Mitigating Sniping in Internet Auctions

by

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- John F. Kennedy

Dedication

To my grandfather, Richard Cochran.

An amazing man whose spirit, stubbornness, and laughter will never be forgotten.

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Abstract

My dissertation discusses a mechanism that thwarts sniping and improves efficiency in ascending Internet auctions with fixed ending times, specifically eBay. The first research chapter proposes a design of the bidding mechanism and the second chapter tests the effectiveness of the mechanism in a controlled environment. In addition, it presents an innovative theoretical representation of the eBay bidding environment.

The first chapter investigates theoretically whether sellers can improve their profits in eBay-like auctions via the implementation of bidder credits. The analysis predicts that providing a credit, similar to a coupon or discount, for early bidding can thwart sniping and increase seller profit. The paper formulates and analyzes a multi-stage auction model with independently and identically distributed private values, where bidders place proxy bids. I show that sniping can emerge as a Bayesian-Nash equilibrium strategy so long as late bids run the risk of not being successfully received by the auctioneer; extending the prior work of Ockenfels and Roth. This equilibrium is inefficient and yields the worst outcome for sellers. The proposed credit mechanism awards a single early bidder a reduction, equal to the value of the credit, in the final price if he wins the auction. The optimal credit satisfies two necessary conditions; first, it increases seller ex-ante profit and second, it incentivizes bidders to deviate from the sniping equilibrium. Relative to the surplus generated by the sniping equilibrium, implementing the credit increases seller surplus and improves welfare.

The second chapter experimentally investigates the effectiveness of the credit mechanism. In particular, it compares bidding strategies, seller profit, and overall

efficiency in auction environments similar to eBay with and without credit incentives. I observe a significant decline in the frequency of sniping when subjects have the opportunity to receive the credit. The credit also improves auction efficiency primary because subjects overbid in auctions with the credit regardless of which subject has the credit. A within-subjects design allows me to directly compare differences across treatments conditional on the subjects being snipers. Auctions with snipers yield significantly lower profits to sellers because non-sniping rivals are bidding less aggressively when competing against a sniper.

CHAPTER 1

Introduction

The primary focus of my dissertation is to analyze bidding behavior in continuous time auctions that have a fixed ending time, meaning the auction ends on a predetermined date at a specific time. Being able to anticipate the auction's ending time, many bidders will strategically wait until the very last moment of the auction to place a single snipe bid. Sniping is detrimental to sellers; they prefer for bidders to bid early and battle for the item in highly competitive bidding wars. The subsequent chapters of my dissertation discuss a bidding mechanism that is designed to mitigate sniping and incentivize early bidding. The first essay formulates theoretical conditions that must be satisfied for the mechanism to be effective. However, the assumptions made in simplified theoretical models may not fully describe individual rational and thus, it is essential to test the theoretical predictions in a controlled environment. The second essay relies on experimental methods to evaluate the effectiveness of the bidding mechanism.

eBay is most recognizable auction house that features auctions with fixed ending times. Founded in 1995, eBay competed directly with Yahoo and Amazon for a share of the Internet auction market. Buyers found the auction's fixed ending time, which was unique to eBay at the time, appealing. High competition among buyers for a limited number of items attracted sellers to the auction house and eventually lead to the demise of Yahoo and Amazon auctions. eBay continues to thrive as a near-monopolist in the market. It currently provides services to approximately 100 million

registered users all over the World and brings in approximately $2 billion in revenue each quarter.

The bidders on eBay are diverse in their experience with Internet auctions and their bidding strategies. Some bidders submit a single early bid and let the proxy bidding system bid for them. Others prefer to manually and frequently increase their bids throughout the auction; this strategy is typically described as naive. Another strategy that is common is waiting until the last seconds of the auction to place a bid, referred to as sniping. The late arrival of a snipe bid does not leave sufficient time for rival bidders to place a bid in response. Thus, sniping exploits naive bidders and the numerous bidders who are underbidding; see Conner (2005).

Sniping on eBay, and bidding behavior in general, has been studied extensively by Ockenfels & Roth (2001, 2002, 2006). Researchers and eBay strategists believe bidders snipe to avoid starting back-and-forth bidding wars with early bidders, which incrementally raise auction prices. [Ely & Hossain (2009) and Gray & Reiley (2005).] Many experienced bidders recognize the benefits of sniping, lower prices, and regularly endorse the strategy in books, blogs, and discussions. Empirical research from Wenyan & Bolivar (2008), Bajari & Hortacsu (2003), and Schindler (2003) provides insight into the popularity of sniping, as does the emergence of third party sniping agencies such as eSnipe. If sniping becomes the norm, then sellers are likely to see revenues dwindling. Thus, to generate greater auction profits, sellers and eBay have a common interest in mitigating sniping.

The first essay in my dissertation develops a theoretical model of an eBay auction and proposes a mechanism, which offers price reductions for bidding early, as a means of incentivizing early bidding (raising prices) and improving auction efficiency. The concept is equivalent to a receiving a store credit which when applied to purchases

lowers the buyer's out of pocket expense. The credit is awarded to a single early bidder, who receives a price reduction, by the amount of the credit, if the bidder also wins the auction. By design, the credit (1) deletes equilibria where bidders snipe and (2) improves ex-ante seller profits relative to her profits when bidders snipe. Furthermore, the credit improves efficiency by insuring the item is sold in equilibrium.

I present a novel theoretical model of an eBay auction as a three-stage game with partially observed actions and incomplete information. Despite its simplicity, the model accurately describes the proxy bidding environment while simultaneously avoiding the complications of permitting bidders to have a continuum of bidding opportunities. In the absence of the credit, I show that sniping constitutes a symmetric Bayesian-Nash Equilibrium which is consistent with Ockenfels & Roth (2006) and Campbell & Zhang (2011). The credit will solicit a bidder to deviate from the sniping and thus, early value bidding is a unique symmetric equilibrium. The optimal credit depends on various factors of the model but I demonstrate that offering credits is feasible. Furthermore, I show that a very small credit can increase the seller's profit by over seven times the amount of the credit.

The second essay experimentally investigates whether the theoretical credit predicted by Nagy (2013) is effective at alleviating sniping behavior. Ariely, Ockenfels, & Roth (2005) and Durham et al. (forthcoming) observe a significant amount of late bidding and sniping by subjects in controlled laboratory environments. I observe approximately half of the subjects placing at least one snipe bid during the baseline eBay treatment. In addition, sniping becomes more frequent by the end of the auction which is consistent with the positive correlation between sniping and experience that is discussed by Ockenfels & Roth (2002). Offering a credit reduces the amount of sniping significantly to less than 1% of all observed bids being a snipe.

Furthermore, a comparison of average seller profit in auctions during the eBay treatment with a sniper and in auctions during the Credit treatment shows a significant increase in profits which is due to aggressive overbidding when credits are offered. Thus, the credit is successful at altering bidder behavior and improving the outcome the auction in favor of the seller.

