Default and Resale-Based Limited Liability in Second Price Auctions*

Krista J. Saral†
Webster University Geneva

March 2016

Abstract

In auctions where bidders are uncertain of their value, the potential for losses exists if bids exceed realized values. If bidders are able to mitigate this downside loss through some form of limited liability, bids will be higher, but whether sellers should prefer to implement limited liability to help bidders overcome losses depends on form of liability. Using a combination of theory and experiment, I examine a second price auction with uncertain private values under three liability environments: full liability, limited liability induced through default with a penalty payment, and resale-based limited liability. The highest bids are observed under a low default penalty, but final revenue is lowest due to the frequency of default. The highest revenue is achieved under resale, which is also as effective as the low default penalty in alleviating bidder losses. In contrast to predictions, bids under a high default penalty are equivalent to full liability. These results imply that allowing resale as a form of limited liability may be preferred by both bidders and sellers over other forms of default-based limited liability and full liability.

JEL Codes: D44 C90
Key Words: Auctions, Limited Liability, Default, Resale, Experimental Economics

1. Introduction

A common problem in many auctions is that a bidder will be uncertain of their valuation for an item while placing a bid. Examples include online auctions for second-hand items (e.g. Ebay) where quality is uncertain, off-shore drilling rights with uncertain deposit amounts, and wireless spectrum with uncertain future demand. When the value of an item cannot be easily verified prior to placing a bid, bidders must choose their bids carefully, but even with meticulous planning

*I would like to thank seminar participants at GATE Lyon Saint-Etienne and ESA Copenhagen. I would also like to thank Tim Salmon and Marco Pagnozzi for helpful comments.
†George Herbert Walker School of Business and Technology, Webster University Geneva, Route de Collex 15, CH-1293 Bellevue, Switzerland, kjsaral@webster.ch

bidders may find themselves in situations where they have overbid relative to their realized final value.

Given the potential for overbidding and possible losses, sellers must stipulate liability rules prior to the auction taking place. However, the structure of these rules may also influence bidding behavior which makes the optimal choice for sellers nontrivial, and partially explains the variety of liability environments observed in the field.

At one end of the liability spectrum, bidders are fully liable for any bids placed and safe guards such as bid deposits, which cap the level of bid possible, can be made to ensure payment. At the other end, bidders may fully default through bid retraction or even non-payment.[1] Between these two extremes, there are also cases where monetary penalties are imposed in the event of default. These penalties require less payment than the amount owed, giving the bidder limited liability, but are still intended to penalize defaulting bidders.[2] More generally, there are numerous bankruptcy rules and other governmental policies which can limit how much of a loss for which an individual or firm is liable. I will refer to this class of limited liability rules as statutory limited liability as these rules will typically be specified in the rules of the auction or relevant part of the bankruptcy code.

In addition to statutory limited liability, there is another form of limited liability that is perhaps not always thought of as a way of achieving limited liability, and that is the opportunity to resell an item. If a bidder realizes he overpaid relative to his value for the item, he may be able to find a new buyer to purchase the item from him and possibility limit the degree of loss or even potentially make a profit on the transaction. While resale opportunities may not always be thought of as a form of limited liability, it is an important form which should be examined since it would likely be less costly than bidder default for sellers who may then prefer to allow resale and restrict default.

The purpose of this study is to investigate how bidding behavior and auction outcomes may change across different liability environments. I use a combination of theory and empirical analysis based on an economic experiment to examine three liability cases: full liability, limited liability induced through default with a penalty payment, and resale-based limited liability.[3]

A number of theoretical papers have established that changing the liability of a bidder changes the underlying incentives of the auction which affects bidding behavior and ultimately,

[1] For example, the online marketplace, eBay, does not require bidders to make a payment until the conclusion of the auction and bidders are allowed to ask for a full bid retraction. Winning bidders can also just refuse payment - while this results in a record created by eBay that a bidder withheld payment that could result in future restrictions, no specific monetary penalty is imposed.

[2] The FCC required a defaulting bidder from the C Block Auctions to pay "a penalty equal to the difference between the amount bid and the amount of the winning bid the next time the license of offered by the Commission plus an additional penalty equal to 3 percent of the subsequent winning bid. If the subsequent winning bid [exceeded] the defaulting bidder's bid amount, the 3 percent penalty [was] calculated based on the defaulting bidder's bid amount."

Source: C.H. PCS, Inc., BTA No. B347 Frequency Block C Order

Retrieved: January 21, 2016 from http://wireless.fcc.gov/auctions/10/releases/da961825.pdf

[3] The use of an experiment has a number of advantages over the field for this study including direct observation of value signals and final values, and explicit control over the liability environment.

auction outcomes. For example, Waehrer (1995) demonstrates that under a bid deposit, which is the maximum payment required under default, bids become more aggressive as the deposit amount is decreased which also leads to higher levels of default. Harstad and Rothkopf (1995) examine the possibility of bid withdrawals, also finding more aggressive bidding under this scheme. Zheng (2001), Pagnozzi (2007), and Board (2007) analyze limited liability induced through wealth constraints where capped downside losses (due to lower initial wealth) result in more aggressive bidding behavior and inefficient allocations. Similar results have also been established in the procurement setting (e.g. Roelofs (2002); Parlane (2003); Burguet, Ganuza, and Hauk (2012)). While more aggressive bidding should lead to higher revenues; it's not necessarily the case that sellers are better off since the winning bidder may default, particularly if sellers are unable to fully recover items (Board, 2007).

While theory predicts more aggressive behavior in response to limited liability, empirically we may expect to see differences in the amount of risk a bidder is willing to accept and the tolerance of bidders to default. A limited number of studies (Roelofs (2002), Onderstal and Van der Veen (2011)) have found empirical evidence that bidders do respond aggressively to the presence of limited liability versus full liability, but how behavior may vary across different limited liability environments remains a critical gap in our understanding.

To begin to fill this gap, the analysis of this paper begins with a second price auction for an item of uncertain private value and two risk neutral bidders. The baseline case assumes full liability, where the winning bidder must cover all losses. This is then extended to a limited liability environment where default is allowed, but under default the winning bidder must still pay a percentage of the auction price. The final environment is resale-based limited liability, where the winning bidder can resell the item won to the losing bidder in a post-auction resale market if the losing bidder's realized value is higher than the winner. In both the default and resale environments, bidding is predicted to be more aggressive than full liability as long as the default penalty remains sufficiently low. Between the limited liability environments, the difference in behavior again depends on the level of default penalty - bidding under a low default penalty (5% of the auction price paid in the event of default) is predicted to be the highest (most aggressive), while bidding under a high default penalty (25% of the auction price) is predicted to be less than bidding under resale-based limited liability in most instances.[4]

The experiment consists of four treatments: Full Liability, 5% Default, 25% Default, and Resale. These treatments mimic the theoretical environment and were designed to ensure tight control over decisions to accurately test the response of bidders to varying liability rules. In the default treatments, whenever the bidder made a loss in the auction which was less than the loss that would be suffered under default, the bidder was forced to automatically default. In the resale treatment, whenever the winning bidder's realized final value was lower than the losing bidder's final value, the item was automatically transferred to the losing bidder at a resale price equal to the losing bidder's value. While these controls abstract from many real world scenarios

[4] There is a small subset of low values for which this relationship is reversed.

where default would be a choice and resale would involve a less structured bargaining process, the decision was made to cleanly test if bidders would react to the default and resale environments without confounds such as default aversion or the possibility that resale would fail to occur.[5]

I find that how a bidder chooses to bid under uncertainty depends critically on the form and level of liability rules. In support of the theoretical predictions, bidding behavior is most aggressive in the 5% default treatment and bidders do integrate resale into their bidding decisions which results in higher bids, but the resale effect weakens over time. In contrast to predictions, I find no evidence that bidding behavior under a higher default penalty (25%) is different from full liability so bidders only react to default limited liability if the penalty is relatively low.

