
	2	2,144,710	100.00	1.89	1.89
12	1	42,034,184	29.83	1.89	1.89
	2	1,864,952	50.56	1.89	1.89
13	1	42,189,685	17.75	1.89	1.89
	2	1,864,951	0.00	–	1.89
14	1	42,983,482	63.50	1.89	1.89
	2	1,864,951	0.00	–	1.89
15	2	34,843,858	61.87	1.93	1.93
16	2	36,426,008	57.49	1.93	1.93

As seen from the table, the clearing price for both control periods has an over-

all declining trend after an initial increase for the first three auctions. Auction 8 onwards the clearing price is the same as the reserve price for both control periods clearly indicating excess supply of allowances relative to the demand. It is consistent with the percentage amount of allowances sold out of total offered allowances through the same period. While initial auctions show a hundred percent of offered allowances being purchased, the later auctions exhibit much less enthusiasm on the bidders part. Overall, in the first control period about 411 million allowances were sold through auctions generating revenues for the participating states to the tune of $952 million[3].

The market monitor reports indicate a similar trend for the secondary market prices during the first compliance period. The average CCFE futures contract price decreased from about $5 in September 2008 to slightly above $3 in December 2009. The decline in futures price continued though the next two years with little fluctuation ending close to $2 in December 2011. RGGI defines *compliance entities* as firms that own fossil fuel-fired electricity generating plants with 25MW or more of capacity. They comprise of all the participating entities to RGGI and hold about 98 percent of the allowances by January 2012. The *non-compliance entities* comprising mainly of banks and hedge funds acquired as much as 14 percent of allowances over the first control period through auctions but held only 2 percent by the end of January 2012 as they sold out most of their holdings on the secondary market. Average daily volume of trading is an indicator of trading activity in the secondary market. For CCFE listed futures contracts of RGGI, the average daily volume was 2.7 million in 2009. It fell drastically to 0.2 million in 2010 and further to 0.03 million in 2011 indicating a very sluggish secondary market for CO_2 allowances.

[3]Market monitor report May, 2011.

4.4 Relation to Theory

A cap and trade scheme like RGGI with explicitly defined primary and secondary markets fits well into the framework of auctions with resale opportunities. The CO_2 allowances enter the primary market via auctions and traded on the secondary market. Since the allowances have no expiration date, they can be thought of as durable goods perfectly transferable between entities. The allowances completely exit the market only when they are "turned in" to the regulatory authority by a compliance entity to cover its emissions. Allowances that are retired in this way can not reenter the market.

Among the two major groups of buyers of allowances, the non-compliance entities can be thought of as having a 'speculative' motive[4] behind their purchases. Aside from a few environmental/cause oriented institutions, the majority of non-compliance entities purchase the allowances in auctions with the sole purpose of reselling. The compliance entities, on the other hand, buy allowances mainly to cover their emissions. The course of auction clearing prices in the first control period indicate the initial interest of 'speculators' resulting in higher prices in first 4 auctions. However, over the course of the first control period, we see the downward trend of prices indicating a shift to buyer's market in the resale stage. Note that the majority of allowances are held by the compliance entities which can be taken as a reflection of higher efficiency[5]. This scenario falls closer to our description of monopsony resale regime in the previous chapters, wherein we would see lower auction and resale prices coupled with higher efficiency.

Looking forward to the second control period, we expect a shift in bargaining power as the prospect of a lowering cap can put an upward pressure on the allowance

[4]As described in Hafalir and Krishna (2008)

[5]In the sense of entities who value the item most end up possessing it. Unfortunately, we don't have access to firm level data to verify in a more precise manner.

prices. Hence, we expect some activity from non-compliance entities during the auctions that are coming up.

Chapter 5

Conclusions

This study investigated the effects of bargaining power in a secondary market on the bidding behavior in first price asymmetric auctions with resale using controlled experiments. The data was collected via computer based experiments that incorporated the essentials of theoretical setup. The undergraduate and graduate students from the University of Oklahoma, Norman participated in the experiments to provide data.

In the first essay, "Auctions with resale opportunities: An Experimental study", we compared the bidding behavior of bidders with asymmetric value supports between the auctions followed by monopoly resale (seller assumes all bargaining power) and monopsony resale (buyer assumes all bargaining power). Two treatments using different value support for the strong bidder were used. The experimental results indicate higher bidding under the monopoly resale regime compared to the monopsony resale regime for both treatments. Resale prices, conditional on trade in the second stage, are also higher under the monopoly resale regime. The observed efficiency levels are similar under both regimes. Using quantile regression analysis and controlling for bidder specific and auction specific characteristics, we find some evidence for bid symmetrization only under the monopsony resale regime.

The second essay, "Bargaining in Auctions with Resale", extended the resale stage setup to a double auction (DA) environment wherein the bargaining power is equally divided between the buyer and seller. The treatments employed in this experimental setup were in line with those in the earlier essay to maintain consistency in comparing the results. The bids and prices under the DA regime were found closer to their monopsony counterparts. While strong bidders bid much higher than predictions, weak bidders bid relatively closer to predictions leading to higher in-

terim efficiencies and less number of trades in the resale stage. We compared the bids by participant characteristics such as major of study, previous participation in real life auctions, attitudes toward risk and gender to find no significant difference in bidding.

Finally, we conclude the analysis by having a look at the emission trading schemes (ETS) in the light of theoretical framework derived for auctions with resale, with particular reference to the Regional Greenhouse Gas Initiative (RGGI). Recent trends in the allowance auction prices for RGGI indicate a transition from monopoly resale regime to monopsony resale regime with low and stable auction prices for the last few auctions. As the restrictions on total allowed emissions are set to increase, we expect to see a revived interest by non-compliance entities in purchasing allowances and thereby pushing up the allowance prices.

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Appendix A

A.1 Equilibrium Bid Distributions under Monopsony Resale

Our setup is the same as in Hafalir and Krishna (2008). There are two risk neutral bidders, bidding in an auction with the possibility of resale having no liquidity constraints. Bidder i's private value is drawn from a *regular* distribution with virtual valuation equal to $x_i - \frac{1-F_i(x)}{f_i(x)}$, that is increasing in x. Given this setup, resale happens invariably from the weak to the strong bidder. The idea that converts this two stage game into a single stage equivalent auction is the symmetrization property. Due to the regularity condition and its uniquely defined resale structure, the first price asymmetric auction with resale becomes a first-price symmetric auction, wherein bidders draw values from a common distribution (Hafalir and Krishna, 2008). This common distribution can be obtained from the bidders' value distributions without any knowledge of the equilibrium bidding strategies. The equivalence of the two auctions implies equivalence of bids and pricing strategies. Given F_s and F_w, the value distributions for strong and weak bidder respectively, and assuming that $F_s(x) < F_w(x)$ for all x, the first price asymmetric auction with resale (FPAR) characterized by the following system of differential equations

$$\frac{d}{db} lnF_k[\phi_k(b)] = \frac{1}{p(b) - b} \qquad \phi_k(0) = 0 \qquad \phi_k(\bar{b}) = a_k \qquad \forall k = s, w \tag{A.1}$$

is the same as a first price symmetric auction without resale (FPWR) characterized by

$$\frac{d}{db} lnF[\phi(b)] = \frac{1}{\phi(b) - b} \tag{A.2}$$

where $F(.)$ is the common distribution derived from F_s and F_w defined over $[0, \bar{p}]$. With $\bar{p}$ as the upper bound of the price in the resale stage, we derive $\bar{b}$, the highest bid and then we can solve for bidding functions from the system of differential equations in (2.4).

The problem under the monopsony regime can be tackled in a similar way. For the purpose of exposition, we refer to weak bidder as "he" and strong bidder as "she" in the following discussion. Note that the weak bidder does not have any control over the resale price. He can only accept or reject the offer made by his opponent. The strong bidder knows her own bid, her private value, and the upper bound of the weak bidder's value distribution. Recall that the weak bidder's value distribution is $[0, a_w]$ and $a_w < a_s$, by assumption. Hence, it will be suboptimal to offer anything above a_w since all offers above this threshold are strictly dominated. Therefore, the resale price will be drawn from an interval $[0, a_w]$, which is the same as the weak bidder's value distribution. Using the idea of equivalence, and given F_s and F_w with $F_s(x) < F_w(x)$ for all x, the first price asymmetric auction with resale (FPAR) characterized by the following system of differential equations

$$\frac{d}{db} lnF_k[\phi_k(b)] = \frac{1}{r(b) - b} \qquad \phi_k(0) = 0 \qquad \phi_k(\bar{b}) = a_k \qquad \forall k = s, w \tag{A.3}$$

is equivalent to a first price symmetric auction without resale (FPWR) characterized by

$$\frac{d}{db} lnF_w(.) = \frac{1}{\phi(b) - b} \tag{A.4}$$

with $F_w(.)$ the common distribution over $[0, a_w]$.

For $r \leq a_w$, the solution satisfies the system of differential equations

$$\frac{d}{db} lnF_k[\phi_k(b)] = \frac{1}{r(b) - b} \qquad \forall k = s, w \tag{A.5}$$

subject to the following boundary conditions:

$$\phi_k(0) = 0, \qquad \phi_s\left(\frac{a_w}{2}\right) = \frac{2a_w a_s}{a_w + a_s}, \qquad \phi_w\left(\frac{a_w}{2}\right) = \frac{2a_w^2}{a_w + a_s}.$$

For $r = a_w$, the solution satisfies the system of differential equations

$$\frac{d}{db} lnF_k[\phi_k(b)] = \frac{1}{a_w - b} \qquad \forall k = s, w \tag{A.6}$$

subject to the following boundary conditions:

$$\phi_s\left(\frac{a_w}{2}\right) = \frac{2a_w a_s}{a_w + a_s} \qquad \phi_w\left(\frac{a_w}{2}\right) = \frac{2a_w^2}{a_w + a_s}$$

$$\phi_s\left(\frac{a_w a_s}{a_w + a_s}\right) = a_s \qquad \phi_w\left(\frac{a_w a_s}{a_w + a_s}\right) = a_w.$$

A.2 Questionnaire

Please answer the following questions while we calculate your payments for today's session. Please note that the answers to these questions have no relation to your payments. The payments were determined by your performance in the rounds of auctions you just played.

1. Please indicate your gender.
   - M
   - F
2. Select the area of education that best depicts your major.
   - PHYSICAL SCIENCES
   - ENGINEERING

- HUMANITIES
- SOCIAL SCIENCES
- BUSINESS & FINANCE
- LIFE SCIENCES

3. Please select if you are a graduate or an undergraduate student.

   - GRADUATE
   - UNDERGRADUATE

4. Have you participated in real life auctions before (like eBay/amazon or charity auctions)?

   - YES
   - NO

5. Have you participated in an auction experiment before?

   - YES
   - NO

6. Suppose you have to choose between the following three options:

   A GETTING 10 RUCHMAS FOR SURE

   B GETTING 20 RUCHMAS OR NO RUCHMAS BASED ON THE TOSS OF A FAIR COIN

   C I AM OKAY WITH EITHER A OR B

   What will you choose?

A.3 Instructions

This is an experiment regarding auctions. If you follow the instructions carefully, you might earn money that will be credited to your sooner sense account. The participation is purely voluntary. If you decide to participate, you will get 65 *Ruchmas* (our experimental currency) that will serve as initial capital (or endowment) for you in addition to what you earn during the experiment. Ruchmas will be converted to Dollars at a rate of 13 *Ruchmas* = \$1. The expected duration of experiment is about 90 minutes. I am going to read out the instructions before we begin.