The experimental results also expose some shortfalls of the mechanism. When the credit becomes available, most of the original snipers adopt a modified sniping strategy of submitting a low early bid to capture the credit and then waiting until the last stage of the auction to bid. The ex-snipers are successful when using this strategy because their rivals continue to bid naïvely. This suggests that the underlying cause of sniping is the inability of bidders to recognize the threat of snipers and to use the proxy bidding system to their advantage. Thus, the best mechanism to thwart sniping may be to simply educate bidders.

CHAPTER 2

Incentivizing Early Bidding Using Credits in Internet Auctions

2.1 Introduction

Internet auction marketplaces, eBay being the largest and most prominent example, have been growing in popularity due to ease of use, worldwide accessibility, and lower price mark-ups, compared to traditional retailers.[1] In any given auction, participating bidders range from first time novices to highly experienced professionals. Given the diverse bidding population, it is no surprise that a variety of bidding strategies are observed.

A distinct feature of eBay auctions is that each concludes at a specific, fixed, ending time. Some bidders have learned that waiting until the last few moments of the auction to submit their bids, referred to as "sniping", can be advantageous.[2] From a sample of 240 auctions on eBay, Ockenfels and Roth (2002) observed 29

[1] Medved, an auction tracking publisher, estimated that 132 million bids were placed on eBay during a 12-month period between 2010 and 2011, a 780% increase from 2006 when approximately 15 million bids were placed.

[2] A lab experiment by Ariely, Ockenfels, and Roth (2005) finds that late bidding becomes more frequent as bidders gain experience.

In addition, the ability to snipe on eBay attracts many bidders to the auction house. So although eBay suffers monetary losses due to sniping, it is at the same time maintaining a steady stream of bidders which generates a demand for more auctions/sellers. It may be the case that the revenue generated from a high quantity of lower-priced auctions outweighs the revenue from a low quantity of high-priced auctions. Thus, eBay focuses on maintaining happy bidders as opposed to happy sellers.

auctions having bids placed in the last 10 seconds, and 89 having bids placed in the last minute. Bajari and Hortacsu (2003) and Schindler (2003) also find empirical evidence to support that some bidders are sniping on eBay.

The popularity of sniping has created a demand for third party sniping agents. eSnipe is one popular sniping service; it places more than 10,000 bids a week on behalf of its members. In addition, numerous eBay bidding strategy books and advice blogs encourage bidders to snipe.[3] This paper will show that there exists a symmetric equilibrium where bidders snipe but it is inefficient and yields the worst outcome for sellers. My primary objective is to design a mechanism that thwarts sniping and improves efficiency.

A snipe bid is placed so there is insufficient time remaining in the auction for a rival bidder to place a bid in response to it. If rival bidders are unable to increase their bids, then sniping can increase the sniper's probability of winning and reduce the price he will pay.[4] Had the time been sufficient to react, then the bidders might have engaged in a back and forth bidding war. Bidding wars will incrementally raise the price and improve the seller's revenue. A field experiment by Ely and Hossain (2009) found that, conditioning on the number of bidders, the average final selling price was significantly lower in auctions where the experimenters sniped than in auctions where they submitted a single early bid, $13.29 compared to $14.30. Intuitively, a mechanism that encourages bidding wars should be advantageous to sellers.

Snipers attempt to bid as close to the auction's ending time as possible to assure

[3]Examples include: Ford (2008), the *eBay Hacks* book series by David Karp, cNet-Insider Secrets: "Better Buying on eBay", and articles posted on eBay Guides such as "Sniping - It's a Solid Strategy for Successful Bidding" (August 2012).

[4]Ockenfels and Roth (2001, 2002) argue that bidders snipe to avoid bidding wars and higher prices. Third party sniping agencies also claim that sniping reduces prices. During a period of 30 days in 2011 (mid-February 2011 to mid-March 2011) eSnipe reported that buyers were willing to pay $16 million on won auction items but only ended up paying $11.2 million.

no rival can respond. Miscalculating the time needed to place a bid may result in a sniper missing the auction's ending time. Snipe bids may also not be received, in other words "lost", because of high Internet traffic, which can slow eBay's ability to process new bids.[5] However, for a sniper, the appeal of paying a low price is worth the risk of his bid not being successfully received by the auctioneer.

eBay has two features that may partially protect sellers and frustrated early bidders from snipers. The first is the "Buy it now" option, which allows bidders to purchase the item at a set price, as opposed to bidding for the item in the auction. The inclusion of the Buy-It-Now option is at the discretion of the seller, and many sellers choose not to include it. This feature allows eager buyers to avoid the risk of being outbid in the last moments of the auction.[6] In auctions when no Buy-It-Now option is available, Onur and Tomak (2003) observe a greater number of snipe bidders and Durham et al. (forthcoming) observe lower prices.

The second feature is the proxy bid system which allows eBay's software to incrementally bid for a bidder, whenever he is not the highest bidder, up to the bidder's submitted proxy bid. eBay does not reveal the highest proxy bid, so a sniper could still be out-bid by a bidder who submitted a higher bid earlier in the auction. eBay's recommendation to bidders is to "bid the maximum amount that you're willing to pay for an item" prior to the last moments of the auction. If a bidder follows this strategy and he is outbid, by perhaps a sniper, then he was fated to lose. If, instead, the bidder bids less than his maximum willingness to pay, then he may lose the auction

[5] In a survey conducted by Ockenfels and Roth (2002) 10% of respondents indicated they missed a snipe due to Internet network delays, and another 10% indicated they missed placing a snipe bid for personal delays. Steiglitz (2007) estimated only 1% of his personal snipe bids were lost but he reported that eSnipe indicated that 5% of their attempted bids were not relayed.

[6] Reynolds and Wooders (2009) show that there is a positive relationship between bidder risk aversion and acceptance of the Buy-It-Now price. Furthermore, they find that the inclusion of a Buy-It-Now price increases seller revenue.

to a rival's bid he would have been willing to exceed.

Conner (2005) argues that, despite the recommendation, many early bidders continue to underbid, which incentivizes their rivals to snipe. In auctions observed by Ockenfels and Roth (2006), 508 bidders, out of 1339, submitted more than one bid during the course of the auction. In addition, they show that sniping is a best response to bidders who initially bid low and then bid upwards in small increments whenever they are not the highest bidder. Ambrus, Burns, and Ishii (2012) show that gradual bidding strategies can be supported in equilibria but the result relies on bidders having randomized opportunities to place bids during the course of the auction.

eBay is strategically equivalent to a second price auction. The bidder with the highest bid at the auction's ending time wins the item and pays (a small increment above) the second highest bid. Various theoretical models have been used to explain sniping, and other bidding strategies, in eBay-like auctions. [Campbell and Zhang (2011), Wang (2006), Ambrus, Burns, & Ishii (2012), Bajari and Hortacsu (2003), Schindler (2003).] In a private values context, Ockenfels and Roth (2006, 2001) show there exist two equilibria: one where all bidders bid their values early, and a second where all bidders snipe.[7] Mutual sniping is an equilibrium if and only if the probability of a snipe bid being successfully received by the auctioneer is not too small nor is it one. The expected price received by the seller, in equilibrium, is higher when the bidders bid early compared to when they all mutually snipe.[8]

[7] There are also equilibria where a bidder submits both early and late bids. However, a recent finding of Gonzales, Hasker, and Sickles (2009) rejects this result.