These results indicate that bidders are sensitive to the type of liability environment they face in an auction. Contrary to theoretical predictions, I do not find that bidders always respond to the presence of limited liability. With default, bidders only alter their bids when the penalty is relatively low. Moreover, under resale, bidding behavior is more idiosyncratic as relatively risk averse bidders are less aggressive in bidding than others. This lack of response to the limited liability incentives also stands in contrast to previous experimental evidence by Roelofs (2002) and Onderstal and Van der Veen (2011), who find more aggressive behavior under limited liability. The contrast is likely explained by the forms of liability rule used. Roelofs (2002) allowed full default and Onderstal and Van der Veen (2011) enforced a relatively low fixed default penalty, so in both cases their results are in-line with the behavior observed under a low default penalty.

Turning to outcomes, while bids are observed to be highest under the 5% default rule, the final revenue achieved in this case was often lower due to the prevalence of default. Consequently, revenue is highest in the resale treatment. From the bidder's perspective, all three limited liability treatments helped mitigate losses, but the resale and the 5% default treatments were most effective. However, since auction prices were also higher in the resale and 5% default treatments average bidder earnings were also lower in these treatments.

This paper contributes to the literature on limited liability in auctions. It builds on the theoretical analyses of Waehrer (1995), Zheng (2001), and Board (2007). Board (2007) is most similar since he examines default across multiple environments. His focus is on the perspective of the seller in the presence of defaulting bidders and various recovery scenarios. Resale is included as one of the recovery options, but his version of resale differs from this paper as I assume that it is not the seller reselling under recovery, but the winning bidder who is reselling to the losing bidder. Pagnozzi (2007) also theoretically examines resale where the winning bidder resells, but the limited liability emphasis is based on different wealth constraints, rather than resale. Haile (2003) theoretically deals with uncertain values and resale opportunities, but again, the focus of Haile is not on the market-based limited liability aspects of resale. On the experimental

[5] If bidders failed to respond to the incentives of the resale market it would be unclear if they were not responding because of beliefs that the resale market would fail or because they misunderstood the limited liability aspects of resale.

side, to my knowledge, only two papers deal with limited liability rules in the auction setting.[6] Roelofs (2002) examines a common value procurement auction with full (costless) default, finding empirical evidence that bidders do choose to bid more aggressively when default is allowed, but mixed evidence on the effectiveness of the theory to predict behavior. Onderstal and Van der Veen (2011) analyze first and second price auctions with a fixed penalty in the event of default finding that bidders react more aggressively than theory predicts to the presence of limited liability. This paper differs from both of these studies in three important ways: (i) differences across limited liability formats are examined (ii) resale is included as a market-based novel form of limited liability (iii) the form of the default penalty is changed to a percentage based penalty, and responses to the level of the penalty are also examined.

In the next section I present the theoretical predictions for bidding behavior and revenue. Section 3 will describe the design of the experiment. Section 4 will present the results and I conclude in section 5.

2. Theory

In this section, I construct a simple model that provides the framework to experimentally investigate the effects of different liability environments on bidding strategies under uncertainty.

Auction: There is a (sealed-bid) second price auction for one item. Each bidder submits one bid for the item and the highest bid is awarded the item. The winner plays a price equal to the second highest bid.

Bidders and Valuations: There are 2 risk-neutral bidders. Each bidder's final use value is denoted by v_i and is independent of all other final use values. Prior to the auction, each bidder only observes a private signal x_i which is drawn from a uniform distribution on the support $[0, 50]$ and is strictly affiliated with v_i but independent of x_j for all j. After the auction, each bidder learns the realization of his use value. With probability $\frac{1}{2}$, the bidder's final use value v_i is equal to the signal draw x_i, and with probability $\frac{1}{2}$, the bidder's final use value is equal to $x_i + 20$ — i.e.,

$$E[v_i] = \frac{1}{2}x_i + \frac{1}{2}(x_i + 20)$$

Full Liability: After the auction, the winning bidder must pay the entirety of the auction price to the seller. Post-auction resale or default is not allowed.

Resale: When resale is allowed after the auction, if bidder i wins the item he can resell it to the losing bidder j. I assume that the winning bidder makes a take-it-or-leave-it offer

[6] Other experimental papers have addressed the possibility of default and limited liability, in a different sense. Limited liability created by budget constraints was examined by Hasen & Lott (1991) in a comment regarding the design of Kagel & Levin (1986). A typical constraint faced in economic experiments, and the issue raised by Hasen & Lott, is that subjects cannot make losses. Therefore, subjects with low cash balances have limited liability because the downside loss is capped at zero. Kagel & Levin (1991) respond to this comment with how they controlled for limited liability by providing cash endowments to the subjects that covered the maximum possible loss. Budget constraints can also be viewed as a form of market-based limited liability, but this type of liability is not examined in this paper.

to the other bidder.[7] While there are other resale mechanisms that could have been used to support the qualitative predictions that follow, the advantage of this set-up is that it provides a clean framework to analyze the response of bidders to the limited liability aspects of a resale opportunity, which is the primary topic of interest. This construction provides the strongest incentives and as a result the strongest test of whether behavioral responses to resale-based limited liability are plausible in the field.

Default: When default is allowed after the auction, I assume that defaulting forces the bidder to pay a percentage α of the auction price to the seller.

In what follows, I solve for the symmetric equilibrium bid strategies under full liability, market-based limited liability induced through resale, and statutory limited liability through default.

Full Liability

I assume throughout that bid functions are symmetric, $b(x_i) = b_j(x_j)$, for all i and j. If bidder i wins the auction at price p, he earns $E[v_i] - p$, while if he loses the auction, he earns 0. So he bids a price such that his expected profit from winning is equal to zero.

The full liability bidding solution is:

$$b^*_{FL}(x_i) = x_i + 10 \tag{2.1}$$

So, the equilibrium is to bid the expected final value.

Resale

I now add the possibility of resale after the auction between the winning and losing bidders. All general assumptions from the full liability case remain. The construction is designed to see how bidder i responds to $b^*(x_j)$, by allowing bidder i to choose to bid according to some other signal, r, which isn't necessarily his. I assume that equilibrium bid functions are increasing in the signal and bidder i will win if $b(r) > b^*(x_j)$,which occurs with probability $F(r)$. The resale market assumes complete information so that realized use values are common knowledge at the conclusion of the auction. By these assumptions, if bidder i wins the item in the auction and resells, he will make an offer to bidder j equal to v_j which will be accepted and obtain the entire resale surplus, $v_j - v_i$.[8]

[7] This is similar to the resale market structured analyzed by Calzolari and Pavan (2006), who assume a take-it-or-leave-it offer bargaining structure where the proposer is chosen randomly. In my set-up, I assume the proposer is the winning seller with certainty.

[8] Under this set-up the entire resale surplus is earned by the winning bidder which ensures that bidders do not engage in strategic demand reduction (dropping out at a low bid to purchase the item in the resale market at a lower price).