- You will act as a potential buyer bidding for 20 fictitious commodities sold in successive rounds.
- At the beginning of the experiment, a random flip of a coin will determine if you are going to be "Bidder type-U" or "Bidder type-P". Please note that your type will remain the SAME throughout the experiment.
- In each successive round, you will be matched with a different opponent who is NOT your type. [for example, if you are Bidder type-U, your opponent will always be a Bidder type-P and vice versa]
- Your opponent will change for each successive round but they will all be of the same type (and that is different than your type).
- In each round, the value of the commodity for a bidder type-U will be a random number up to two decimal places between 0.00 and 10.00 *Ruchmas* (that is, any value between 0.00 and 10.00 is equally likely). FIGURE 1 describes the likelihood of all possible values for bidder type-U. So your value is the result of a spin of the arrow attached to this wheel for every round.
- Similarly, in each round, the value of the commodity for a bidder type-P will be a random number up to two decimal places between 0.00 and 20.00 *Ruchmas* (that is, any value between 0.00 and 20.00 is equally likely). FIGURE 2

describes the likelihood of all possible values for bidder type-P. So your value is the result of a spin of the arrow attached to this wheel for every round.

- **To summarize, your type remains the same in today's session (it is either P or U) but your value may change in every round. Your value for each round is determined by a spin of the arrow. Please note that every spin is independent.**
- **You will be reminded of your type at the beginning of every new round.**
- Each round will have two stages: The Auction Stage and The Resale Stage. Here is how a typical round will proceed:

Figure 1: Value Distribution for BIDDER TYPE U

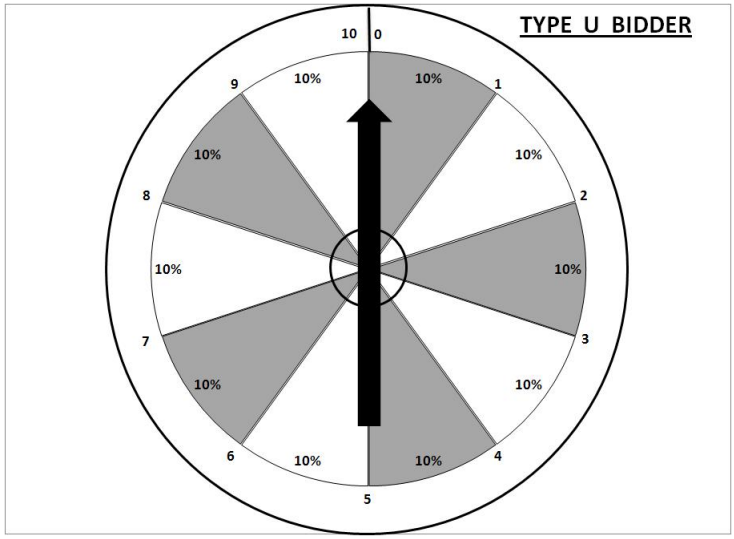
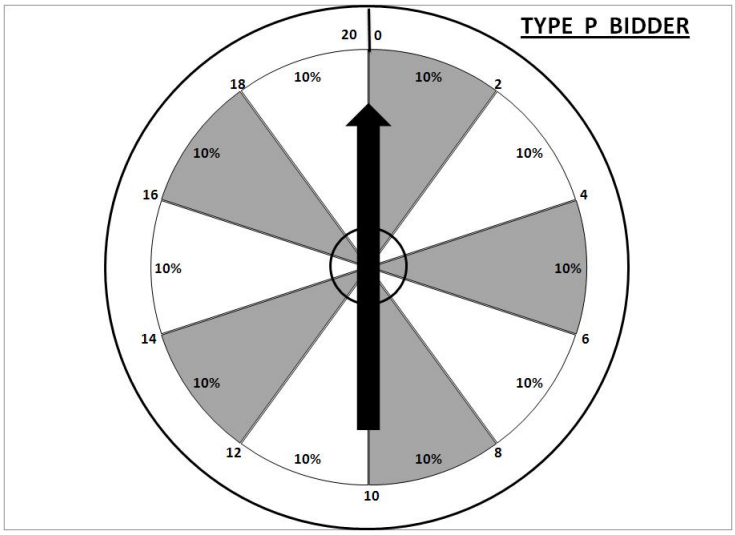


Figure 2: Value Distribution for BIDDER TYPE P



Stage I-The Auction Stage:

In this stage, every player will submit a bid for a fictitious commodity being sold at an auction.

- You will receive the information about *your value* only.
- After finding out your value for the commodity, you will begin by choosing a number or a *"bid"*. Please think carefully before you make your choice. You may use a calculator by clicking on the icon that will appear to the right hand side of your screen. You will have 45 seconds to make a decision. Your Opponent will also choose a bid at the same time. *Neither player can see his opponent's value or bid.*
- The person with the high bid will win the commodity being sold and pay his own bid as the price. In the case of a tie, a random coin flip will decide the winner.
- You will be informed whether you won the auction or not.
- The following schematic describes the auction stage and the interim payoff calculations.
- *Note that this is just the interim payoff.* The final payoff of a round will be determined at the end of stage II- the *Resale Stage*. It will begin *immediately* after the auction stage.

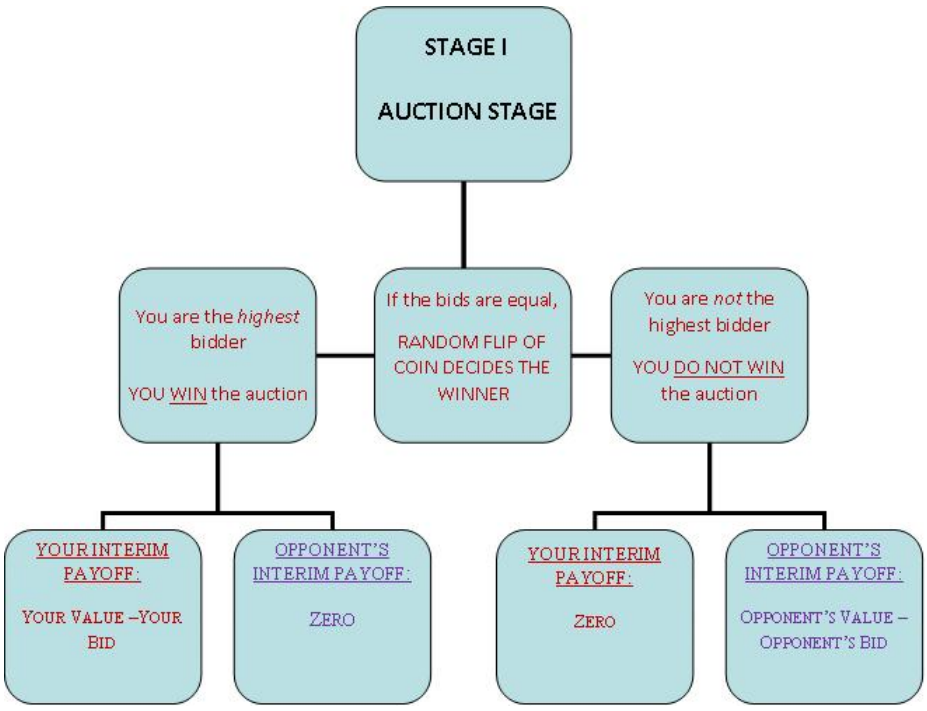


Figure 3: Interim Payoff Calculations

Stage II-The Resale Stage (Owner Makes An Offer):

In this stage, the bidder who **won the first stage** will have the opportunity **to resell** the commodity **to his opponent**. It works in the following way:

- The winning bidder can choose to make a *'take-it-or-leave-it'* offer to the opponent.
- If the winning bidder does not want to make an offer, he may quote a price of 9999 *Ruchmas*.
- If the offer is made and accepted, trade takes place and the owner will receive the difference between the offer and his first stage bid. The opponent will receive the difference between his value and the offer.
- If the offer is rejected (or is 9999) there will be NO trade in the second stage. So, the first stage winner will keep the commodity and receive the difference between his value and the first stage bid. The opponent will receive nothing for that round.
- The following schematic describes the course of the second stage where the owner makes an offer:
- This will conclude a typical round and a new round will begin with Stage I as described earlier.
- The total earnings for a player will be equal to the **SUM** of all final payoffs from each round. The dollar amount to be credited on your sooner sense account will be calculated on the basis of the conversion rate mentioned earlier.
- Are there any questions at this stage? Please feel free to ask before we begin.

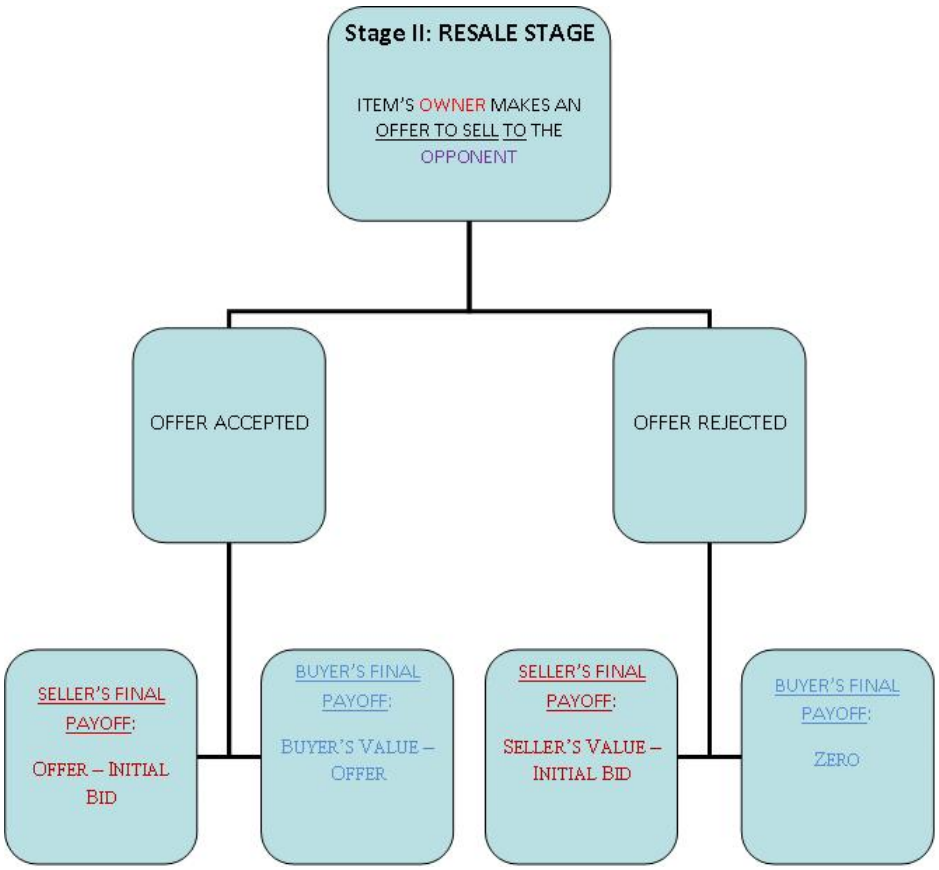
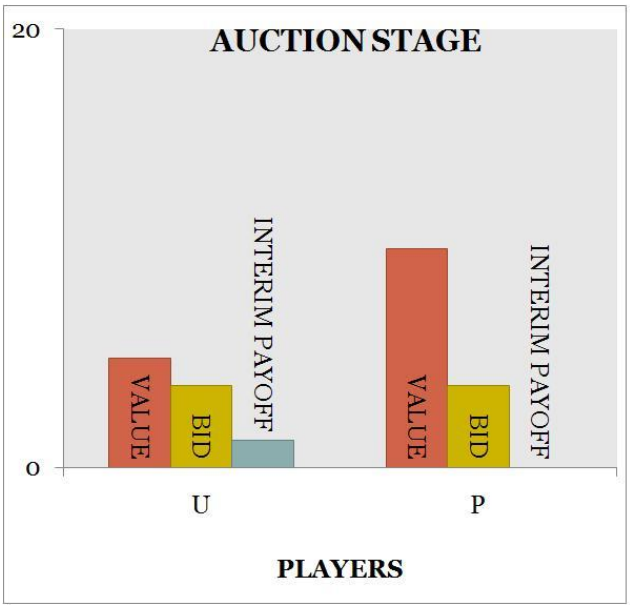