[8] When the uncertainty in a late bid being successfully received is removed and values are affiliated, Wang (2006) concludes that late bidding is no longer a symmetric equilibrium. However, if the auction is immediately repeated with identical items, and one less bidder, then Wang (2006) shows sniping is a symmetric perfect Bayesian equilibrium but only when undominated and monotonic strategies are considered. Sniping is beneficial in the first auction because bidding early reveals information about the bidder's value which could hinder him if he participates in the second auction.

An auction mechanism that gives an incentive for bidders to bid early, and start a bidding war, could increase seller revenue via a transfer of surplus from the bidders to the sellers. The incentive mechanism I have devised offers a "credit" to a single bidder who bids early; if the winning bidder has a credit, then the final price is reduced by the amount of the credit. The opportunity to receive a discount on the final price encourages bidders to deviate from equilibrium sniping strategies in an attempt to capture the credit. The credit also increases the bidder's maximum willingness to pay for the item, which may lead to an increase in the final price.

I use a second price auction model with private values and two bidders that is similar to Ockenfels and Roth (2006) but has two distinct differences. First, values are drawn from a continuous distribution as opposed to being simply High or Low. Second, the auction is divided into unique stages to avoid having to condition bidder strategies on a continuous time variable. In the absence of the credit mechanism, the most profitable symmetric Bayesian-Nash Equilibrium strategy for bidders is to coordinate on sniping.

The objective of the credit is to omit the sniping equilibrium and improve the seller's profit. By implementing the credit, I am able to construct a necessary condition for which bidding early is the unique symmetric equilibrium. This condition creates a lower bound on the optimal credit a seller should offer. Offering a credit is costly to the seller so, by construction, the credit must generate higher profits. Given the seller's constraint and the bidders' incentive condition, I show by example that

Bidders also do not bid their values in the first auction by the same reasoning. Alternative non-private value models have been used to model the eBay auction environment. Bajari and Hortacsu (2003) assume items have a common value and each bidder receives a private signal. They find sniping is a symmetric Nash equilibrium and argue that late bidding is a consequence of bidders wanting to keep their private signals secret, preventing rival bidders from updating their information on the item's value. Schindler (2003) arrives at a similar conclusion using an interdependent values model and shows seller revenue is smaller when bidders snipe.

it is feasible to offer credits as a means of thwarting sniping. The optimal credit can also improve efficiency by assuring the good is always allocated to a bidder.

2.2 Model: Multi-Stage Auction

On eBay, bidders place multiple bids throughout the course of the auction; the submission time of each bid is recorded down to the millisecond. To model the auction's continuous time structure, Ockenfels and Roth (2001, 2006) and Campbell and Zhang (2011) allow bidders to place bids at a continuum of times on the unit interval.[9] Bids submitted at times strictly less than 1 can be reacted to by rival bidders in the future. The submission times converge towards an endpoint where time is equal to 1. Bids submitted at time 1 cannot be reacted to by rival bidders. This approach, of allowing for a continuum of bidding opportunities, can be problematic because it results in bidders having an infinite number of strategies. My approach is to, instead, deconstruct an eBay auction into unique stages.

eBay can naturally be described in three, simple, stages. The first is an initial bidding stage where bidders can submit their first bids. Bids in this stage are submitted early enough for rival bidders to place bids in reaction to them. A bidder who bids early would submit a bid in this stage. Next is a responding bidding stage where bidders can react to submitted bids; back-and-forth bidding wars would take place in this stage. The responding stage begins once the first bid is observed and ends significantly close to the auction's ending time. In the final stage, there is only enough time remaining for the bidders to submit one last bid. A bidder who intends

[9] Ambrus, Burns, and Ishii (2012) use a similar approach with the auction starting at time $T < 0$ and ending at time 0. Their model differs significantly from Ockenfels and Roth (2006) and Campbell and Zhang (2011) because it randomizes bidding opportunities and assumes a public common value.

to snipe would only bid in the last bidding stage.

Similar mutli-stage models have been used by previous researchers to explain eBay auctions. Schindler (2003) and Bajari and Hortacsu (2003) both divide the auction into two distinct stages. The first stage is an open-exit ascending auction, where bidders decide when to drop out,[10] and the second stage is a standard second price sealed bid auction. The problem with using an open-exit ascending auction is that it does not fully capture the proxy bidding component implemented on eBay. Alternatively, Ariely, Ockenfels, and Roth's (2005) experimental design uses an endogenous number of "early" bidding periods and a single late bidding period; each bidding period is a second-price auction but with the bidders' highest bids being stored across periods. The late bidding period begins once an "early" bidding period passes with no new bids being placed. To incorporate the "Buy-It-Now" feature, Onur and Tomak (2003) present an informal model with three bidding stages that all occur with certainty. In the first stage, each bidder chooses between buying it now, waiting, or acting; then in the second and third stages, each chooses between waiting or acting.

I propose modeling an eBay auction as a multi-stage game with partially observed actions and incomplete information. The auction, as a game, consists of three bidding stages where in each stage bidders can simultaneously submit a single, private, proxy bid. At the start of each stage bidders observe the outcome, comprised of the highest bidder and the second highest bid, of every previous stage. All the bidders' actions are not fully observed in each stage because eBay does not reveal the highest bidder's proxy bid.

[10] In Bajari and Hortacsu (2003) bidders observe the time and prices at which bidders drop out of the first stage of the auction; however, regardless of the bidder's drop out time they still participate in the second stage. Schindler (2003) uses a Japanese (ascending clock) auction for the first stage; a Japanese auction is essentially an ascending button auction. As the auctioneer slowly raises the price bidders must decide, at each new price, whether to stay in the auction or drop out; the dropout price is a binding bid for the bidder.

Stage 1 is the early (initial) bidding stage[11] where bidders have the option of either submitting or not submitting a bid. If at least one bidder submits a bid in Stage 1, then the auction proceeds to Stage 2 and all bidders have the opportunity to react to the Stage 1 bids. In Stage 2, a bidder can either submit a new higher bid or keep his previous Stage 1 bid.[12] Bids in Stage 1 and Stage 2 are received by the auctioneer with 100% certainty. If no bidder submits a bid in Stage 1, then Stage 2 will not exist because there are no initial bids to react to.

The auction moves to Stage 3, the late bidding stage, at the end of Stage 2 or if no bids were submitted in Stage 1. In Stage 3, each bidder can submit a new higher bid or keep their previous bid. Unlike in the previous stages, bids submitted in Stage 3 have a positive probability of not being received by the auctioneer. If a bidder's bid is not successfully received, then the bidder keeps his bid from the previous stage. The uncertainty in the success of a late bid is consistent with a bidder's inability to perfectly predict the time required to submit a new bid.

The auction ends at the conclusion of Stage 3 with the highest bidder winning the auction. The price the winning bidder pays is (a small increment above) the second highest bid. The winning bidder's profit is his value minus the price, and the losing bidder's profit is zero. The next section provides a theoretical representation of the proposed three stage game.