The second price auction problem is defined as follows under resale for bidder i:

$$\max_r U_i(x_i, b_j(x_j), r) = \int_0^{r-20} \left[\tfrac{1}{2}(x_i - b_j(t)) + \tfrac{1}{2}(x_i + 20 - b_j(t))\right] dF(t) + \\ \int_{r-20}^{r} \left[\tfrac{1}{4}(x_i - b_j(t)) + \tfrac{1}{2}(x_i + 20 - b_j(t)) + \tfrac{1}{4}(t + 20 - b_j(t))\right] dF(t) + \\ \int_r^1 0 * d[1 - F(t)] \tag{2.2}$$

With the equilibrium condition

$$\frac{\partial U_i(x_i, b_j(x_j), r)}{\partial r}|_{r=x_i} = 0 \tag{2.3}$$

The first term in equation (2.2) represents the utility of bidder i in the event he wins the auction and keeps the item. We integrate over the possible prices, which are the bids the opponent is expected to make, and multiply by the probability bidder i wins. For this first interval, resale is impossible because bidder j's highest possible use value, $v_j = x_j + 20$, falls below bidder i's lowest possible use value, $v_i = x_i$, so all earnings are based on keeping the item. The second term represents the utility of bidder i if he wins the auction and keeps the item (the first two parts of the second term), or wins the auction and resells (last part of the second term). Resale in this interval only occurs when bidder i realizes his lowest use value, $v_i = x_i$ and bidder j realizes his highest use value, $v_j = x_j + 20$. Again, we integrate over all possible prices bidder i would pay and multiply by the probability bidder i wins. The last term represents the utility of bidder i in the event he loses the auction. Although it is possible that bidder i would have the highest realized value, since resale results in a trading price equal to his value earnings are still zero.

The resale (R) bidding solution is:

$$b_R^*(x_i) = x_i + 15 \tag{2.4}$$

When resale is allowed, a bidder has the additional option of reselling the item to the losing bidder who may have realized a higher final use value. This option serves as a form of limited liability in the event the winning bidder is making losses at the conclusion of the auction since resale to a higher valued losing bidder can mitigate losses, but trades can still take place even if the bidder is not making a loss if potential gains are present. Consequently, a bidder is willing to bid up to an auction price that reflects the price he expects to sell at in the resale market and equilibrium bidding behavior is therefore more aggressive than the baseline full liability case.

Default

The third case removes the option of resale and introduces a default option for bidders making losses. All general assumptions from the full liability case remain. If a bidder defaults, they must pay a penalty percentage, $0 < \alpha < 1$, of the price that results from the auction. Bidder i will choose to default if the cost of default, αb_j, is less than the loss from keeping the item.

Therefore, the expected utility resulting to bidder i winning the item is defined as follows:

$$\begin{aligned}&U_i(x_i, b_j(x_j), \alpha) = \tfrac{1}{2}\max\{x_i - \mathbb{E}[b_j(t)|b_i > b_j], -\alpha\mathbb{E}[b_j(t)|b_i > b_j]\} + \\ &\tfrac{1}{2}\max\{x_i + 20 - \mathbb{E}[b_j(t)|b_i > b_j], -\alpha\mathbb{E}[b_j(t)|b_i > b_j]\}\end{aligned} \tag{2.5}$$

Whether bidder i will default depends critically on the default penalty α. In the limit, as α approaches 1, the problem reduces to the full liability case examined previously and a bidder will never choose to default for positive use values.[9] Choices of α that are less than the full liability case result in a kinked equilibrium bid function defined around a cutoff value, v_c.

The default (D) bidding solution is:

$$b_D^*(x_i, \alpha) = \begin{cases} \frac{1}{1+\alpha}(x_i + 20) & if \quad x_i < v_c \\ x_i + 10 & if \quad x_i \geq v_c \end{cases} \tag{2.6}$$

Where the cutoff value, v_c, is defined as:

$$v_c = 10(\frac{1-\alpha}{\alpha}) \tag{2.7}$$

Proof: See Appendix.

The intuition behind the default bid function and cutoff value is straightforward. For signals above v_c, the default cost is too high so bidders bid in a manner identical to the full liability case. For signals below v_c, the bidder bids a percentage of their highest possible realized use value and equilibrium bidding behavior in this case is more aggressive than the full liability case. However, the level of aggressive bidding is inversely related to the penalty level α. Higher penalties bring equilibrium default bids in this interval closer to the full liability case. It is also worthwhile to note that v_c is decreasing in α; the higher the penalty, the lower the cutoff, so higher penalties make aggressive bidding due to limited liability more likely for lower values only.

In the experiment two default treatments are implemented. One which uses a high penalty, $\alpha = 0.25$, and another which uses a low penalty, $\alpha = 0.05$. I use these parameterizations to

[9] For realized use values equal to zero, the bidder is indifferent between default and no default, therefore it is assumed they will choose to not default.

derive specific theoretical predictions. Under the low default penalty, $\alpha = 0.05$, the predicted cutoff is $v_c = 190$, which is above the maximum possible signal draw, 50, so the equilibrium bid under a low default penalty is always higher than the full liability baseline. Under a high default penalty, $\alpha = 0.25$, the cutoff is defined as $v_c = 30$, which is below the highest possible signal draw. Therefore, the bid function in this case is kinked with higher signals resulting in a bid that is equivalent to full liability and lower signals resulting in a bid higher than full liability, but lower than the corresponding low penalty equilibrium bid.

Summing up, the theoretical predictions are as follows:

Result 1. *Bids are higher under resale (market-based limited liability) than full liability.*

Result 2. *Bids are higher under a low default penalty ($a = 0.05$) than full liability.*

Result 3. *Bids are higher under a high default penalty ($a = 0.25$) than full liability for low signal draws ($x_i \leq 30$), and equivalent to full liability for high signal draws ($x_i > 30$).*

Result 4. *Bids will be rank ordered such that $b_{D5\%} > b_R > b_{D25\%} \geq b_{FL}$ for all signals except very low draws ($x_i < 5$). For these low signal draws, the order becomes $b_{D5\%} > b_{D25\%} > b_R > b_{FL}$. Auction prices follow the same order.*

3. Experiment Design

The experiments are designed to analyze bidding behavior under various liability conditions. The design consists of four treatments. The baseline full liability treatment requires winning bidders to pay the full auction price, even when making losses. The three remaining treatments introduce forms of limited liability that vary between a high default penalty where bidders are liable for 25% of the auction price if they default, a low default penalty where bidders only pay 5% of the auction price under default, and a resale treatment which induces limited liability through trading in a post-auction resale market to the highest realized use value.

In all treatments, each round began with a second price (clock) auction with 2 bidders bidding for a hypothetical item of uncertain value. Each bidder drew a signal of the value, x_i, which was an i.i.d. draw from a uniform distribution on the range [0,50]. The final use value was determined using a simple 50/50 lottery over the two possible final use values, x_i or $x_i + 20$. During the auction, bidders knew the distribution of signals, their own draw, and the probability ($\frac{1}{2}$) that either x_i or $x_i + 20$ would become the realized final value after the lottery was played out. They also knew this probability was common across all bidders.

Bidders participated in the auction through a computer interface where they were able to see a bid clock increasing from 0 in increments of 1. The clock represented the current price in the auction and subjects chose to "drop out" when the bid clock reached a price they were no longer willing to pay. The auction was sealed, so in contrast to the more typical open clock auction format of the ascending (english) auction, subjects were not made aware of the dropout price of their opponent. The auction ended once both bidders dropped out. The winner of the auction was the subject who dropped out last (the highest bid), and the auction price was equal to the first dropout bid (second highest bid). If neither subject dropped out, the auction automatically ended at a price of 70, the maximum possible final use value. Any ties were broken randomly by the computer software.

At the conclusion of the auction, the uncertainty in final use values was resolved using a random draw by the computer software. A bidder who won the item earned the difference between his realized final value and the auction price. In the default penalty treatments, if the winning bidder was making losses he would automatically default if the penalty payment under default, which was a percentage of the auction price, was less than the loss from not defaulting. In the resale treatment, regardless of whether or not the winning bidder was making losses after final values were realized, the software would determine if the winner held the maximum realized value in the group and if not, it would automatically trade the item at a resale price equivalent to the highest realized value. The winning bidder would then earn the difference between the resale price and the auction price. While alternative, non-automated bargaining mechanisms for resale could have been used (e.g. take-it-or-leave-it offers or free-form bargaining), this design choice was made to keep experimental control over the resale market.[10]

The treatments are summarized below:

Full Liability (FL): The winner is fully liable for all losses in the event that earnings are negative.