Figure 4: Resale Stage Payoff

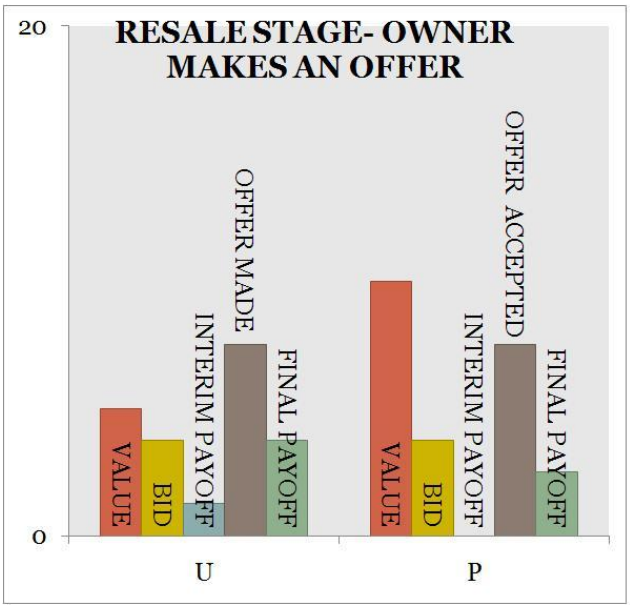
- The following graphical example will show how a *typical* round will proceed:



SINCE THE BIDS ARE EQUAL, TOSS OF A FAIR COIN DECIDES THE WINNER.

SUPPOSE THAT PLAYER 'U' WINS THE AUCTION STAGE.

THE SECOND GRAPH SHOWS THE RESALE STAGE WHEN **OWNER (U) MAKES AN OFFER**.



Stage II-The Resale Stage (Owner Receives An Offer):

In this stage, the bidder **who did not win the first stage** will have the opportunity **to buy** the commodity **from his opponent**. It works in the following way:

- The bidder **not** winning the first stage can choose to make a *'take-it-or-leave-it'* offer to the opponent.
- If he does not want to make an offer, he may quote a price of 0 (Zero) *Ruchmas*.
- If the offer is made and accepted, trade takes place and the owner will receive the difference between the offer and his first stage bid. The opponent will receive the difference between his value and the offer.
- If the offer is rejected (or is 0) there will be NO trade in the second stage. So, the first stage winner will keep the commodity and receive the difference between his value and the first stage bid. The opponent will receive nothing for that round.
- The following schematic describes the course of the second stage where the owner makes an offer:
- This will conclude a typical round and a new round will begin with Stage I as described earlier.
- The total earnings for a player will be equal to the **SUM** of all final payoffs from each round. The dollar amount to be credited on your sooner sense account will be calculated on the basis of the conversion rate mentioned earlier.
- Are there any questions at this stage? Please feel free to ask before we begin.

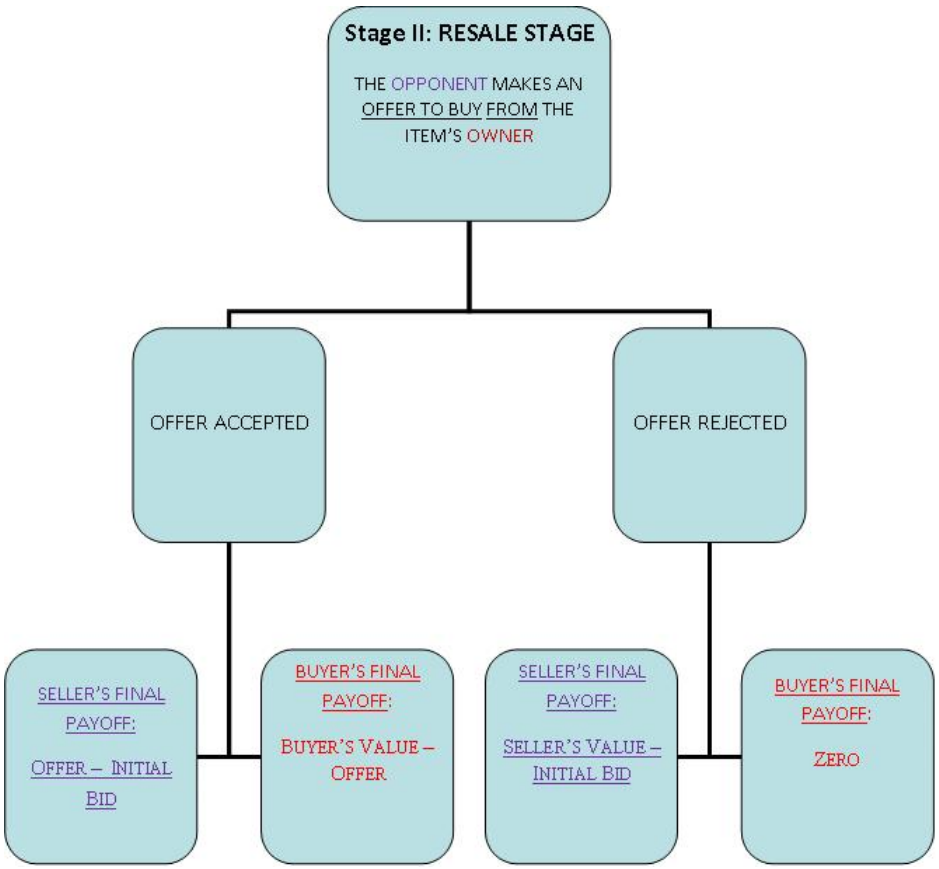
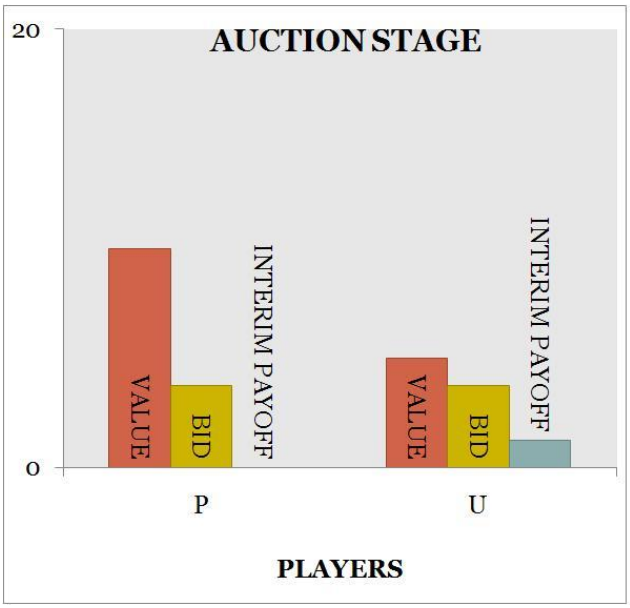


Figure 5: Resale Stage Payoff

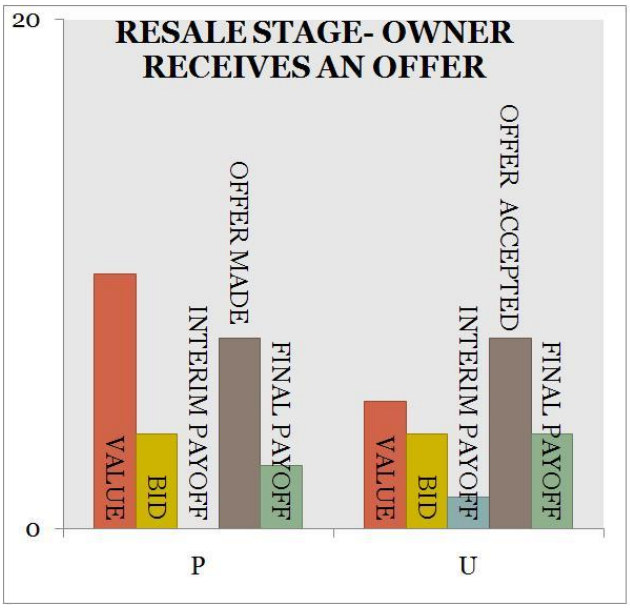
- The following graphical example will show how a *typical* round will proceed:



SINCE THE BIDS ARE EQUAL, TOSS OF A FAIR COIN DECIDES THE WINNER.

SUPPOSE THAT PLAYER 'U' WINS THE AUCTION STAGE.

THE SECOND GRAPH SHOWS THE RESALE STAGE WHEN **OWNER (U) RECEIVES AN OFFER**.



A.4 zTree: Screen-shots and code

Next, we present the screen-shots from z-Tree to give an idea of how the experiment appeared to the players. Final three figures present screen-shots of z-Tree code used to create the experiment.