[11] Although I refer to this stage as the early bidding stage it does not necessarily represent the first moments of the auction. It simply represents the portion of the auction up to when the first bid, which can be reacted to, is observed. If the first bid is placed 2 hours before the auction ends, then Stage 1 would last from the auction's start until 2 hours before it's end.

[12] The bid in Stage 2 can be thought of the highest bid a bidder would submit during the reaction stage. The process with which the bidder arrived at that bid, such as through a bidding war or a single proxy bid, is irrelevant.

2.3 Theoretical No Credit Model

For simplicity I consider a two bidder case, $N = 2$. There are two symmetric and risk-neutral bidders in an auction for a single indivisible good. Each bidder, indexed by $i \in N = \{1, 2\}$, has a private value, or maximum willingness to pay for the good; bidder i's value is denoted by $v_i \in V = [\underline{v}, \overline{v}]$ where $0 < \underline{v} < \overline{v}$. Each v_i is independently drawn from the same distribution represented by the c.d.f. F with support $[\underline{v}, \overline{v}]$; let f be the corresponding density function. Let G denote the c.d.f. of the second highest value of N bidders and let g denote the density function. In the two bidder case, if i has the highest value, then G is the c.d.f of v_{-i} and $G(v_{-i}) = F(v_{-i})$. The seller's value for the good is normalized to 0.

The auction is comprised of a null stage and three bidding stages; stages are indexed by $t \in T = \{0, 1, 2, 3\}$. The stage at $t = 0$ is a, non-bidding, null stage where bidders learn their values. In each bidding stage, $t > 0$, bidders have the option of submitting a bid or not bidding. Any submitted bid must be greater than the public reserve price, or minimum starting bid, r. Assume $0 < r < \underline{v}$ to ensure that both bidders are willing to participate in the auction.

The public outcome of stage t consists of a price and high bidder. The price at the end of stage t is denoted $p^t \in P = [r, \infty)$ and is equal to the second highest bid. The highest bidder at the end of stage t is denoted $w^t \in W = N \cup \{\emptyset\}$. If $w^t = \emptyset$, then there is no high bidder and consequently no bids. The public outcome of stage t is expressed as a 2-tuple $(p^t, w^t) \in P \times W$. The history, of public outcomes, observed at the beginning of stage t is $h^{t-1} \in H^{t-1} = \left\{ \left(p^{t'}, w^{t'}\right)_{t' \leq t-1} \ , p^{t'} \in P, w^{t'} \in W \right\}$. Histories depend on the bidders' actions in each stage of the auction.

Bidder i's action in stage t is a (proxy) bid denoted b_i^t. Bidders act simultaneously in each bidding stage $t > 0$. If bidder i has not submitted any bids at the beginning

of stage t', then $b_i^t = 0 \; \forall t < t'$. Bidders do not bid in the null stage so $b_i^0 = 0 \; \forall i$. If a bidder chooses to submit a positive bid in stage $t > 0$, then his bid must satisfy three criteria. First, it must be at least r. Second, it must be greater than his bid from the previous stage. And third, it must be greater than p^{t-1}. For the two bidder case, the third criteria is unnecessary because both bidders' bids at time t are either greater than or equal to the price at the end of stage t.

Each bidder's set of feasible bids at stage $t > 0$ is dependent only on his bid in the previous stage. Let $B_i(b_i^{t-1})$ denote bidder i's feasible set of bids in stage t and let B_i^t be the set of all feasible bids in stage t. Given $b_i^0 = 0$, then the set of feasible bids at $t = 1$ is $B_i(b_i^0) = [r, \infty) \cup \{0\}$. For $t > 1$, if $b_i^{t-1} = 0$, then $B_i(b_i^{t-1}) = [r, \infty) \cup \{0\}$; or if $b_i^{t-1} \geq r$, then $B_i(b_i^{t-1}) = [b_i^{t-1}, \infty)$.

A strategy for bidder i is a sequence of functions, $\left\{\beta_i^t\right\}_{t=1}^3$, where each $\beta_i^t : V \times H^{t-1} \rightarrow B_i(b_i^{t-1})$; so $\beta_i^t(v_i, h^{t-1}) \in B_i(b_i^{t-1})$. Let β_i represent i's strategy profile for the entire auction.

If neither bidder bids in Stage 1, then the bidders do not bid in Stage 2. Regardless of whether Stage 2 is reached, a bidder's strategy must dictate his action in Stage 2. If Stage 2 is bypassed, then the bid recorded by the auctioneer may not be identical to the bids described in the bidders' strategies. Let the bidders' recorded actions in stage t be a two-tuple $(a_1^t, a_2^t) \in A^t = B_1^t \times B_2^t$ where a_i^t denotes the recorded action of bidder i in stage t and A^t denotes the set of all possible recorded actions in stage t. The recorded actions of the bidders in each bidding stage will depend directly on β_1 and β_2.

The game progresses through each bidding stage sequentially. At the conclusion of Stage 3, a move by Nature determines whether each bidder's Stage 3 bid was successfully submitted. Let y_i denote Nature's move for bidder i such that $y_i \in Y =$

$\{0,1\}$. If $y_i = 0$, then bidder i's bid was unsuccessful; if $y_i = 1$, then bidder i's Stage 3 bid was successful. The likelihood that a bidder has sufficient time to place a "last-second" bid is represented by $\rho \in (0,1)$, i.e. Prob$(y_i = 1) = \rho$, which is exogenous. Nature's move is a two-tuple $(y_1, y_2) \in Y \times Y$ that is unobservable to the bidders.

Bidders do not bid in the null stage, $t = 0$, so the outcome is $(r, \emptyset)$ and $H^0 = \{(r, \emptyset)\}$. In stage $t = 1$, bidders simultaneously submit bids according to their bid functions β_1^1 and β_2^1. The outcome, (p^1, w^1), determines how the auction proceeds through Stage 2. If $h^1 \in \{(p^0, w^0)\ ,\ (p^1, w^1) \mid w^1 \in N\}$, indicating at least one bidder bid in Stage 1, then both bidders bid according to β_i^2 in Stage 2 and $a_i^2 = b_i^2\ \forall i$. If $h^1 \in \{(p^0, w^0)\ ,\ (p^1, w^1) \mid w^1 = \emptyset\}$, indicating neither bidder bid in Stage 1, then Stage 2 is bypassed and $a_i^1 = a_i^2\ \forall i$. If $a_i^1 = a_i^2\ \forall i$, then the outcome of Stage 2 is identical to the outcome of Stage 1; $(p^2, w^2) = (p^1, w^1)$. After both bidders observe $h^2 \in H^2$, each decides whether to submit a new bid in Stage 3. The move by Nature determines the recorded actions of the bidders in Stage 3. For bidder i, if $y_i = 0$, then $a_i^3 = a_i^2$; if $y_i = 1$, then $a_i^3 = b_i^3$. Payoffs are realized at the end of the auction and are calculated using the outcome of Stage 3, (p^3, w^3).