Resale (R): In the event that the losing bidder has a higher realized final value from the lottery than the winner, the winner automatically resells to the losing bidder at a price equal to the final value of the losing bidder.

5% Default (D5%): In the event that the winning bidder would make a loss, the bidder automatically defaults (if the loss is less under default) and pays a default cost equal to 5% of the auction price.

25% Default (D25%): In the event that the winning bidder would make a loss, the bidder automatically defaults (if the loss is less under default) and pays a default cost equal to 25% of the losing bid.

The subjects were students at Florida State University and were recruited using ORSEE (Greiner, 2004). At the start of the experiment, they were given instructions and run through the Holt & Laury (HL) (2002) risk tolerance procedure. One of the choices from the HL procedure was randomly chosen for payment. Immediately after the HL procedure, all subjects participated in 30 paid auction rounds. In the first ten auction rounds subjects participated in the full

[10]For example, it is known that in less structured resale procedures (Pagnozzi & Saral, 2013) subjects often split the surplus of resale more favorably than what is predicted in a take-it-or-leave framework, or resale may even fail to occur because of disagreement. Under these less controlled resale mechanisms, if subjects bid less aggressively it would be unclear if subjects were choosing to do so because they do not understand the limited liability aspects of resale or because they believed that they would not be able to extract the resale surplus.

	Sessions	Subjects
FL / R	2	32
FL / D5%	2	32
FL / D25%	2	32
Session Structure		
Rounds 1-5	FL	
Rounds 6-10	R, D5%, or D25%	
Rounds 11-20	FL	
Rounds 21-30	R, D5%, or D25%	

Table 3.1: Experimental sessions and round structure

liability baseline (5 periods) followed by one of the limited liability treatments (5 periods). Prior to the beginning of each treatment, subjects were given instructions that included an example of bidding behavior, and the opportunity to participate in one unpaid practice period against a computerized bidder (robot) prior to the start of the paid periods. The last twenty auction rounds were separated into 10 full liability baseline rounds followed by 10 limited liability treatment rounds. Table 3.1 summarizes the treatment and session structure.

A total of 6 sessions were run with 16 participants in each session. In each session, the 16 subjects were divided into 2 groups for random rematching of partners in each period, leading to two independent groups per session. The same value draws were used between the full liability and limited liability treatments. The experiment was programmed using Z-tree software (Fischbacher, 2007) and in each session, the subjects' earnings were denominated in experimental currency units (ECUs). These were exchanged into dollars at a rate of $0.04 per ECU. Subjects were given 150 ECUs as an endowment that losses and profits were added to as the experiment progressed. The earnings from the HL procedure were not included in this endowment. Average earnings of the subjects were $28.16, including the show-up fee of $10 and HL earnings.

4. Results

Summary Statistics

I begin the results with summary statistics that provide a broad picture of the main treatment effects. Formal regression analysis and statistical tests of the observed regularities follow in later sections. In the analysis that follows, I differentiate between results based on data from all periods and results based on data from the last 20 periods by explicitly stating when the data was restricted (last 20).

Table 4.1 summarizes average bids and prices across treatments. We include the observed averages and the predicted averages, based on the lower bound draws used in the experiment. By results 1 and 2, bids under resale and the 5% default treatment should be greater than bids under full liability. While the observed averages are highest under these two treatments, the differences are not as high as predicted. In the 25% default treatment, we also find that average

		Bid	Price	
			Auction	Final
	FL	34.6(34.9)	25.1(26.5)	
	R	38.1(39.5)	29.1(30.8)	31.3(31.7)
	D5%	38.6(42.4)	28.8(34.8)	20.5(22.8)
	D25%	34.2(36.4)	25.1(29.2)	23.2(27.5)
last 20	FL	35.6(34.0)	26.0(25.8)	
	R	37.5(38.4)	28.3(29.8)	29.9(30.7)
	D5%	38.9(41.4)	29.0(33.5)	19.1(22.0)
	D25%	34.1(35.5)	24.7(28.6)	23.0(26.7)

Table 4.1: Average observed bids, prices, and efficiency. Predicted values in parentheses.

bids are slightly lower than predicted and comparable on average to the full liability treatment.

Prices can be examined at both the auction stage and post-default/post-resale stage (final prices). Auction prices result from the first drop out bid in a group and reach their highest levels in both the resale and 5% default treatments, but in contrast to the predictions of result 4 that provide a theoretical ranking in favor of the 5% default treatment, we find that average auction prices are actually slightly higher in the resale treatment. Restricting the data to the last 20 periods, reverses this ranking but again the differences between the two treatments remain small.

Final prices take into account any resale opportunities or default. In the resale treatment, the final price is equal to the maximum realized value of the group in the event that resale took place otherwise the final price remains equal to the auction price. In the default penalty treatments, the final price is equal to the percent of the auction price paid in the event of default; in the case of no default, the final price is again equal to the auction price. In the default treatments, the final price represents the revenue obtained by the auctioneer whereas the auction price in the resale treatment is the earned revenue. As expected, default lowers the final price but the effect is much less harsh in the high penalty (25% default) treatment than the 5% default treatment. We also observe a slight uptick in the final price of the resale treatment above what is observed at the auction stage, indicating an active resale market.[11]

Table 4.2 summarizes bidder earnings at the auction stage and final earnings, which are adjusted for default and resale. Also included are frequency measures for auctions ending in default or resale, and summary earnings conditioned on a bidder suffering a loss at the auction stage.

Focusing first on unconditional average earnings, it is clear that higher auction prices in the resale and 5% penalty treatments resulted in lower average earnings at the auction stage for bidders. In all treatments, bidders suffered losses at the auction stage but losses were most common in the low penalty (5%) treatment. Examining all periods, losses were least common in the full liability treatment but restricting the data to the last 20 periods demonstrates that bidders actually were less likely to make losses in the 25% penalty treatment in later periods.

[11] Out of 240 auction pairs, 71 (29.6%) of winners resold the item to the high value holder.

	(n)	Earnings Auction	Final	% Losses (n)	% Resale/Default (n)	Earnings in case of Loss Auction	Final
	FL (720)	17	17	18.5 (133)	–	−8.4	−8.4
	R (240)	11.9	15.3	22.5 (54)	29.6 (71)	−11.4	−0.4
	D5% (240)	12.2	14.4	25 (60)	22.9 (55)	−10.5	−1.9
	D25% (240)	14.9	15.5	20.4 (49)	8.8 (21)	−8.3	−5.4
last 20	FL (480)	14.9	14.9	22.7 (109)	–	−8.7	−8.7
	R (160)	11.6	14.6	22.5 (36)	29.3 (47)	−11.4	−2.1
	D5% (160)	11.8	14.6	26.9 (43)	25.6 (41)	−12.4	−2.0
	D25% (160)	14.6	15	20.6 (33)	7.5 (12)	−7.3	−5.5

Table 4.2: Average earnings and frequency of losses, default, and resale

Moreover, default was also exercised less frequently in the 25% default treatment, as only 12 of the 33 (36%) loss cases had losses greater than the penalty. Resale was frequently used, but it was not only used to mitigate losses. Out of the 71 resale active markets observed, 39 (55%) were cases of the winning bidder making losses and in 32 cases (45%), resale occurred despite no losses at the auction stage.

To examine the effectiveness of various liability rules in helping bidders with losses, I provide average earnings at the auction and final stage for cases where losses were sustained in the auction stage. In all limited liability treatments, contrasting average final earnings with those at the auction stage indicates that losses were considerably lessened through limited liability rules. The resale treatment was initially most effective at mitigating losses, but in later periods the random nature of whether or not a resale market would produce a bidder with a higher value led to approximately equal final losses in the 5% default and resale treatments.