Figure A.1: Opening Screen for Bidders declaring player type



Figure A.2: Bidding Screen for Auction Stage

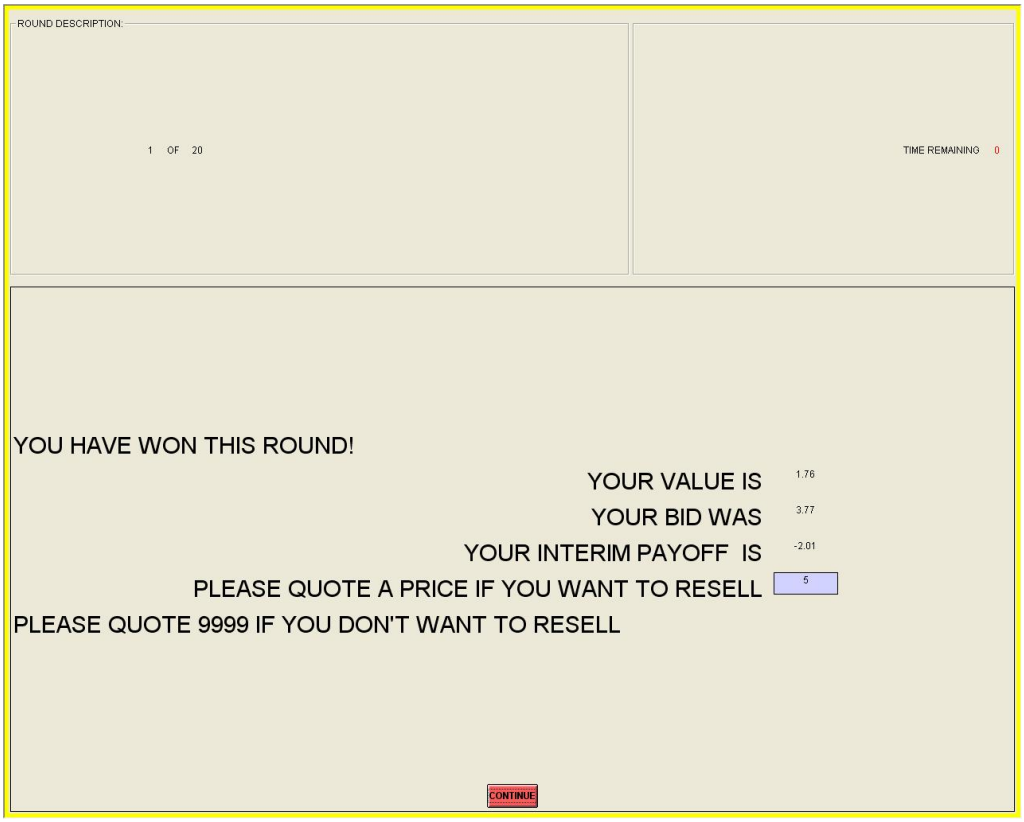


Figure A.3: Auction Stage Winner: Monopoly Resale



Figure A.4: Auction Stage Loser: Monopoly Resale

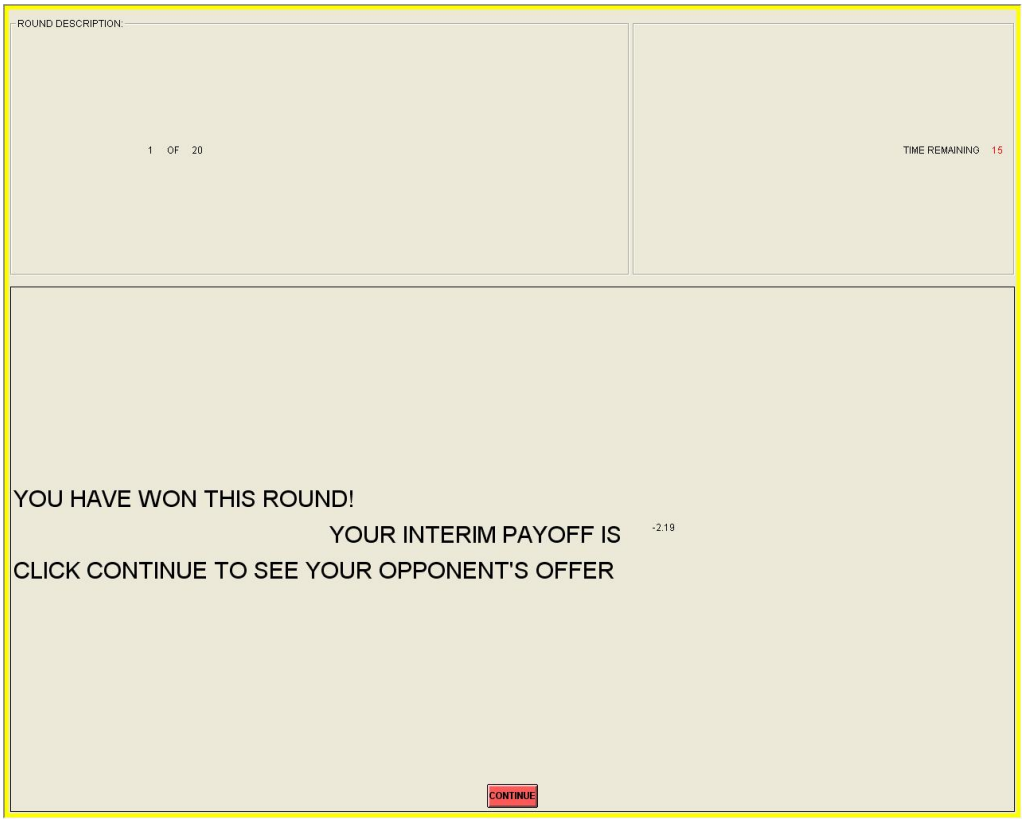


Figure A.5: Auction Stage Winner: Monopsony Resale



Figure A.6: Auction Stage Loser: Monopsony Resale

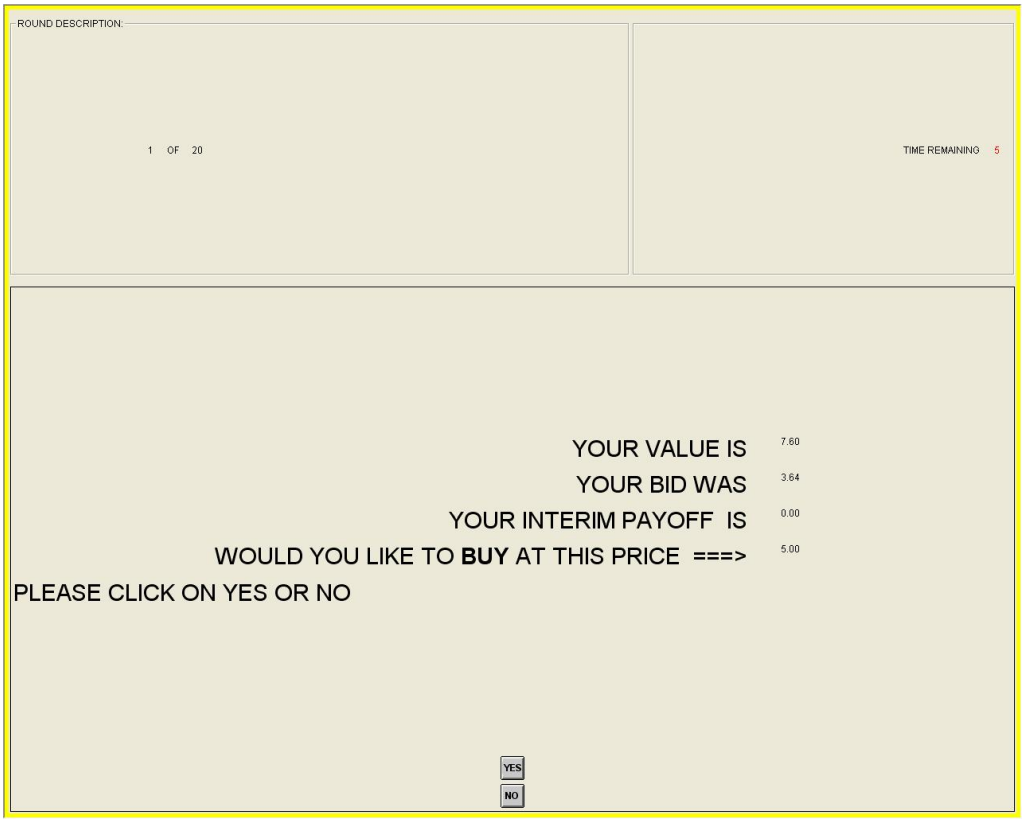


Figure A.7: Second Stage Offer: Monopoly Resale

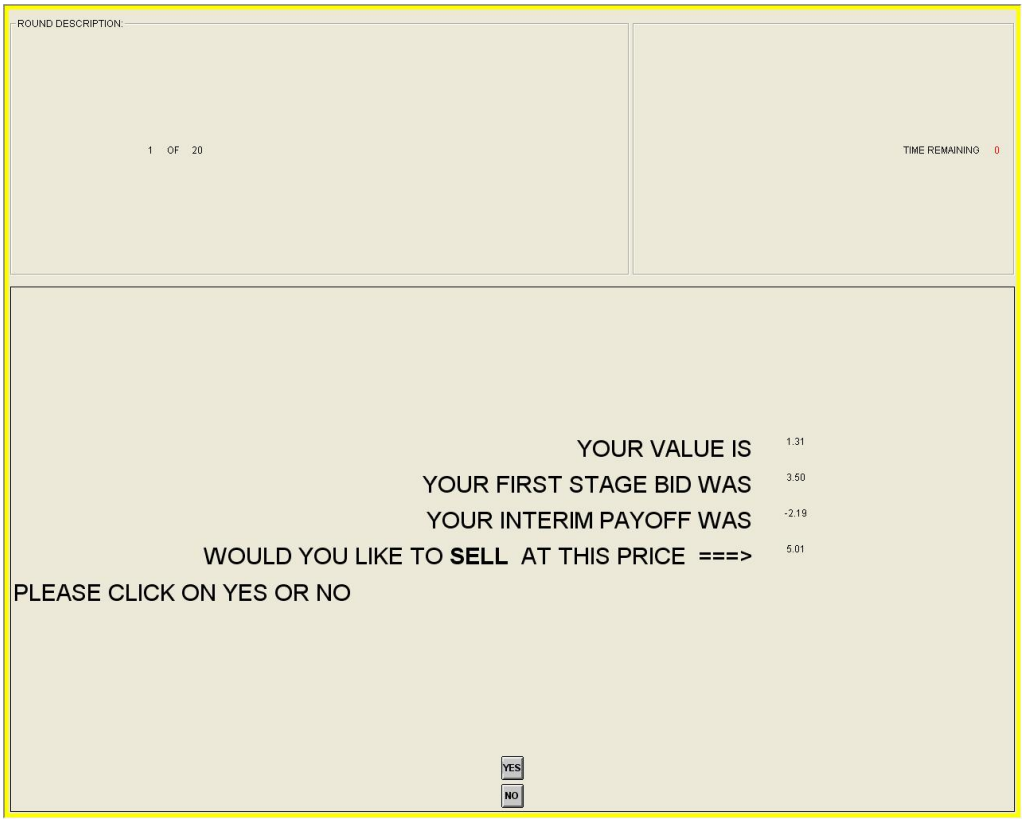


Figure A.8: Second Stage Offer: Monopsony Resale

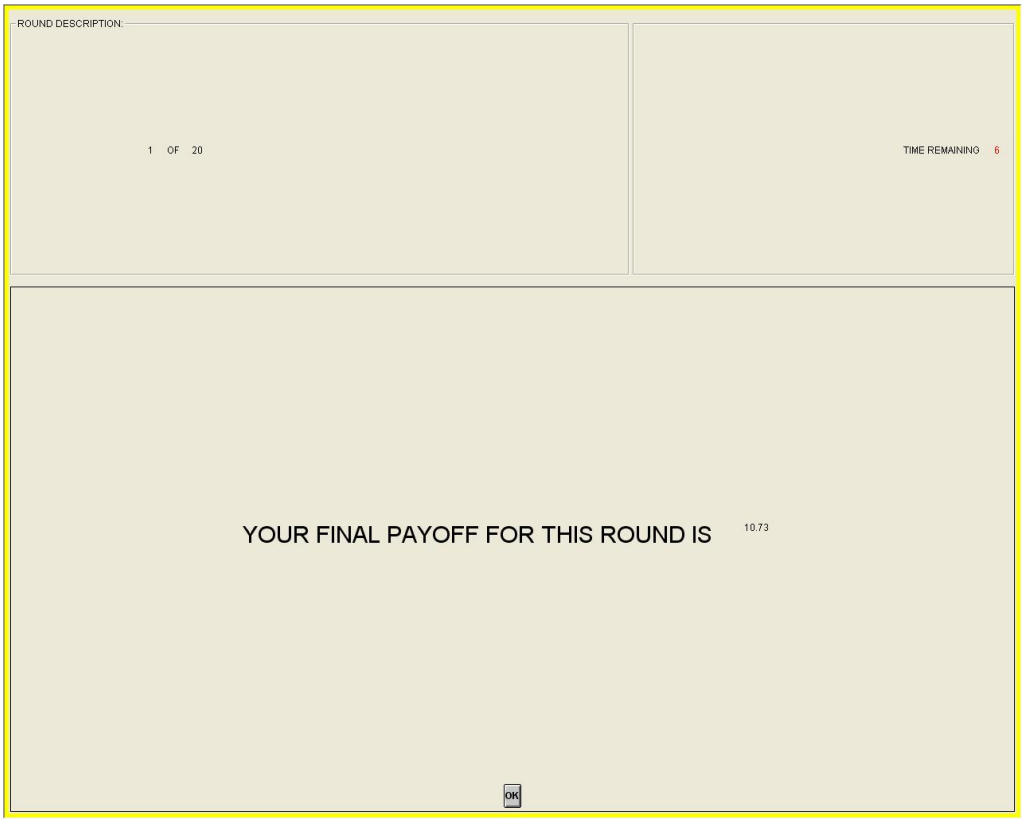


Figure A.9: Final Payoff Screen

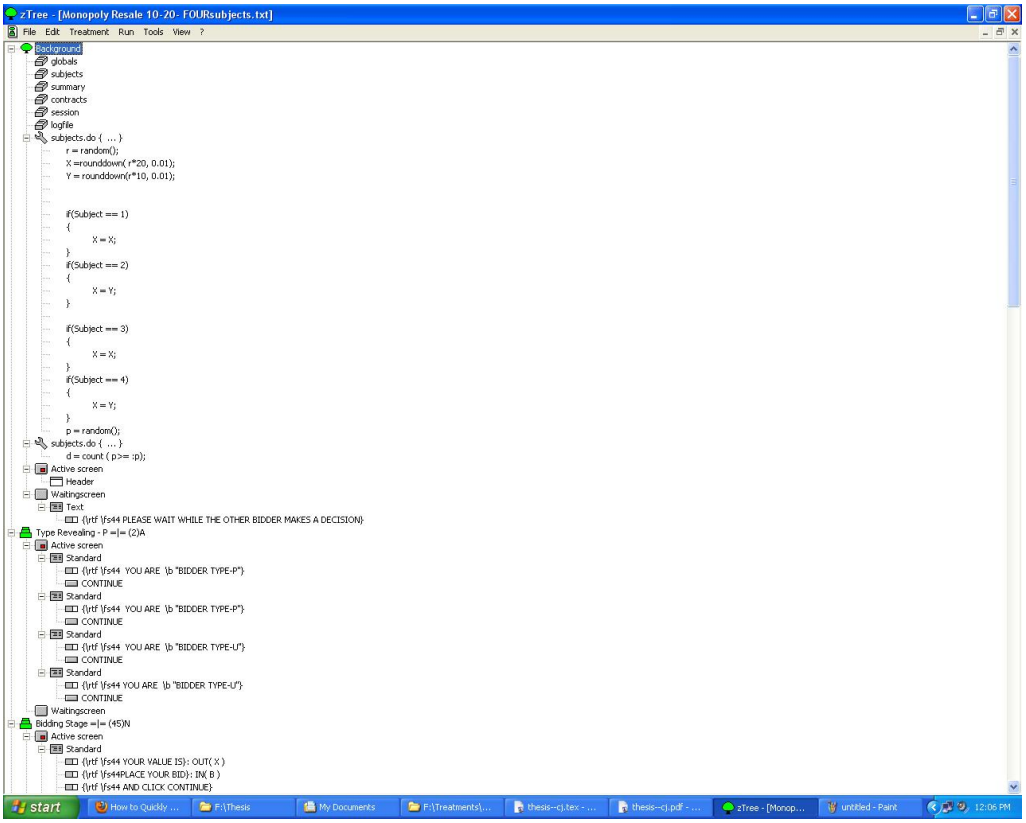


Figure A.10: Code - 1

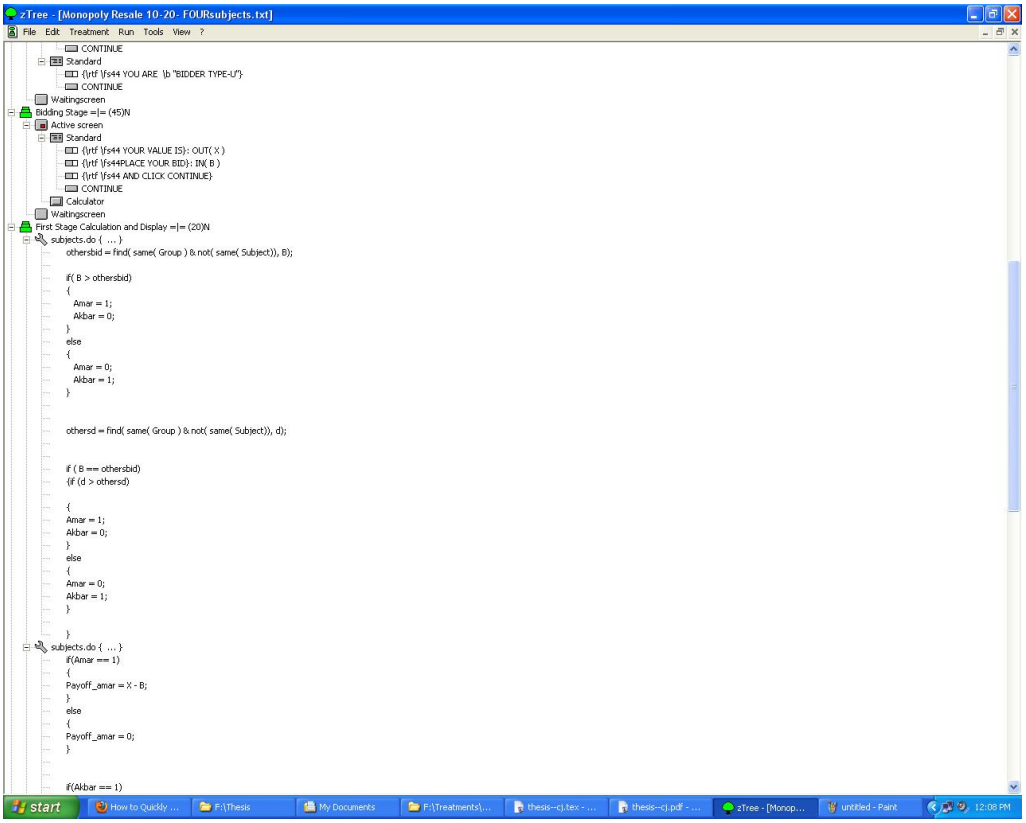


Figure A.11: Code - 2

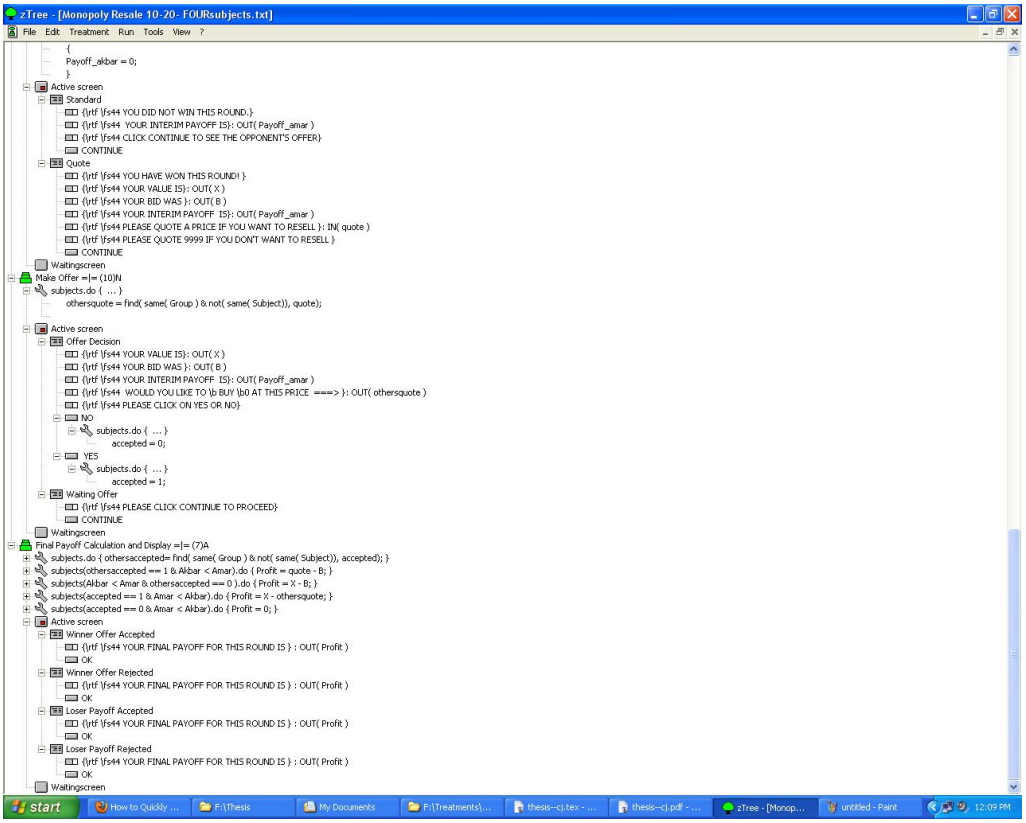


Figure A.12: Code - 3

Appendix B

B.1 Derivation of Equilibrium Bidding Strategies

Following Cheng and Tan (2008), the resale game has the double auction format preceded by a first price auction under this setup. The value distributions are uniform and asymmetric with