As previously mentioned, the outcome of stage t is a pair (p^t, w^t) and is determined using the bidders' recorded actions (a_1^t,a_2^t). The highest bidder at the end of stage t is

$$w^t = \arg\max_{i \in N} \left\{ a_{(i)}^{\bar{t}} \mid a_{(i)}^{\bar{t}} \geq r \right\} \quad \text{such that } \bar{t} = \min \left\{ \arg\max_{t' \leq t} \left\{ a_i^{(t')} \right\} \right\} \ ,$$

where $\bar{t}$ gives precedence to the earlier bidder in the event of a tie. However, if both bidders place identical bids in the same stage, then the high bidder is randomly determined. The losing bidder in the two bidder model, denoted $-w^t$, is the second highest bidder. The price at the end of stage t is $p^t = \max\left\{a_{-w^t}^t\ ,\ r\right\}$, the maximum of the second highest bid and the reserve price.

A strategy profile for the auction is denoted $\beta = (\beta_1, \beta_2)$. Given a strategy profile β, there are four possible Stage 3 outcomes, (p^3, w^3), depending on Nature's move. Thus, each β will map into four possible Stage 3 histories. However, since Nature's move is unobservable, bidders assign a probability to each possible history and each will bid to maximize their expected profit. Bidder i's expected profit is a function $\pi_i : \beta \times V \to \mathbb{R}$. If $w^3 = i$, then bidder i wins the auction and receives $v_i - p^3$; or if $w^3 \neq i$, then bidder i losses and receives 0. The seller's profit is the price at the end of Stage 3 which depends on β and the bidders' values. The seller's ex-ante profit is a function $\Pi^S : \beta \to \mathbb{R}$.

2.3.1 Results: No Credit Model

In the No Credit model, there is no reward given to bidders who bid early. My approach is to fix bidder 2's strategy and derive bidder 1's best response. Given that bidders' values are drawn from an identical distribution, it is natural to focus on symmetric equilibria. I begin in Stage 3 and then work backwards through the previous stages, those at $t = 2$ and $t = 1$, to find symmetric Bayesian-Nash Equilibria; hereafter referred to as *equilibrium* or *equilibria*. The equilibria of the auction are outlined in *Theorems 2* and *3*.

Proposition 1. *In any symmetric equilibrium,* $\beta_i^3(v_i, h^2) = v_i \ \forall h^2 \in H^2 \ \forall i$.

Proof. See Appendix A.1**.** □

The bidding environment in Stage 3 is equivalent to a second price auction but with some uncertainty in whether bids are successfully submitted. *Proposition 1* indicates that, for any observed history, it is a weakly dominant strategy for bidders to bid their values in Stage 3. This result is consistent with the symmetric equilibrium bidding

strategy in a second price sealed bid auction as shown by Vickrey (1961). Recall that a bidders strategy for the auction must specify a bid in every stage.

Theorem 2. *Early bidding is a symmetric equilibrium such that* $\beta_i^t(v_i, h^{t-1}) = v_i$ $\forall h^{t-1} \in H^{t-1}, \forall\ t > 0\ \forall i.$

Proof. See Appendix A.2. □

Let β^{early} denote the strategy profile where both bidders bid their values at $t = 1$. Given β^{early} , the expected profit for bidder 1 is $\int_{\underline{v}}^{v_1} (v_1 - v_2)\, g(v_2) dv_2$. The seller's profit is equivalent to the expectation of the second highest value, $E[v_2 | v_2 < v_1]$.

Theorem 3. *If* ρ *is not too small, then there exists a symmetric equilibrium where both bidders snipe. Specifically if*

$$\frac{\rho}{1+\rho} > \frac{1}{\bar{v} - r} \int_{\underline{v}}^{\bar{v}} G(v_{-i}) dv_{-i},$$

then it is an equilibrium for both bidders to bid according to the strategy

$$\beta_i^{snipe} = \begin{cases} \beta_i^1(v_i, h^0) = 0 & \forall h^0 \in H^0 \\ \beta_i^2(v_i, h^1) = v_i & \forall h^1 \in H^1 \\ \beta_i^3(v_i, h^2) = v_i & \forall h^2 \in H^2 \end{cases} .$$

Proof. See Appendix A.3. □

Bidder i is willing to follow β_i^{snipe} if

$$\frac{\rho}{1+\rho} > \frac{1}{v_i - r} \int_{\underline{v}}^{v_i} (v_i - v_{-i}) g(v_{-i}) dv_{-i}. \tag{2.1}$$

This condition is consistent with Ockenfels and Roth (2006) and Campbell and Zhang (2011). Because the restriction on ρ is conditional on a bidder's value, the inequality must be satisfied for both bidders in order for neither bidder to deviate. The right-hand side of the condition is weakly increasing in v_i; it is strictly increasing if $v_i > \underline{v}$. This implies that there exist values of ρ for which bidders with high values will deviate and bidders with low values will not; however, the reverse is never true. Thus, if ρ is large enough so that a bidder with value $\overline{v}$ finds it profitable to follow β_i^{snipe}, then a bidder with any other value is also willing to snipe. Setting $v_i = \overline{v}$, yields the condition in *Theorem 3.*

Note that although Stage 2 is bypassed in equilibrium, the bidders' strategies specify that if Stage 2 is reached, then a bidder bids his value to punish his rival for deviating. A bidder will only observe if his rival places an early bid. He does not observe the size of the rival's bid and thus, he cannot infer any additional information about the bidder's value. In second price auctions, learning the size of a rival's bid has no benefit because bidding one's value is costless. In other words, a bidder who wins with a bid of his value or with a bid epsilon below his value will always pay his rival's bid. In either case, the payoff to the bidder is the same.

In reality ρ is ambiguous; thus, it is the specification of the parameters, i.e. the reserve price and the value distribution function, that will determine whether an equilibrium exists. However, if ρ is close to 1, then mutual sniping is more likely to transpire. Researchers and "expert" bidders have indicated that the likelihood a bid is lost on eBay is relatively small, which implies that ρ is close to 1.

Claim 4. *A higher public reserve price deters sniping.*

Proof. The right-hand side of the condition in *Theorem 3* is strictly increasing in

r. □

Snipers believe that by bidding late they are more likely to pay a lower price. When all bidders attempt to snipe, it is possible that only one of the snipers' bids will be successfully transmitted to the auctioneer; in this event, the final price is the reserve price. Consequently, higher reserve prices reduce the appeal of sniping which is likely to lead to earlier bidding and higher prices. This argument is consistent with the empirical findings of Bryan et al. (2007) who observe a positive relationship between reserve prices and final prices.