		Auction Efficiency pre-lottery	post-lottery	Final Efficiency
	FL	.94(1)	.92(.96)	.92(.96)
	R	.93(1)	.92(.95)	1(1)
	D5%	.94(1)	.92(.94)	.74(.67)
	D25%	.92(1)	.91(.96)	.87(.88)
last 20	FL	.95(1)	.92(.95)	.92(.95)
	R	.94(1)	.93(.95)	1(1)
	D5%	.94(1)	.93(.94)	.72(.67)
	D25%	.93(1)	.92(.95)	.88(.86)

Table 4.3: Average observed efficiency. Predicted values in parentheses.

Table 4.3 summarizes the efficiency of the auction and how efficiency changes through the resolution of value uncertainty, resale, and presence of a default option. The lottery of final value creates two forms of auction efficiency. The first, pre-lottery auction efficiency is defined as the signal of the winner of the auction divided by the maximum signal of the two bidders. In theory, this efficiency should be 1 in all treatments because bid functions are increasing in the signal. The actual efficiency of the auction (pre-lottery), while lower than the theoretical prediction, was relatively high across all treatments. The lowest efficiency was realized in the 25% default penalty treatment, but overall the limited liability treatments do not differ by a large degree from the full liability baseline.

The second form of auction efficiency, post-lottery auction efficiency, is calculated after the uncertainty of the lottery is resolved and is equal to the realized value of the winner divided by the maximum realized value of the two bidders in the bidding group. In all treatments, the resolution of uncertainty resulted in a slightly lower efficiency.

In some treatments, bidders could default or resell and so the auction efficiency does not always capture final allocative efficiency. To account for this, table 4.3 includes a final efficiency measure. In the resale treatment, the secondary market always generates a final efficiency equal to 1 as item is always transferred to the bidder with the highest realized value in the group, so the more interesting form of final efficiency is in the default treatments since under default the item is returned to the auctioneer and the value generated is 0. Final efficiency in the 5% default treatment was much lower as bidders in these treatments almost always exercised the default option once the uncertainty was resolved. Default was not exercised as often in the 25% default treatment, so while the final efficiency under a high penalty is slightly lower than auction levels, the effect is not as strong as the low penalty option.

Bidding Behavior

I begin the analysis of bidding behavior by charting out the observed bids against the signal draws in figure 4.1. The experiment implemented a between subjects design for the limited liability treatments and a within subjects design for the comparison of bidding behavior to the full liability baseline. Hence, the graphs separate the full liability data by the particular limited liability treatment a subject would participate in for a better visual comparison of behavior. In addition to the bid observations, each graph includes lines for the lower bound (signal, x_i) and upper bound ($x_i + 20$) of the value lottery, regression lines for observed bids, and theoretical bid functions. To improve readability, a subsample of the full sample of observed bids is plotted.[12]

Bids appear higher when bidders have limited liability through a resale opportunity or with a low 5% default penalty than when they are bidding under full liability. In these two treatments, contrasting the regression line with the theoretical prediction, it is evident that bidders do not choose to bid as aggressively as predicted in the 5% default treatment, and they appear to only bid as aggressively as predicted for the lower range of values in the resale treatment. In the 25% penalty treatment, bids should theoretically be more aggressive than full liability bids before

[12] Specifically bids placed in rounds 3, 8, 13, 16, 23, and 26.

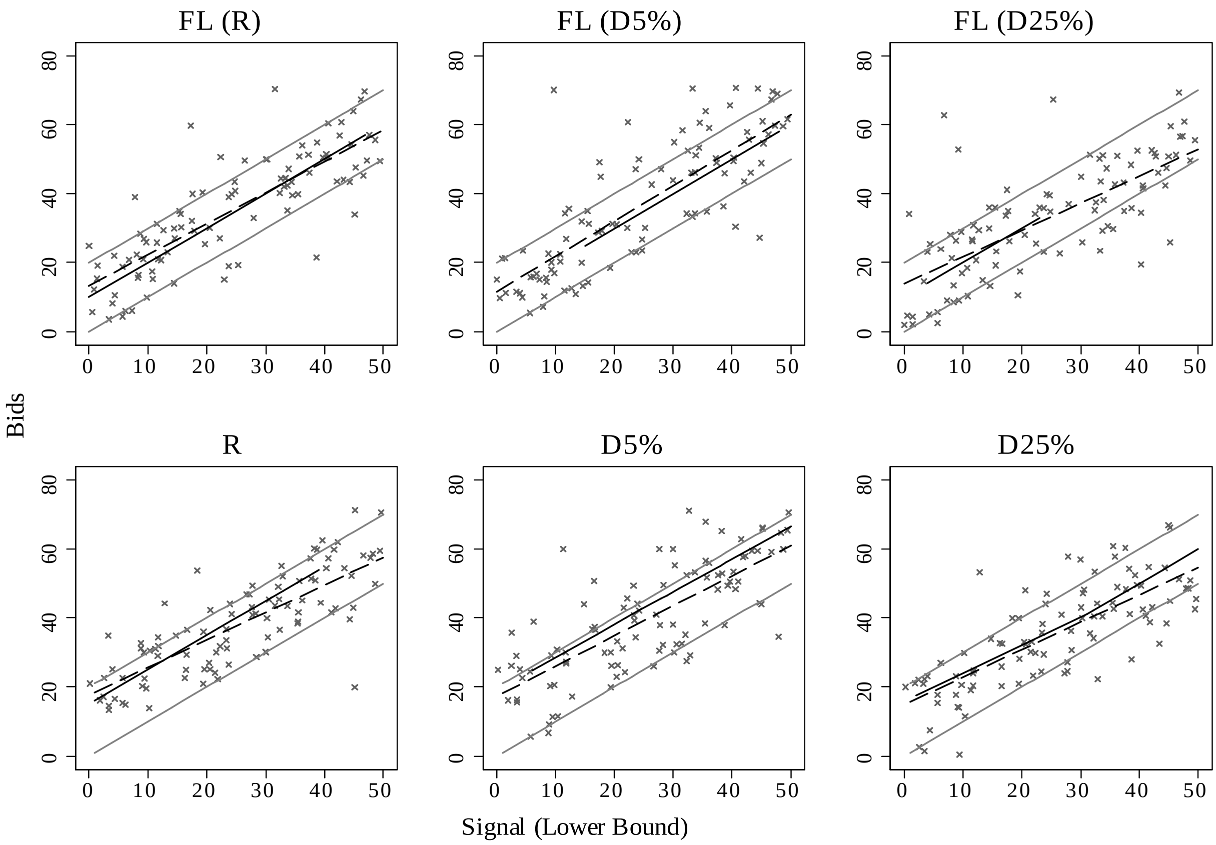

Figure 4.1: Sample of observed bids plotted against the lower bound signal draws, x_i. The upper ($x_i + 20$) and lower bounds (x_i) of are indicated in light gray. The dashed black lines are regression lines, while the solid black lines indicate theoretical bid functions.

the cutoff of 30. After, bids should be equivalent. The regression lines and overall scatterplots of the data in this treatment seem to indicate that bidders are not responding more aggressively to the presence of limited liability.