$$v_w \sim U[0, a_w] \qquad v_s \sim U[0, a_s] \Rightarrow \quad F_w(v) = \frac{v}{a_w} \qquad F_s(v) = \frac{v}{a_s}.$$

where a_w and a_s are the upper bounds for weak and strong bidders' value distributions respectively and $a_w \leq a_s$. The pricing functions for the seller and the buyer in the resale game can be described as follows:

$$p_s(v_w) = c_1 v_w + d_1 \qquad p_b(v_s) = c_2 v_s + d_2 \tag{B.1}$$

where c_1, c_2, d_1, d_2 are constants. A weak bidder (seller) with value v_w chooses $p_s \leq kc_2 v_w + d_2$ to maximize the following profit function[1]:

$$\Pi_w(v_w) = \int_{\frac{p-d_2}{c_2}}^{kv_w} \left[\frac{p + c_2 v_s + d_2}{2} - v_w \right] dv_s$$

which leads to

$$p_s(v_w) = \frac{2}{3} \left[\frac{2 + kc_2}{2} \right] v_w + \frac{1}{3} d_2. \tag{B.2}$$

Similarly, a strong bidder (buyer) with a value v_s chooses $p_b \geq \frac{v_s}{k} c_1 + d_1$ to maximize:

$$\Pi_s(v_s) = \int_{\frac{v_s}{k}}^{\frac{p-d_1}{c_1}} \left[v_s - \frac{p + c_1 v_w + d_1}{2} \right] dv_w$$

[1] where k is the ratio $\frac{a_s}{a_w}$

which leads to

$$p_b(v_s) = \left[\frac{2}{3} + \frac{c_1}{k}\right] v_s + \frac{1}{3} d_1. \tag{B.3}$$