Assuming values are uniformly distributed on the interval $[\underline{v}, \bar{v}]$, if bidder i's value satisfies

$$v_i < \frac{\rho}{1+\rho}(\bar{v} - \underline{v}) + \underline{v} + \sqrt{\frac{\rho}{1+\rho}(\bar{v} - \underline{v})\left(\frac{\rho}{1+\rho}(\bar{v} - \underline{v}) + \underline{v} - r\right)},$$

then bidder i will snipe. This inequaility is derived from equation 2.1. Furthermore, the condition in *Theorem 3* simplifies to

$$\rho > \frac{\bar{v} - \underline{v}}{\bar{v} + \underline{v} - 2r}. \tag{2.2}$$

Theorem 3 only gives a necessary condition for a mutual sniping equilibrium to exist. The right hand side of equation 2.2 is strictly less than 1 because, by assumption, $\underline{v} > r$. Hence, there always exists a ρ for which mutual sniping is an equilibrium. Sniping becomes less likely, meaning the restriction on ρ becomes too stringent, as $r \to 0$ or $(\bar{v} - \underline{v}) \to 0$. Example 1 provides some evidence on the flexibility of ρ for a specific parameterization of the model. The specific parameter values are adopted from a laboratory experiment conducted by Ariely, Ockenfels, and Roth (2005) which

investigated bidding behavior in eBay-like auctions.

Example 5. *Suppose* $v_i \sim U[6, 10]$ *and* $r = 1$*. Equation 2.1 reduces to* $\frac{\rho}{1+\rho} > \frac{1}{8} \cdot \frac{(v_i-6)^2}{v_i-1}$ *which is shown in Figure 2.1 below. Mutual sniping will be an equilibrium for all possible values so long as* $\rho > \frac{2}{7}$*. Figure 2.2 shows the positive relationship between reserve prices and the likelihood of a Stage 3 bid being successfully submitted. For mutual sniping to remain an equilibrium for all possible values, a higher reserve price requires a higher* ρ*.*

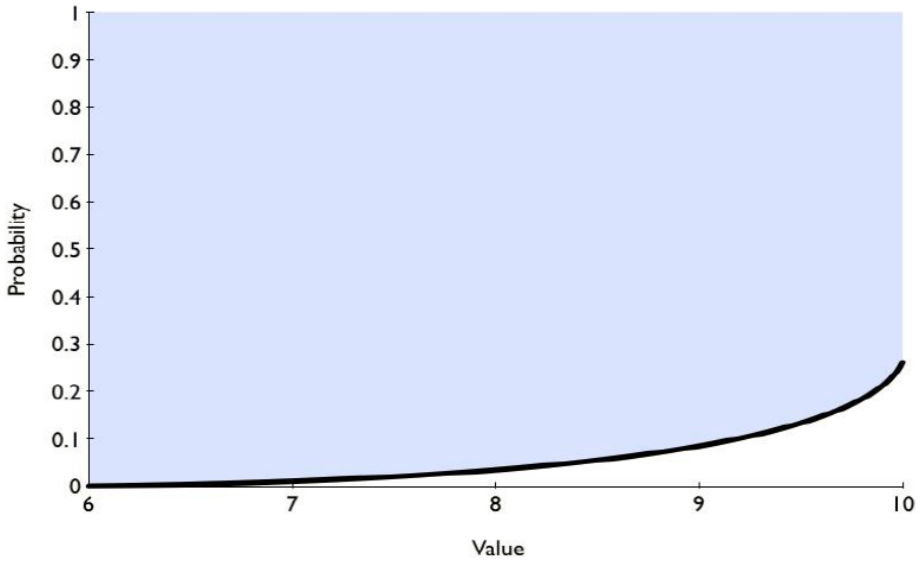

FIGURE 2.1. Probabilities for which sniping is supported by a symmetric BNE.

Let β^{snipe} denote the strategy profile when bidders follow the sniping strategy β_i^{snipe} described in *Theorem 3*. According to β^{snipe}, bidder i's expected profit is $\rho(1-\rho)(v_i - r) + \rho^2 \int_{\underline{v}}^{v_i} (v_i - v_{-i}) g(v_{-i}) dv_{-i}$. Sniping is highly advantageous for the winning bidder if his rival's bid is lost because he pays only the reserve price. If neither his bid or his rival's bid is lost, then the outcome of the auction is idential to the outcome when both bid early. In fact, if the condition in *Theorem 3* is true, then not bidding

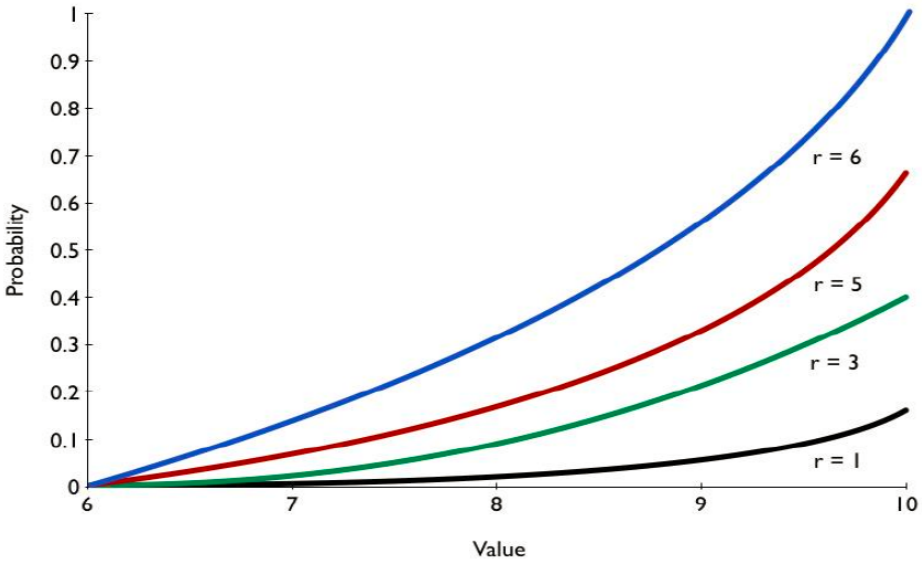

FIGURE 2.2. Relationship between ρ and the reserve prices of 1, 3, 5, or 6.

in Stage 1 is at least as good as bidding in Stage 1. If bidder 1 follows β_1^{snipe} and bidder 2 follows β_2^{early}, then bidder 1 will have the opportunity to submit a bid in Stage 2 and thus, bidder 1 is no worse off than when he opted not to bid in Stage 1.

The seller's expected profit when bidder i has value $v_i = v$ and both bidders follow β_i^{snipe} is

$$\Pi^S(\beta^{snipe} \mid v_i = v) = \rho^2 \int_{\underline{v}}^{v} v_{-i} g(v_{-i}) dv_{-i} + \rho(1-\rho)r.$$

By integrating over all possible values for bidder i and given the symmetry of the model, the seller's total ex-ante profit is

$$\Pi^S(\beta^{snipe}) = 2\rho(1-\rho)r + 2\rho^2 \int_{\underline{v}}^{\bar{v}} v_{-i}(1 - F(v_{-i}))g(v_{-i})dv_{-i}.$$

This is equivalent to $2\rho(1-\rho)r + \rho^2 E[v_2|v_2 < v_1]$. The seller earns more profit, in expectation, when bidders bid their values early if

$$E[v_2|v_2 < v_1] > 2\rho(1-\rho)r + \rho^2 E[v_2|v_2 < v_1],$$

which reduces to

$$\frac{E[v_2|v_2 < v_1]}{r} > \frac{2\rho}{1+\rho}.$$

The above inequality holds with certainty; thus, sellers strictly prefer for the bidders to bid early because $\rho \in (0,1)$.