In all treatments, bids are theoretically predicted to lie below the upper bound of the lottery. While the majority of observed bids lie between the bounds of the lottery, we do observe some observations outside of these bounds.[13] Bids above the upper bound of the lottery appear most frequently in the resale and 5% default treatments, while bids below the lower bound of the

[13] In the resale treatment, bidding above the upper bound of the lottery bidding behavior might be explained as speculation (bidding aggressively to win the item and resell). However, because speculation can only occur in an auction where a secondary market exists, the presence of overbidding in the default penalty and full liability treatments dilutes the speculation hypothesis. It is also similar to behavior in sealed-bid second price auctions with known valuations (see Kagel, Harstad, and Levin (1987); Cooper & Hang (2008)). Note that this form of overbidding should be differentiated from overbidding in auctions that are not second price, particularly the first price auction, where overbidding has been attributed to risk aversion, starting with Cox, Smith & Walker (1988).

lottery appear more likely in the full liability and 25% default treatments.[14]

To test the relationship between theory and what was actually bid, regressions (reported in the appendix) were run using the predicted bid as an independent variable in each treatment. If subjects were bidding as theory predicted, the coefficient on the predicted bid would be equal to 1. In all cases, the coefficient on the predicted bid was less than 1, but significantly different from 1 in the resale treatment ($p = 0.0628$) and 5% default treatments ($p = 0.003$) providing evidence that bidding behavior in these two treatments were less aggressive than predicted.[15]

	(1)	(2)	(3)	(4)
	$x_i < 30$	$x_i < 30$ & last 20	$x_i > 30$	$x_i > 30$ & last 20
x_i	0.963***	0.970***	0.684***	0.697***
	(0.0312)	(0.0356)	(0.0719)	(0.0920)
R	2.988**	1.571	2.742**	1.826
	(1.253)	(1.509)	(1.290)	(1.487)
D5%	2.740**	3.607**	3.509**	3.460*
	(1.199)	(1.516)	(1.533)	(2.020)
D25%	0.289	-0.842	0.297	-0.0197
	(1.024)	(1.284)	(1.746)	(1.540)
# Safe	-0.525	-0.617	-0.0217	-0.356
	(0.488)	(0.490)	(0.470)	(0.488)
Losses_{t-1}	-1.177	-1.073	0.0251	-0.250
	(0.810)	(0.886)	(1.200)	(1.418)
Constant	15.46***	16.54***	21.37***	25.35***
	(2.753)	(2.730)	(4.166)	(4.741)
Observations	830	612	562	348
Clusters	96	96	96	84

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.4: Random effects regressions with bid as dependent variable using data from all treatments. Standard errors clustered at the subject level.

To formally examine the main treatment effects on bidding behavior, table 4.4 presents random effects bid regression results. To account for prediction differences based on signal draws, models 1 and 2 restrict the data to low values ($x_i < 30$), while models 3 and 4 are run on higher signal draws. Models 2 and 4 also restrict the data to the last 20 periods of play to examine learning dynamics. In all specifications, the full liability treatment is the baseline treatment and the signal x_i and treatment dummies are also included. The variable # Safe represents the number of safe choices made by a subject in the Holt and Laury (2002) risk preferences procedure and the variable Losses_{t-1} tracks if a subject made losses at the auction stage in the previous round.

[14] Bidders choosing to bid below the lower bound of the lottery, was also observed by Katok and Salmon (2009) in a similar experimental design under full liability rules.

[15] See table 5.1 in the appendix for these regression estimates.

Empirical Result 1: *Compared to the full liability baseline, bidding behavior is consistently more aggressive in the low penalty (5%) default treatment. Under resale bidding is only more aggressive in early periods and under a high default penalty bidding is never more aggressive than full liability.*

The positive significant coefficients across all specifications on the 5% default treatment give partial support for the theory. Bids under the 25% default penalty treatment are not significantly different from full liability for any signal, resulting in bids less aggressive than predicted for lower values. In models 1 and 3, the positive significant coefficients on resale indicate that this treatment resulted in more aggressive bidding (as predicted), but this effect losses significance once the data is restricted to the last periods of data (models 2 and 4). It is important to note that this is not necessarily due to less aggressive bidding in later periods in the resale treatment, as the constant rises in model 2, indicating higher average bids in the full liability treatment which makes it less likely to observe differences if bidders in the resale treatment were also not increasing bids over time.

Moving away from comparisons with full liability to differences in bidding behavior between limited liability treatments, 4.5 presents random effects regressions on bids in the limited liability treatments only. Across all models, the resale treatment is the baseline treatment. Models 1, 3, and 5 examine data from all periods, while the remaining models are the same models but restricted to the last 20 periods.

Empirical Result 2: *Between limited liability treatments, bidding behavior is least aggressive under a high default penalty.*

The robust finding is that bidding under the 25% default penalty is less aggressive than the resale treatment and the 5% default treatment (joint coefficient tests between D5 and D25 in models 1 and 2, $p \leq 0.039$). No significant differences are found between bidding behavior in the baseline resale case and the low default (5%) penalty.

Empirical Result 3: *Bidders who selected more safe choices in the HL test bid significantly less in the resale treatment.*

Beginning with model 3, additional controls are added for the number of safe choices made during the HL phase of the experiment interacted with treatment, where strong evidence emerges that risk preferences influenced bidding. The key result is that individuals who made more safe choices also bid significantly less in the resale treatment. This effect lies solely in the resale treatment as joint coefficient tests on the interactions with the variable Safe in specifications 3 - 6 are not significantly different from zero (coefficient tests $p \geq 0.632$ in the D5% treatment and $p \geq .793$ in the D25% treatment). This effect is robust, as it remains strong even when adding in additional controls for time effects.

	(1)	(2) last 20	(3)	(4) last 20	(5)	(6) last 20
x_i	0.899***	0.954***	0.916***	0.956***	0.916***	0.956***
	(0.0283)	(0.0292)	(0.0278)	(0.0289)	(0.0279)	(0.0290)
$x_i > 30$	-1.126	-1.354	-1.354	-1.373	-1.449	-1.362
	(1.167)	(0.917)	(1.150)	(0.924)	(1.166)	(0.919)
D5%	-0.116	0.785	-11.56*	-10.35	-14.77**	-8.617
	(1.995)	(2.157)	(6.160)	(6.639)	(6.317)	(9.267)
D25%	-4.286**	-4.052**	-14.71***	-13.61**	-16.73***	-19.33**
	(1.905)	(1.995)	(5.540)	(6.162)	(5.386)	(7.882)
D5%$\times(x_i > 30)$	1.504	1.816	1.483	1.768	1.657	1.783
	(1.572)	(1.455)	(1.548)	(1.461)	(1.515)	(1.447)
D25%$\times(x_i > 30)$	0.923	1.846	0.901	1.798	1.011	1.750
	(1.747)	(1.375)	(1.720)	(1.374)	(1.698)	(1.371)
# Safe			-1.821***	-1.944**	-1.820***	-1.944**
			(0.646)	(0.759)	(0.646)	(0.760)
D5×# Safe			2.207**	2.149*	2.206**	2.150*
			(1.034)	(1.123)	(1.035)	(1.124)
D25×# Safe			2.003**	1.850*	2.002**	1.850*
			(0.949)	(1.029)	(0.949)	(1.030)
Period			0.156***	0.123	0.0736	0.0732
			(0.0419)	(0.0931)	(0.0565)	(0.168)
D5×Period					0.152	-0.0656
					(0.0945)	(0.258)
D25×Period					0.0959	0.216
					(0.0993)	(0.196)
Constant	16.47***	15.61***	22.36***	22.40***	24.10***	23.73***
	(1.383)	(1.532)	(4.147)	(5.306)	(4.150)	(6.504)
Observations	1,440	960	1,440	960	1,440	960
Clusters	96	96	96	96	96	96

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.5: Random effects regressions with bid as dependent variable using data from the limited liability treatments. Standard errors clustered at the subject level.

Outcomes

In this section, I formally analyze auction prices, final revenue, final efficiency, and buyer earnings. Table 4.6 presents six pooled OLS regressions with standard errors clustered at the session level. The first two models focus on auction price, first across all periods and then the restricted set of 20 periods. The variables $X_{(1)}$ and $X_{(2)}$ represent the highest and second highest signal draws in the group, respectively, and we also include a variables for the risk profile of the group, max Safe, which is the highest number of safe choices in the group and min Safe, which is the minimum number of safe choices.