Solving (B.2) and (B.3) using (B.1), we find the following equilibrium pricing functions in the resale game:

$$p_s(v_w) = \left[\frac{a_s + 3a_w}{4a_w}\right] v_w \quad \forall v_w \in [0, a_w]$$

$$\begin{aligned} p_b(v_s) &= \left[\frac{3}{4} + \frac{a_w}{4a_s}\right] v_s \quad \forall v_s \in \left[0, \frac{a_s(a_s + 3a_w)}{3a_s + a_w}\right] \\ &= \frac{a_s + 3a_w}{4} \quad \forall v_s \in \left[\frac{a_s(a_s + 3a_w}{3a_s + a_w}, a_s\right]. \end{aligned}$$

Using these prices in the differential equations system that solves for the inverse bidding strategies, we get the two part solution as below:

$$\frac{d}{db} ln F_k[\phi_k(b)] = \frac{1}{\frac{1}{2}\left[\frac{a_s+3a_w}{4a_w}\phi_w(b) + \left[\frac{3}{4} + \frac{a_w}{4a_s}\right]\phi_s(b)\right] - b} \qquad \forall k = s, w \tag{B.4}$$

subject to the following boundary conditions:

$$\phi_k(0) = 0, \qquad \phi_k\left[\frac{(a_s + a_w)(3a_w + a_s)}{4(3a_s + a_w)}\right] = \left[\frac{a_k(a_s + 3a_w)}{3a_s + a_w}\right] \qquad \forall k = s, w.$$

For the second part, the solution satisfies the system of differential equations

$$\frac{d}{db} ln F_k[\phi_k(b)] = \frac{1}{\frac{1}{2}\left[\frac{a_s+3a_w}{4a_w}\phi_w(b) + \frac{a_s+3a_w}{4}\right] - b} \qquad \forall k = s, w \tag{B.5}$$

subject to the following boundary conditions:

$$\phi_k\left[\frac{(a_s + a_w)(3a_w + a_s)}{4(3a_s + a_w)}\right] = \left[\frac{a_k(a_s + 3a_w)}{3a_s + a_w}\right],$$

$$\phi_k \left[\frac{a_s(3a_w + a_s)}{2(3a_s + a_w)} \right] = a_k \qquad \forall k = s, w.$$

B.2 Questionnaire

Please answer the following questions while we calculate your payments for today's session. Please note that the answers to these questions have no relation to your payments. The payments were determined by your performance in the rounds of auctions you just played.

1. Please indicate your gender.
   - M
   - F
2. Select the area of education that best depicts your major.
   - PHYSICAL SCIENCES
   - ENGINEERING
   - HUMANITIES
   - SOCIAL SCIENCES
   - BUSINESS & FINANCE
   - LIFE SCIENCES
3. Please select if you are a graduate or an undergraduate student.
   - GRADUATE
   - UNDERGRADUATE
4. Is English your native language?
   - YES

- NO

5. Have you participated in real life auctions before (like eBay/amazon or charity auctions)?

   - YES
   - NO

6. Have you participated in an auction experiment before?

   - YES
   - NO

7. Suppose you have to choose between the following three options:

   A GETTING 10 RUCHMAS FOR SURE

   B GETTING 20 RUCHMAS OR NO RUCHMAS BASED ON THE TOSS OF A FAIR COIN

   C I AM OKAY WITH EITHER A OR B

   What will you choose?

B.3 Instructions

This is an experiment regarding auctions. If you follow the instructions carefully, you might earn money that will be credited to your sooner sense account. The participation is purely voluntary. If you decide to participate, you will get 100 *Ruchmas* (our experimental currency) that will serve as initial capital (or endowment) for you in addition to what you earn during the experiment. Ruchmas will be converted to Dollars at a rate of 7 *Ruchmas* = \$1. The expected duration of experiment is about 90 minutes. I am going to read out the instructions before we begin.

- You will act as a potential buyer bidding for 40 fictitious commodities sold in successive rounds.
- At the beginning of the experiment, a random flip of a coin will determine if you are going to be "Bidder type-U" or "Bidder type-P". Please note that your type will remain the SAME for the first 20 rounds of the experiment.
- Your type will change for the next 20 rounds and will remain SAME for the rest of the session. There will be two practice rounds in the beginning to make you familiar with the setup.
- In each successive round, you will be matched with a different opponent who is NOT your type. [for example, if you are Bidder type-U, your opponent will always be a Bidder type-P and vice versa]
- Your opponent will change for each successive round but they will all be of the same type (and that is different than your type).
- In each round, the value of the commodity for a bidder type-U will be a random number up to two decimal places between 0.00 and 10.00 *Ruchmas* (that is, any value between 0.00 and 10.00 is equally likely). FIGURE 1 describes the likelihood of all possible values for bidder type-U. So your value is the result of a spin of the arrow attached to this wheel for every round.

- Similarly, in each round, the value of the commodity for a bidder type-P will be a random number up to two decimal places between 0.00 and 20.00 *Ruchmas* (that is, any value between 0.00 and 20.00 is equally likely). FIGURE 2 describes the likelihood of all possible values for bidder type-P. So your value is the result of a spin of the arrow attached to this wheel for every round.
- Each round will have two stages: The Auction Stage and The Resale Stage. Here is how a typical round will proceed:
- **To summarize, your type will change only once in today's session (it is either P or U) but your value may change in every round. Your value for each round is determined by a spin of the arrow. Please note that every spin is independent.**
- **You will be reminded of your type at the beginning of every new round.**

Figure 1: Value Distribution for BIDDER TYPE U

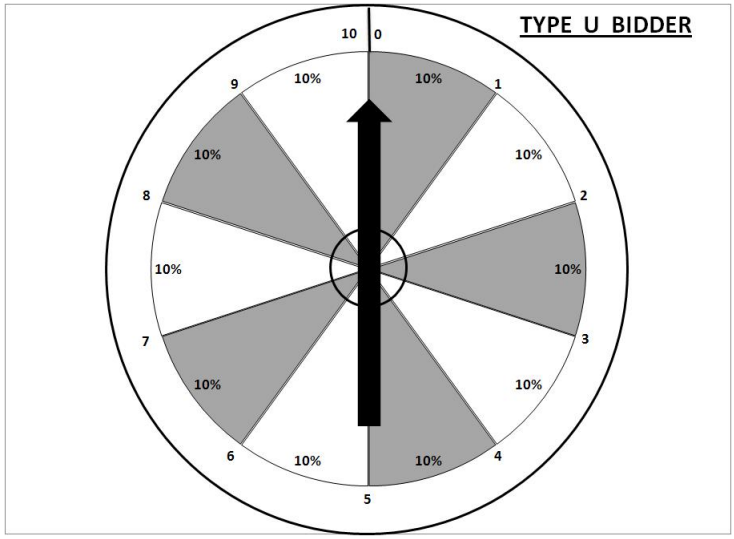
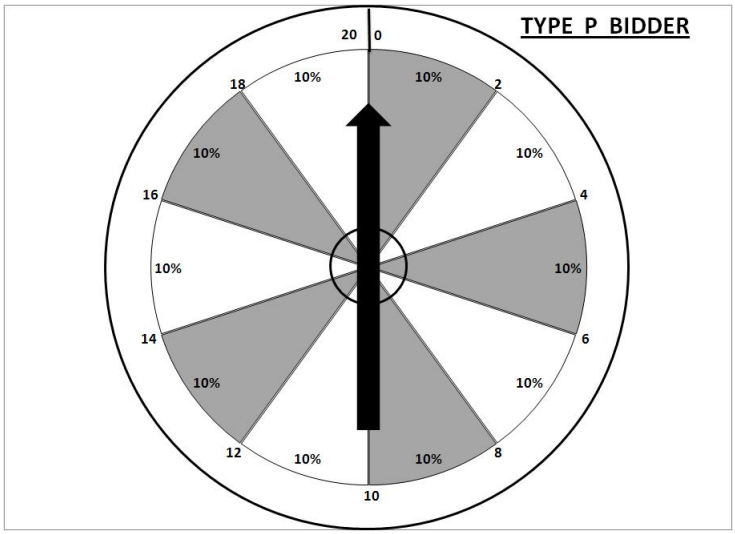


Figure 2: Value Distribution for BIDDER TYPE P



Stage I-The Auction Stage:

In this stage, every player will submit a bid for a fictitious commodity being sold at an auction.

- You will receive the information about *your value* only.
- After finding out your value for the commodity, you will begin by choosing a number or a *"bid"*. Please think carefully before you make your choice. You may use a calculator by clicking on the icon that will appear to the right hand side of your screen. You will have 45 seconds to make a decision. Your Opponent will also choose a bid at the same time. *Neither player can see his opponent's value or bid.*
- The person with the high bid will win the commodity being sold and pay his own bid as the price. In the case of a tie, a random coin flip will decide the winner.
- You will be informed whether you won the auction or not.
- The following schematic describes the auction stage and the interim payoff calculations.
- *Note that this is just the interim payoff.* The final payoff of a round will be determined at the end of stage II - the *Resale Stage*. It will begin *immediately* after the auction stage.

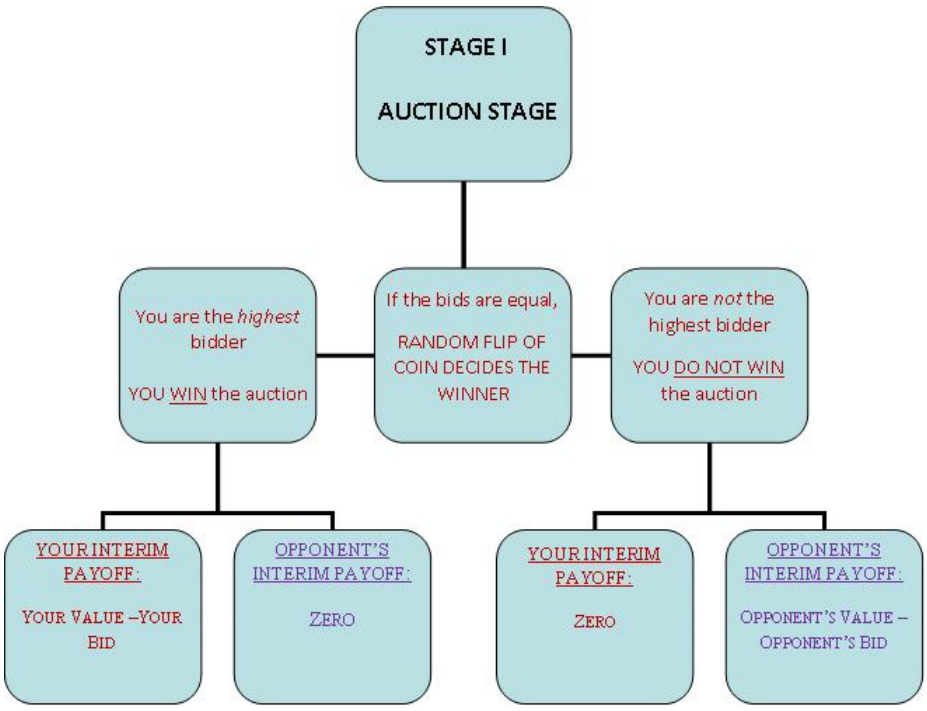


Figure 3: Interim Payoff Calculation

Stage II-The Resale Stage:

In this stage, the bidders will have one more opportunity **to resell/buy** the commodity **to/from his opponent**. It works in the following way:

- Both bidders can choose to make an offer to the opponent.
- If the winning bidder does not want to make an offer, he may quote a price of **21** *Ruchmas*.
- If the opponent does not want to make an offer, he may quote a price of **0** *Ruchmas*.
- If the offers are made and buyers offer is at least as high as the sellers offer, trade takes place.
- If trade takes place, the resale price is halfway between the buyers offer and the sellers offer. The seller will receive the difference between the resale price and his initial bid. The opponent will receive the difference between his value and the resale price.
- If the buyers offer is less than the sellers offer (or is 0), there will be NO trade in the second stage. So, the first stage winner will keep the commodity and receive the difference between his value and the first stage bid. The opponent will receive nothing for that round.
- The following schematic describes the course of the second stage:
- This will conclude a typical round and a new round will begin with Stage I as described earlier.
- The total earnings for a player will be equal to the **SUM** of all final payoffs from each round. The dollar amount to be credited on your sooner sense account will be calculated on the basis of the conversion rate mentioned earlier.
- Are there any questions at this stage? Please feel free to ask before we begin.