2.4 Theoretical Credit Model

The previous subsection showed that, for large values of ρ, bidders will find it more profitable to snipe than to bid early. To incentivize early bidding, I propose a mechanism which gives one bidder the opportunity to receive a monetary credit, similar to a price reduction, if the bidder bids in Stage 1. The bidder with the credit will receive a reduction in the final price if he wins the auction; if he loses, then the benefit of the credit is lost.

Let c denote the credit offered by the seller, assume $0 < c < \underline{v}$. The credit is only given to one bidder who bids in Stage 1. If both bidders bid in Stage 1, then the credit is randomly given to one of the bidders. If only one bidder bids in Stage 1, then the credit is given to the bidder who submitted a bid. If neither bids, then the credit is forfeited. At the conclusion of Stage 1, bidders are informed of whether they have received the credit. Let the bidder who has been given the credit be denoted by $\kappa \in N \cup \{\emptyset\}$. If $\kappa = \{\emptyset\}$, then neither bidder has the credit.

I refer to this model as the Credit model; it differs from the previous model only by the inclusion of the credit. As before, the auction is divided into a null stage and three bidding stages. Bidders are able to submit bids in stages $t = \{1, 2, 3\}$ but Stage 2 occurs if and only if at least one bidder submitted a bid in Stage 1. Bids in Stage 3 are each submitted with probability $\rho \in (0, 1)$. Nature's move at the conclusion of Stage 3 determines whether a bid is successfully submitted.

As before, a bidder's strategy will depend on his private value and the history of outcomes he observes at the start of each bidding stage. However, receiving the credit will increase a bidder's maximum willingness to pay for the good by the size of the credit. A bidder's bid will depend on whether he has the credit and on the size of the credit; thus, bidding strategies are also conditional on κ. A strategy for bidder i is a sequence of functions, $\left\{\beta_i^t\right\}_{t=1}^3$, where each $\beta_i^t : V \times H^{t-1} \times \kappa \rightarrow B_i^t$. As before, a bidder's set of feasible bids are also conditional on the bidder's previous bid. A feasible bid for bidder i at time $t > 1$ is $b_i^t \in B(b_i^{t-1})$. Let β_i represent i's strategy for the entire auction and let $\beta = (\beta_1, \beta_2)$ represent a strategy profile.

As in the previous model, the outcome of Stage t is a price and high bidder, (p^t, w^t), which are determined by the bidders' recorded actions (a_1^t,a_2^t). For any given β and observed κ, there exist four possible Stage 3 outcomes because of the four possible post-Stage 3 moves by Nature. Bidders assign probabilities to each of Nature's moves and each will bid to maximize their expected earnings, conditional on κ, with respect to the four possible outcomes. A bidder's expected profit depends on β, his private value, and the credit information. Bidder i's profit is a function $\pi_i : \beta \times V \times \kappa \rightarrow \mathbb{R}$. If $w^3 = i$, then bidder i receives $v_i - (p^3 - c1_{(\kappa=i)})$ where $1_{(\kappa=i)}$ is an indicator function that takes on the value of 1 if $\kappa = i$, or the value of 0 if $\kappa \neq i$. If $w^3 \neq i$, then bidder i receives 0 regardless of whether he has the credit.

The expected final auction price depends on β and the four possible outcomes. The seller's profit will depend on the final auction price and whether the winning bidder has the credit. If $w^3 = \kappa \neq \emptyset$, then the profit received by the seller is the price at the end of Stage 3 minus the credit; otherwise her profit is the price at the end of Stage 3. The seller's ex-ante profit is a function $\Pi^S : \beta \times \kappa \rightarrow \mathbb{R}$; her profits are $p^3 - c1_{(w^3=\kappa\neq\emptyset)}$ where $1_{(w^3=\kappa\neq\emptyset)}$ is an indicator function that takes on the value of 1 if $w^3 = \kappa \neq \emptyset$, or the value of 0 otherwise.

2.4.1 Results: Credit Model

In the Credit Model, bidders, in addition to observing a history of outcomes, observe whether they have the credit. Thus, equilibrium bidding strategies will specify optimal bids for each stage of the auction that are conditional on κ. I again focus on symmetric Bayesian Nash equilibria. I begin by deriving the bidders' optimal bids in Stage 3 and then work backwards through each stage of the auction.

Proposition 6. *In any symmetric equilibrium,* $\beta^3(v_i, h^2 \mid \kappa) = v_i + c1_{(\kappa=i)}$ $\forall h^2 \in H^2$ $\forall i$ *where* $1_{(\kappa=i)}$ *is an indicator function that takes on the value of* 1 *if* $\kappa = i$*, and 0 otherwise.*

Proof. See Appendix A.4. □

Even with the inclusion of the credit, the Stage 3 bidding environment is equivalent to a second price auction. If a bidder with value v has the credit, then his maximum willingness to pay for the good is increased from v to $v + c$. *Proposition 6* indicates that in Stage 3, a bidder without the credit bids v and a bidder with the credit bids $v + c$. This result is consistent with equilibrium bidding strategies for a second price

auction; see Vickrey (1961).[13]

Theorem 7. *If bidders follow the strategy of bidding early according to*

$$\beta_i^{early}: \begin{cases} \beta^1(v_i, h^0 \mid \kappa) = v_i \\ \beta^2(v_i, h^1 \mid \kappa) = v_i + c1_{(\kappa=i)} & \forall h^1 \in H^1 \quad \forall i, \\ \beta^3(v_i, h^2 \mid \kappa) = v_i + c1_{(\kappa=i)} & \forall h^2 \in H^2 \end{cases}$$

then $(\beta_1^{early}, \beta_2^{early})$ *is a symmetric equilibrium.*

Proof. See Appendix A.5. □

Let β^{early} denote the strategy profile where bidders bid according to β_i^{early} in *Theorem 7*. According to β^{early}, both bidders simultaneously submit bids in Stage 1 so each is equally likely to receive the credit. If bidder 1 has the credit, then he wins when $v_1 + c > v_2$. If bidder 1 does not have the credit, then he wins if $v_1 > v_2 + c$. In equilibrium, bidder 1's expected profit is

$$\frac{1}{2}\left[\int_{\underline{v}}^{v_1+c} (v_1 - (v_2 - c))\, g(v_2)dv_2 + \int_{\underline{v}}^{v_1-c} (v_1 - (v_2 + c))\, g(v_2)dv_2\right].$$

The seller's expected profit, conditional on bidder 1 winning with value v, is

$$\Pi^S(\beta^{early}, \kappa \mid v_1 = v) = \frac{1}{2}\left[\int_{\underline{v}}^{v+c} (v_2 - c)\;\; g(v_2)dv_2 + \int_{\underline{v}}^{v-c} (v_2 + c)\;\; g(v_2)dv_2\right].$$

[13] Alternatively, in the credit model, the auction can be thought of an asymmetric second price sealed bid auction. The bidder who does not have the credit has a maximum willingness to pay drawn from the distribution $U[\underline{v}, \overline{v}]$. The bidder with the credit has a maximum willingness to pay drawn from the distribution $U[\underline{v}+c, \overline{v}+c]$, $U[\underline{v}, \overline{v}]$ shifted to the right by c. Regardless of the distributions, it is still an equilibrium for bidders to bid their maximum willingness to pay in asymmetric second price auctions; see Maskin and Riley (2000).