In theory, the auction price should follow the predictions of bidding, so the highest price

	(1)	(2)	(3)	(4)	(5)	(6)
	Auction Price		Final Revenue		Final Efficiency	
		last 20		last 20		last 20
$X_{(1)}$	0.129***	0.106***	0.186***	0.170***	0.00590***	0.00611***
	(0.0194)	(0.0202)	(0.0235)	(0.0269)	(0.000915)	(0.000795)
$X_{(2)}$	0.766***	0.888***	0.655***	0.716***	-0.00469***	-0.00628***
	(0.0189)	(0.0286)	(0.0380)	(0.0645)	(0.000997)	(0.00138)
R	4.623***	3.365***	4.532***	3.112***	0.0751***	0.0741***
	(0.612)	(0.872)	(0.556)	(0.797)	(0.00732)	(0.00764)
D5%	3.748***	3.564***	-4.508***	-6.466***	-0.177***	-0.195***
	(0.741)	(0.828)	(0.891)	(1.632)	(0.0213)	(0.0325)
D25%	0.206	-1.134	-1.654**	-2.711*	-0.0491**	-0.0293
	(0.705)	(0.912)	(0.685)	(1.298)	(0.0209)	(0.0187)
max Safe	-0.461*	-0.707**	-0.524*	-0.610**	-0.00571	-0.00331
	(0.243)	(0.264)	(0.261)	(0.232)	(0.00453)	(0.00483)
min Safe	0.272	0.581	0.138	0.232	-0.00298	-0.0101
	(0.466)	(0.614)	(0.337)	(0.490)	(0.00640)	(0.00920)
Constant	9.852***	10.44***	10.76***	12.02***	0.851***	0.885***
	(2.707)	(2.972)	(2.350)	(2.761)	(0.0521)	(0.0482)
Observations	1,440	960	1,440	960	1,440	960
Clusters	12	12	12	12	12	12

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.6: Pooled OLS regressions on noted variables clustered at session level.

should result from the 5% default treatment and the lowest price should occur in the full liability treatment.

Empirical Result 4: *Auction prices are highest in the 5% default and resale treatments.*

The significant coefficients on the resale and 5% default treatment dummies, across both specifications, and joint coefficient tests between resale and the 5% default treatment ($p > 0.212$) provides evidence for empirical result 4 and support for the theory that predicts the highest prices in the 5% default treatment.

The second highest signal, $X_{(2)}$, impacts auction price more than the highest signal, $X_{(1)}$, which would be expected in a second price auction where the highest losing bid sets the price. The data also provides an interesting behavioral effect of risk aversion on prices. The negative and significant coefficient on max Safe gives evidence that groups with more risk averse bidders also had lower prices, and this effect is strengthened over time as the magnitude is higher in the model 2 where the data is restricted to the last 20 periods.

Empirical Result 5: *Final revenue and final efficiency are highest in the resale treatment.*

Models 3 and 4 examine final revenue accrued by the auctioneer, which can differ from the auction price in the 5% and 25% default treatments because of bidder defaults, since the auctioneer only earns the penalty percentage of the auction price. In the full liability and resale treatments, final revenue is equivalent to the auction price. It is immediately evident that more aggressive bidding and the lack of a default option in the resale treatment leads to the highest final revenue. While auction prices were observed to also be high in the 5% treatment, the frequency of default significantly lowered revenue below what would be obtained under full liability. Default also significantly lowered final revenue in the 25% default treatment, but the magnitude of this effect is much weaker.

The last two models examine final efficiency, which takes into account changes in efficiency generated by default and resale. Under default, final efficiency is 0 and under resale, final efficiency is 1. In all other cases, final efficiency is equivalent to the auction efficiency. The positive significant coefficient on the resale treatment dummy provides evidence for empirical result 5. This result is driven by the experiment design because the resale market was always efficient - if there were gains from trade after the resolution of the lottery, the winning bidder would automatically resell to the losing bidder.

Final efficiency is significantly lower in the 5% default treatment than full liability. Behavioral differences in bidding also impacted efficiency as we find evidence that increases in the second highest signal of a group reduces efficiency. The higher the signal of the bidder who should, in theory, lose, the more likely it is that the auction allocation would be inefficient.

Table 4.7 provides pooled OLS regressions on bidder final earnings, which takes into account both resale and default. Models 1 and 2 are unconditional final earnings which provides a general view of which liability condition leads to an improvement in the welfare of bidders who are making losses and models 3 and 4 condition earnings on a bidder having made a loss in the auction stage to determine which liability treatment is most effective in mitigating losses.

The negative coefficients on the treatment dummies for the resale and 5% default treatment indicate that bidders earned significantly less under the 5% default and resale treatments. Coefficient tests also indicate that earnings are not statistically different between these two treatments ($p \geq 0.650$). More aggressive bidding under the limited liability treatments raises prices which directly impacts bidder earnings. In contrast, the 25% default treatment does not result in significantly different earnings from the full liability baseline.

Empirical Result 6: *For bidders making losses at the auction stage, resale and the 5% default penalty are equally effective in mitigating losses.*

Models 3 and 4 provide evidence that both resale and a low default penalty (5%), perhaps unsurprisingly, positively affect earnings when a bidder is making losses. The key point in this analysis is that the effect is equivalent - coefficient tests between these two treatments in models 3 and 4 indicate that no significant differences exist ($p \geq 0.524$).

	(1)	(2)	(3)	(4)
	Final Earnings		Final Earnings|Losses	
		last 20		last 20
$X_{(1)}$	0.832***	0.836***	0.00555	-0.0389
	(0.0319)	(0.0350)	(0.0606)	(0.0937)
$X_{(2)}$	-0.801***	-0.908***	-0.0297	0.0229
	(0.0379)	(0.0462)	(0.0650)	(0.0935)
R	-2.084***	-1.036	7.786***	6.489**
	(0.616)	(0.914)	(2.131)	(2.859)
D5%	-1.844**	-0.381	6.489***	6.684***
	(0.757)	(1.444)	(0.582)	(0.676)
D25%	-1.369	0.692	3.097***	3.379***
	(1.256)	(1.325)	(0.582)	(0.659)
max Safe	-0.0145	0.377	-0.170	-0.140
	(0.247)	(0.324)	(0.430)	(0.427)
min Safe	0.244	0.0636	-0.187	-0.368
	(0.481)	(0.666)	(0.421)	(0.479)
Constant	1.485	-0.335	-6.061**	-5.557
	(2.859)	(3.070)	(2.493)	(3.377)
Observations	1,440	960	296	221
Clusters	12	12	12	12

Clustered standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4.7: Pooled OLS regressions on final earnings and final earnings, conditional on a loss made at the auction stage. Standard errors clustered at session level

5. Conclusion

The primary goal of this paper is to study how different liability conditions affect bidder strategies in auctions and consequently seller revenue and bidder welfare. I provide direct evidence from an incentivized environment that bidders do respond to changes in liability environments, but the level of the response depends on the form and level of liability. Bidders are most aggressive when statutory liability requirements of the auction (i.e. default payments) are low, but they also respond aggressively to external market-based limited liability which is induced through the presence of a resale market. In contrast to predictions, bids under a high default penalty are not more aggressive than the full liability baseline and are significantly lower than the other limited liability environments.

Although the most aggressive bidding is observed under a low default payment, this does not translate into higher revenues because default limited the revenue collected by the seller to the penalty paid, which was a fraction of the full auction price. Therefore the highest revenue was achieved in the resale treatment, since slightly more aggressive bidding led to higher prices and default was not allowed. From the bidder's perspective, both resale and the low default penalty were most useful for mitigating losses.

This paper provides a first empirical look into bidder response to different limited liability environments, but there are a number of key differences between the environments tested here and the field that are important to note when interpreting these results. First, the choice of default was automated and future penalties either in reputation or monetary payment were not possible. In the field, bidders may be apprehensive about exercising a default option, particularly if reputation effects are likely, so these results are more informative for auctions where repeated interaction is not likely. Second, the resale market was also automated and transfers of the item between the winning and losing bidder took place immediately after the auction if gains from trade existed. While resale does not bear the same stigma as default, market frictions (e.g. disagreement or incomplete information of prospective buyers) are more likely in the field which would limit the efficiency of the resale market and probability of resale, which would lower the limited liability incentives provided by resale. However, if differences in behavior across the laboratory environments studied in this paper were not found, it would be difficult to claim that differences should be expected in the field.