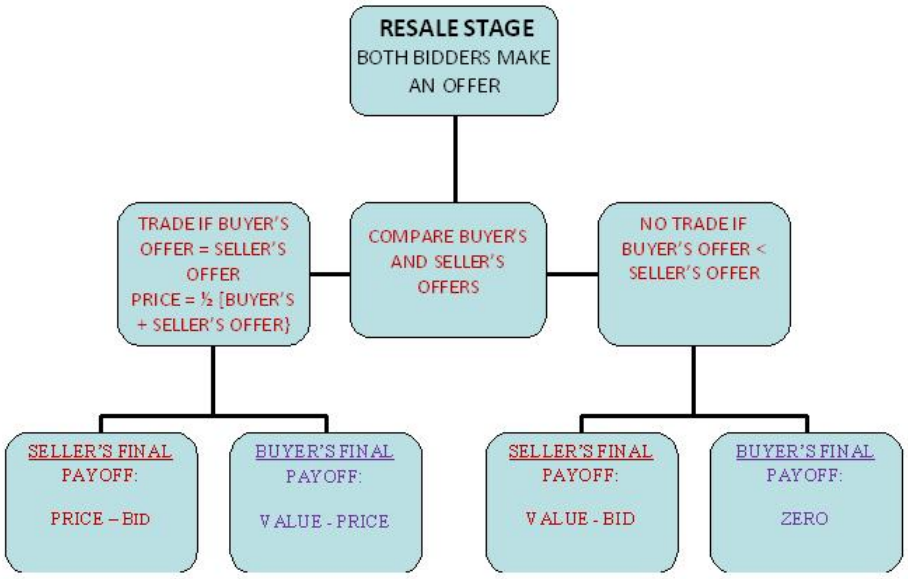
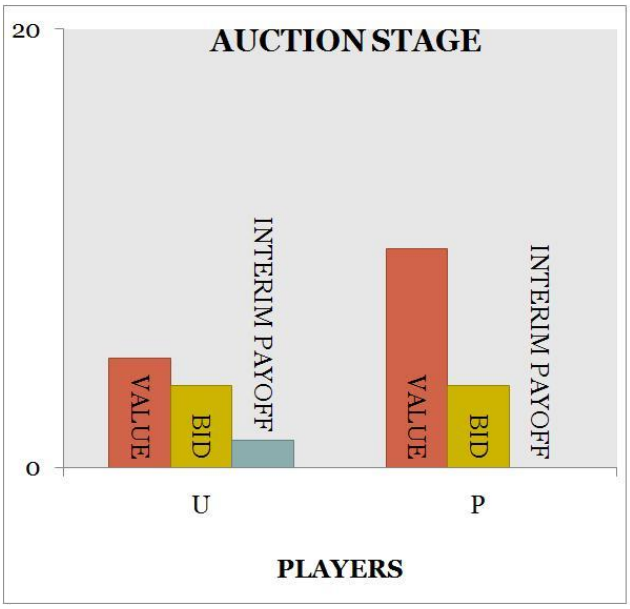


Figure 4: Resale Stage Payoff

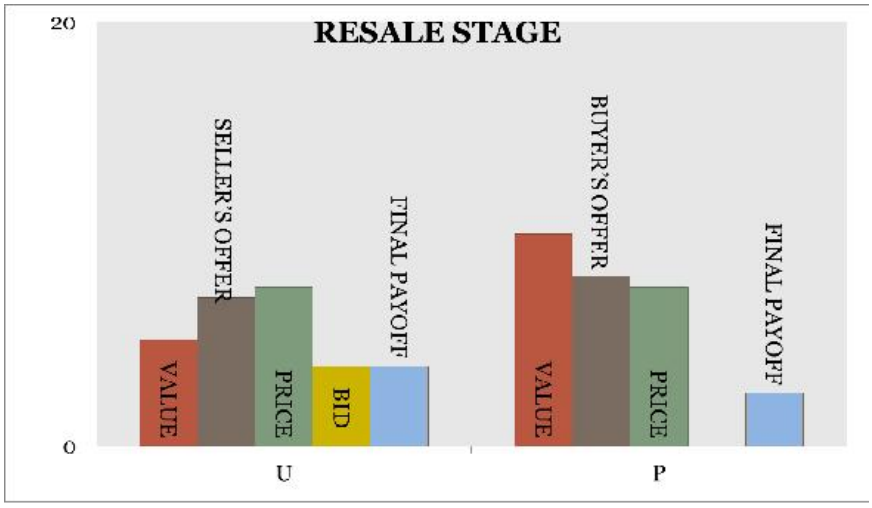
- The following graphical example will show how a *typical* round will proceed:



SINCE THE BIDS ARE EQUAL, TOSS OF A FAIR COIN DECIDES THE WINNER.

SUPPOSE THAT PLAYER 'U' WINS THE AUCTION STAGE.

THE SECOND GRAPH SHOWS THE RESALE STAGE



B.4 zTree: Screen-shots and code

Next, we present the screen-shots from z-Tree to give an idea of how the experiment appeared to the players. Final four figures present screen-shots of z-Tree code used to create the experiment.



Figure B.1: Opening Screen for Bidders declaring player type



Figure B.2: Bidding Screen for Auction Stage

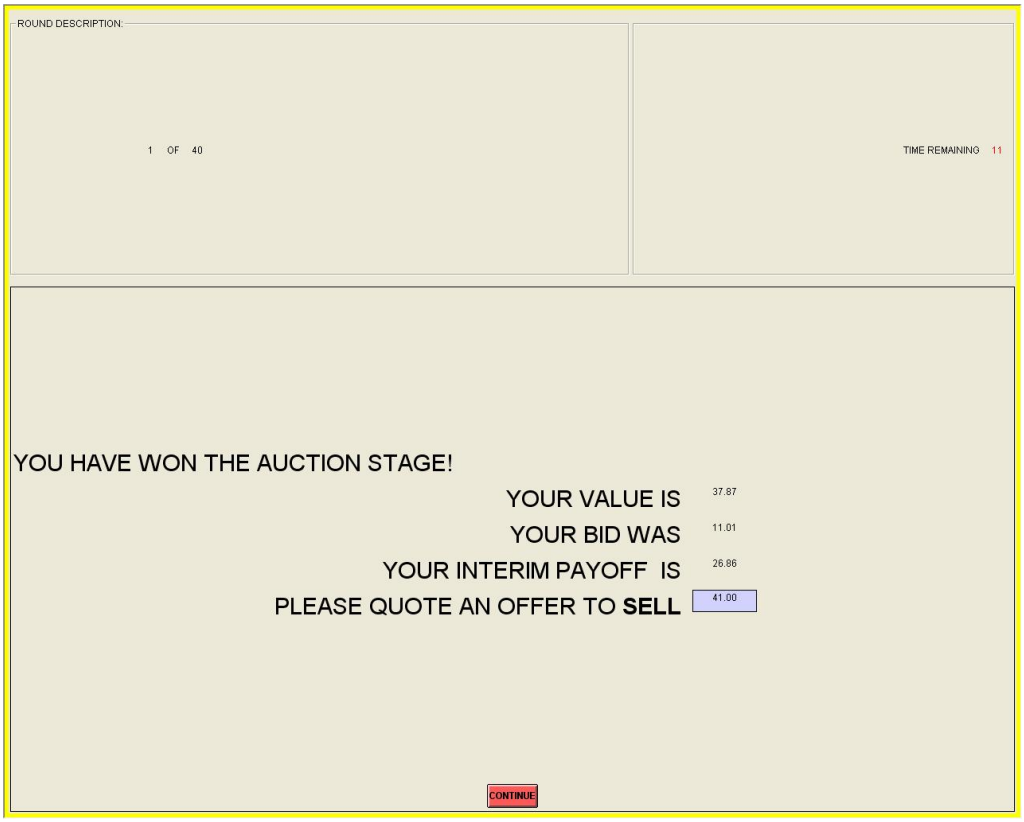


Figure B.3: Auction Stage Winner

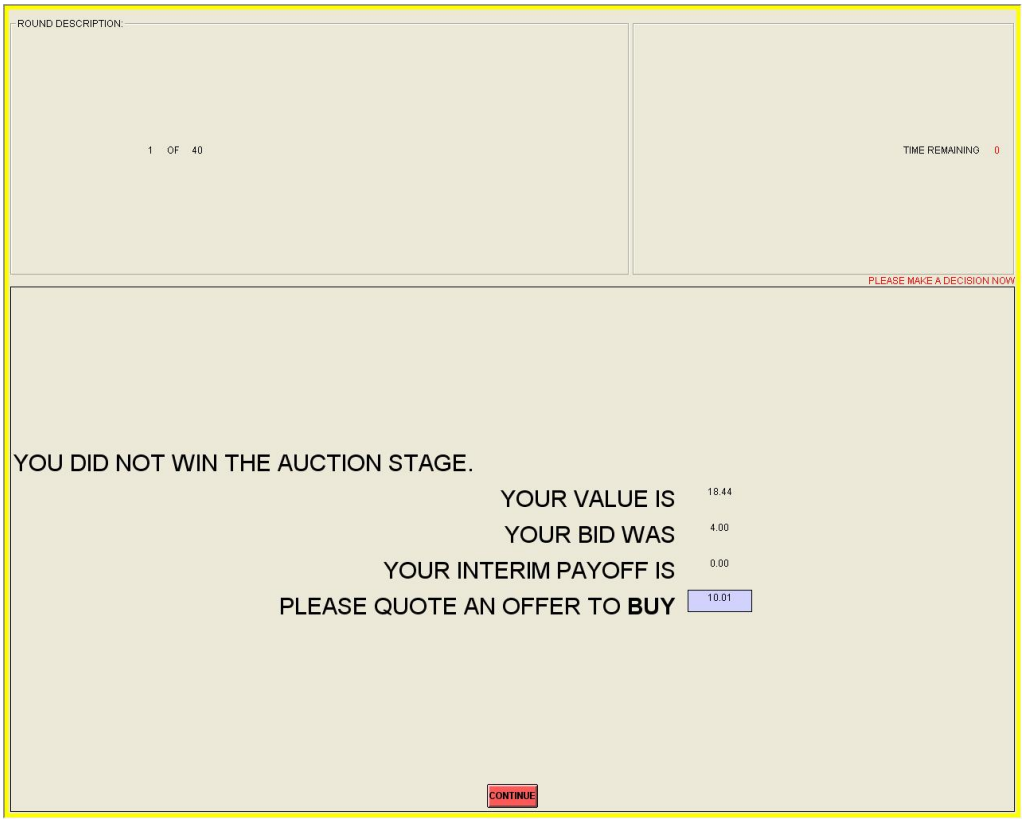


Figure B.4: Auction Stage Loser



Figure B.5: Final Payoff Screen when resale takes place.