In sum, the level of liability (high or low) and type of limited liability (e.g. statutory or market-based through resale) are both critical factors influencing the behavioral response of bidders who will in some cases bid more aggressively and in others bid as if the limited liability option didn't exist. These results suggest that sellers and bidders may prefer to allow post-auction resale as a way to help bidders with value uncertainty avoid losses while simultaneously increasing revenue, but in all cases, the structure of liability must be carefully considered when designing markets as it will change bidder strategies and consequently the revenue and efficiency achieved.

References

[1] Board, S. (2007). "Bidding into the Red: A Model of Post-Auction Bankruptcy," *Journal of Finance*,vol. 62(6), 2695-2723.

[2] Burguet, R., J.-J. Ganuza, and E. Hauk (2012). "Limited liability and mechanism design in procurement," *Games and Economic Behavior* 76(1), 15-15.

[3] Calzolari, G. and A. Pavan (2006), "Monopoly with Resale." *RAND Journal of Economics*, 73(2), 362-375.

[4] Cooper, D.J., and Fang, H. (2008). "Understanding Overbidding in Second Price Auctions: An Experimental Study," *The Economic Journal*, vol. 118 (532),1572 - 1595.

[5] Cox, J., Smith, V., Walker, J. (1988) "Theory and Individual Behavior of First-Price Auctions," *Journal of Risk and Uncertainty*, Springer, vol. 1(1),61-99.

[6] Fischbacher, U. (2007). "Z-Tree: Zurich Toolbox For Readymade Economic Experiments," *Experimental Economics* 10 (2), 171–178.

[7] Greiner, B. (2004) "The Online Recruitment System ORSEE 2.0 — A Guide for the Organization of Experiments in Economics." University of Cologne, Working Paper n.10.

[8] Haile, Philip A. (2003) "Auctions with Private Uncertainty and Resale Opportunities," *Journal of Economic Theory* 108, 72-110.

[9] Harstad, R.M., and M.H. Rothkopf. (1995) "Withdrawable bids as winner's curse insurance," *Operations Research* 43, no. 6 (1995): 983-994.

[10] Holt, C. and S. Laury (2002) "Risk Aversion and Incentive Effects," *American Economic Review* 92 (5), 1644-1655.

[11] Kagel, J.H. and Levin, D. (1986) "The Winner's Curse and Public Information in Common Value Auctions," *American Economic Review*, 76, 894–920.

[12] Kagel, J.H. and Levin, D. (1991) "The Winner's Curse and Public Information in Common Value Auctions: Reply," *American Economic Review*, 81, 362–369.

[13] Kagel, J.H., R.M. Harstad, and D. Levin (1987), "Information Impact and Allocation Rules in Auctions with Affiliated Private Values: A Laboratory Study," *Econometrica* 55, 1275-1304.

[14] Katok, E. and Salmon, T. (2009) "Response of Risky Choice to Variance Reduction," Working Paper.

[15] Onderstal, S. and Van der Veen, A. (2011) "Keeping out Trojan horses: Auctions and bankruptcy in the laboratory," Working Paper.

[16] Parlane, S. (2003) "Procurement contracts under limited liability," *The Economic and Social Review* 34(1), 1-21.

[17] Pagnozzi, M. (2007) "Bidding to Lose? Auctions with Resale," *RAND Journal of Economics*, 38(4), 1090-1112, Winter 2007.

[18] Pagnozzi, M. and K.J. Saral (2013) "Multi-Object Auctions with Resale: An Experimental Analysis," Working Paper.

[19] Roelofs, M. (2002) "Common Value Auctions with Default: An Experimental Approach," *Experimental Economics* Springer, vol. 5(3), pages 233-252.

[20] Waehrer, K. (1995) "A Model of Auction Contracts with Liquidated Damages," *Journal of Economic Theory*, 67(2), 531-555.

[21] Zheng, C. (2001) "High Bids and Broke Winners," *Journal of Economic Theory*, 100(1), 129-171.

Appendix

Default Proof:

If bidder i wins the auction at price p he can choose to keep the item, earning his final use value less the price $v_i - p$, or default and pay a penalty percentage, α, of the auction price for a total default payment of αp. If he loses the auction, he earns 0.

Any bid above the maximum possible realized use value, $v_i = x_i + 20$ will lead to negative expected earnings and is weakly dominated, so we restrict attention to bids less than $x_i + 20$.

For any auction price p below $x_i + 20$ bidder i will never choose to default if his realized final value is $v_i = x_i + 20$, since this always results in positive earnings. If his realized final value is low, $v_i = x_i$, he will choose to default if his payoff from defaulting $-\alpha p$ is greater than the payoff from not defaulting $x_i - p$ which occurs when

$$x_i - p \leq -\alpha p \quad \Leftrightarrow \quad p \leq \frac{x_i}{1-\alpha}$$

This defines the range of prices for which bidder i will never default, $0 < p \leq \frac{x_i}{1-\alpha}$, and the range of prices for which bidder i will always default if his realized final use value is low, $\frac{x_i}{1-\alpha} < p \leq x_i + 20$.

Since losing the auction will result in a payoff of 0, bidder i is willing to bid up to a price such that his expected payoff from winning the auction is equal to zero. This implies that bidder i is willing to bid up to a price in the interval where he may exercise default if his expected payoff is strictly positive for the range of prices below that where he would never default $0 < p \leq \frac{x_i}{1-\alpha}$. The expected payoff if the auction price reaches $p = \frac{x_i}{1-\alpha}$ is

$$\frac{1}{2}\left(x_i - \frac{x_i}{1-\alpha}\right) + \frac{1}{2}\left(x_i + 20 - \frac{x_i}{1-\alpha}\right)$$

which is strictly positive if and only if

$$x_i < 10\left(\frac{1-\alpha}{\alpha}\right) \equiv v_c$$

Bidder i will bid in the range of prices where default is exercised $\frac{x_i}{1-\alpha} < p \leq x_i + 20$ if his signal draw x_i is lower than the cutoff value v_c. For $x_i \geq v_c$, bidder i will never bid above $\frac{x_i}{1-\alpha}$ and consequently will never choose to default.

Therefore, if $x_i < v_c$ bidder i will bid in the range $\frac{x_i}{1-\alpha} < p \leq x_i + 20$, defaulting if $v_i = x_i$ and not defaulting if $v_i = x_i + 20$. His expected payoff if he wins at price p is

$$\frac{1}{2}(-\alpha p) + \frac{1}{2}(x_i + 20 - p)$$

and bidder i bids a price such that his expected payoff from winning the auction is equal to zero

$$p = \frac{1}{1+\alpha}(x_i + 20)$$

Which is the asserted equilibrium bid function, $b_D^*(x_i, \alpha)$ when $x_i < v_c$.

If $x_i \geq v_c$ bidder i will never default so his expected payoff if he wins at price p is

$$\frac{1}{2}(x_i - p) + \frac{1}{2}(x_i + 20 - p)$$

and bidder i bids a price such that his expected payoff from winning the auction is equal to zero

$$p = x_i + 10$$

Which is the asserted equilibrium bid function, $b_D^*(x_i, \alpha)$ when $x_i \geq v_c$.

□

5.1. Additional Regressions

	(1) FL	(2) R	(3) D5%	(4) D25%
Equilibrium bid, b_i	0.972***	0.943***	0.914***	0.947***
	(0.0196)	(0.0298)	(0.0268)	(0.0316)
Observations	1,440	480	480	480
Subject Clusters	96	32	32	32

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5.1: Pooled OLS regressions with bid as dependent variable using data from all treatments. Standard errors clustered at the subject level.