Figure B.6: Final Payoff Screen when resale does not take place.

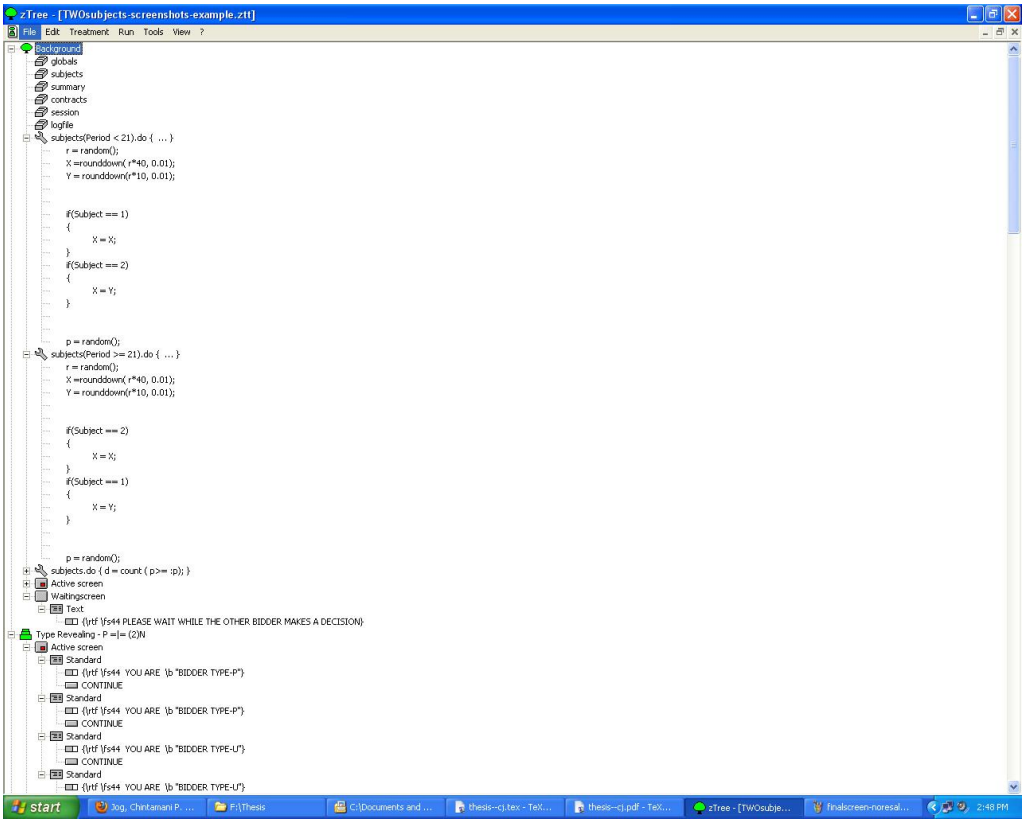


Figure B.7: Code - 1

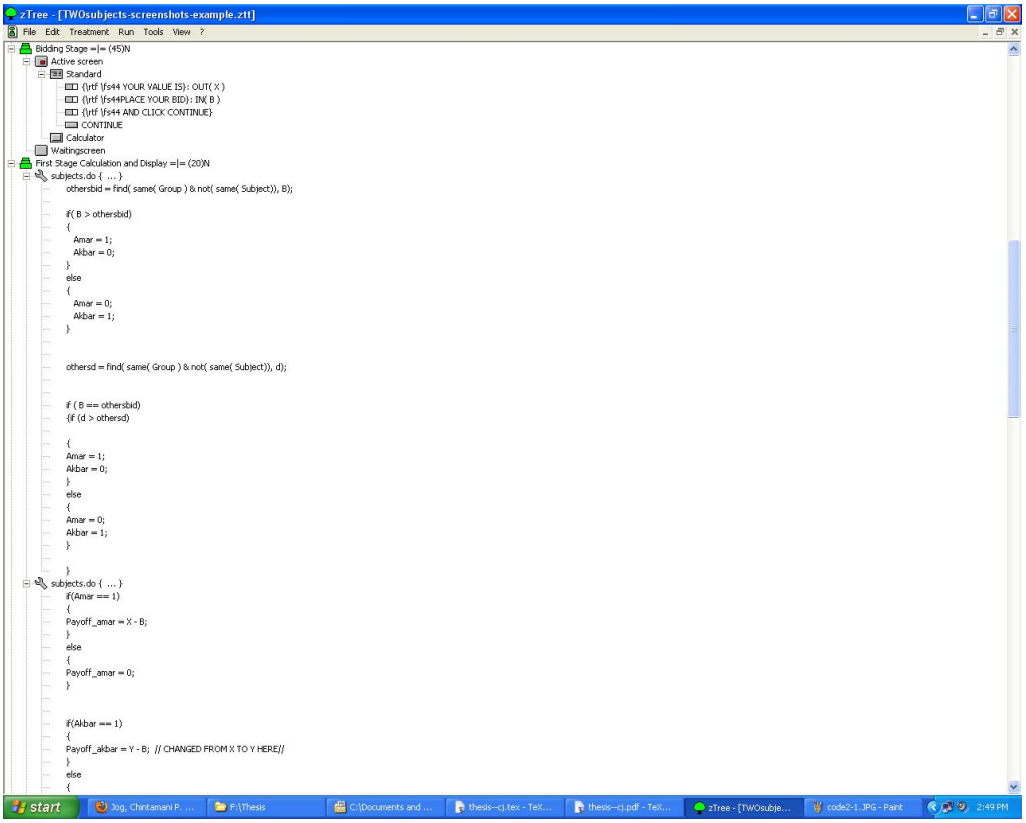


Figure B.8: Code - 2

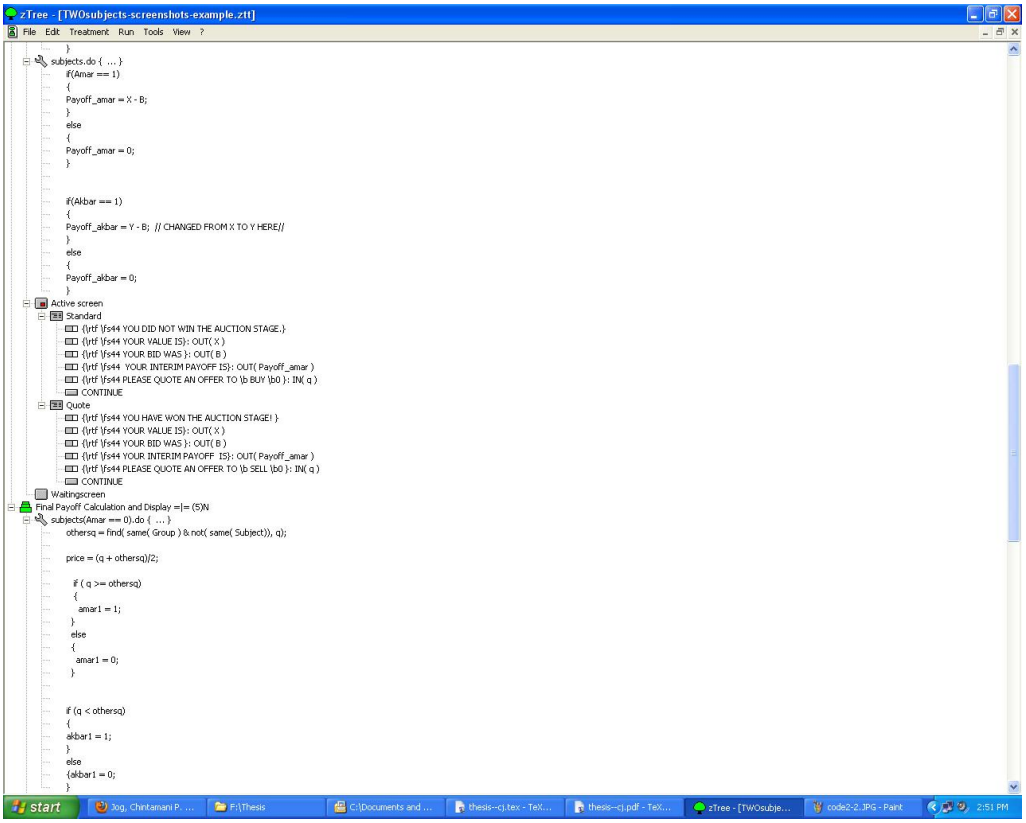


Figure B.9: Code - 3

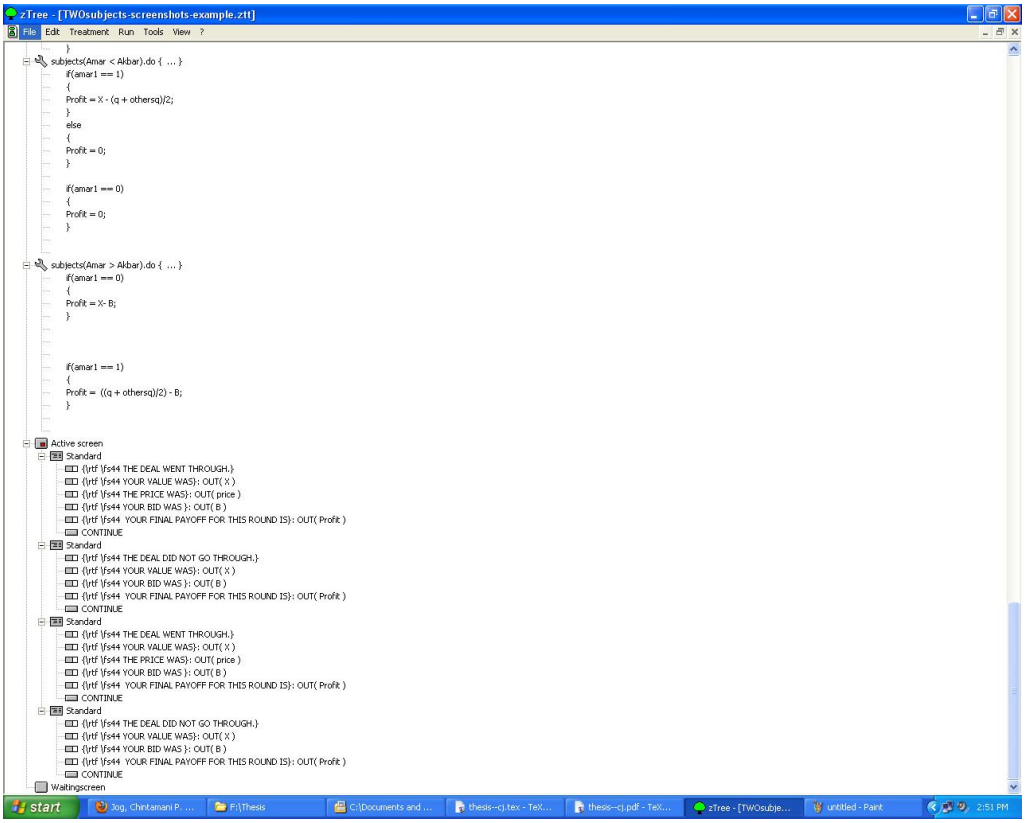


Figure B.10: Code - 4