Using the symmetry of the model and integrating over all possible values for bidder 1, the seller's total ex-ante profit is

$$\Pi^S(\beta^{early}, \kappa) = \int_{\underline{v}}^{\bar{v}} \left(2v_2 - F(v_2 - c)(v_2 - c) - F(v_2 + c)(v_2 + c)\right) g(v_2) dv_2.$$

Suppose, to the contrary, both bidders snipe by not placing bids in Stage 1. In this case, neither bidder can receive the credit; thus, the bidders' expected profits and equilibrium bidding strategies are identical to those discussed in *Theorem 3*. The appeal of the credit should incentivize snipers to deviate and bid early. The bidder who deviates, bids in Stage 1, is guaranteed the credit. If, for a given ρ, the size of the credit is large enough so that the bidder earns more from bidding early, then sniping will no longer be an equilibrium strategy. Specifically for bidder i to deviate, c must be large enough to satisfy the inequality

$$\rho^2 \int_{\underline{v}}^{v_i} G(v_{-i}) dv_{-i} + \rho(1-\rho)(v_i - r) < \int_{\underline{v}}^{v_i + c} G(v_{-i}) dv_{-i};$$

see the proof for *Proposition 8*. For a given ρ, if $v_i \sim U[\underline{v}, \bar{v}]$, then a bidder with value v_i is indifferent between sniping and deviating when

$$c = -(v_i - \underline{v}) + \sqrt{\rho^2 (v_i - \underline{v})^2 + 2(\bar{v} - \underline{v})\rho(1-\rho)(v_i - r)}.$$

Mutual sniping is no longer a symmetric equilibrium if the credit is large enough to incentivize one of the two bidders to bid early. The bidder with the lower value finds sniping more profitable because it gives him a positive probability of winning the good. A credit which incentivizes the lower valued bidder to deviate will always incentivize the higher valued bidder to also deviate; however, the reverse is not true.

The seller chooses c ex-ante using the expectation of the highest bidder's value. If $v_i \sim U[\underline{v}, \bar{v}]$, then the expected highest value is $\frac{1}{3}(\underline{v} + 2\bar{v})$. *Proposition 8* gives a necessary condition for when sniping strategies (ex-ante) are no longer supported in equilibrium.

Proposition 8. *For large enough values of c, late bidding is no longer an equilibrium. Specifically for a given ρ and r, if $v_i \sim U[\underline{v}, \bar{v}]$, then c must satisfy the following inequality*

$$c > \frac{2}{3}\left(-(\bar{v}-\underline{v}) + \sqrt{\rho^2(\bar{v}-\underline{v})^2 + \frac{3}{2}(\bar{v}-\underline{v})\rho(1-\rho)(2\bar{v}+\underline{v}-3r)}\right).$$

Proof. See Appendix A.6. □

Larger credits are more appealing to the bidders because their expected profit is strictly increasing in c. The primary purpose of the credit is to incentivize early bidding which should lead to higher final prices and greater seller revenue; however, the credit is costly to the seller. If the price gain from offering a credit, the difference between the price when all bidders bid early and when all snipe, does not exceed the size of the credit, then the seller prefers to not offer a credit. In deciding whether to offer a credit, the seller compares her ex-ante profit when no credit is offered and the bidders snipe to her ex-ante profit when she does offer a credit and the bidders bid early. Recall the seller's profit in the Credit model when both bidders bid early is

$$\int_{\underline{v}}^{\bar{v}} \left(2v_2 - F(v_2-c)(v_2-c) - F(v_2+c)(v_2+c)\right) g(v_2) dv_2$$

which is strictly decreasing in c. The seller's profit when bidders snipe, see *Theorem 3*, is

$$2\rho(1-\rho)r + 2\rho^2 \int_{\underline{v}}^{\bar{v}} v_2 \left(1 - F(v_2)\right) g(v_2) dv_2.$$

It is profitable for the seller to offer a credit if there exists a c such that

$$\begin{aligned} & 2\rho(1-\rho)r + 2\rho^2 \int_{\underline{v}}^{\bar{v}} v_2 \left(1 - F(v_2)\right) g(v_2) dv_2 \\ < & \int_{\underline{v}}^{\bar{v}} \left(2v_2 - F(v_2 - c)(v_2 - c) - F(v_2 + c)(v_2 + c)\right) g(v_2) dv_2. \end{aligned}$$

To summarize, the credit the seller offers must satisfy two conditions: (i) it must be large enough, in expectation, to incentivize early bidding and (ii) it must be small enough to not reduce her ex-ante profits. Assuming $v_i \sim U[\underline{v}, \bar{v}]$, the first condition requires

$$c > \frac{2}{3}\left(-(\bar{v} - \underline{v}) + \sqrt{\rho^2(\bar{v} - \underline{v})^2 + \frac{3}{2}(\bar{v} - \underline{v})\rho(1-\rho)(2\bar{v} + \underline{v} - 3r)}\right) \tag{2.3}$$

and the second condition requires

$$-(\bar{v} - \underline{v})\rho(1-\rho)r + (1-\rho^2) \int_{\underline{v}}^{\bar{v}} v_2 \left(1 - \frac{v_2 - \underline{v}}{(\bar{v} - \underline{v})}\right) dv_2 > c^2. \tag{2.4}$$

The first and second conditions create a lower and upper bound on c, respectively. Because the seller's profit is strictly decreasing in c, the seller offers a credit just ε above the c that makes a bidder indifferent between sniping and bidding early. In other words, the optimal credit is ε above the c when expression 2.3 holds with equality; conditional on expression 2.4 being satisfied. Example 9 shows that, using the parameter values from Example 5, it is feasible to offer a credit which satisfies

both constraints.

Example 9. *Suppose* $\rho = 0.80$, $v_i \sim U[6, 10]$, *and* $r = 1$. *Expression 2.3 is*

$$\begin{aligned} c &> \frac{2}{3}\left(-(4) + \sqrt{(.8)^2(4)^2 + \frac{8}{3}(.8)(.2)(23)}\right) \\ c &> 0.319 \end{aligned}$$

and expression 2.4 is

$$\begin{aligned} c^2 &< -4(.8)(.2) + (1-(.8)^2)\int_6^{10} v_2\left(1 - \frac{v_2 - 6}{4}\right) dv_2 \\ c &< 2.15. \end{aligned}$$

When $\rho = 0.8$, *the optimal credit for a seller to offer is* $c^* = 0.319 + \varepsilon$. *Figure 2.3 shows the optimal credit, when* $\varepsilon = 0.01$, *for every feasible* ρ. *Recall from Example 5 in the No Credit model, sniping constitutes an equilibrium strategy if* $\rho > \frac{2}{7}$.

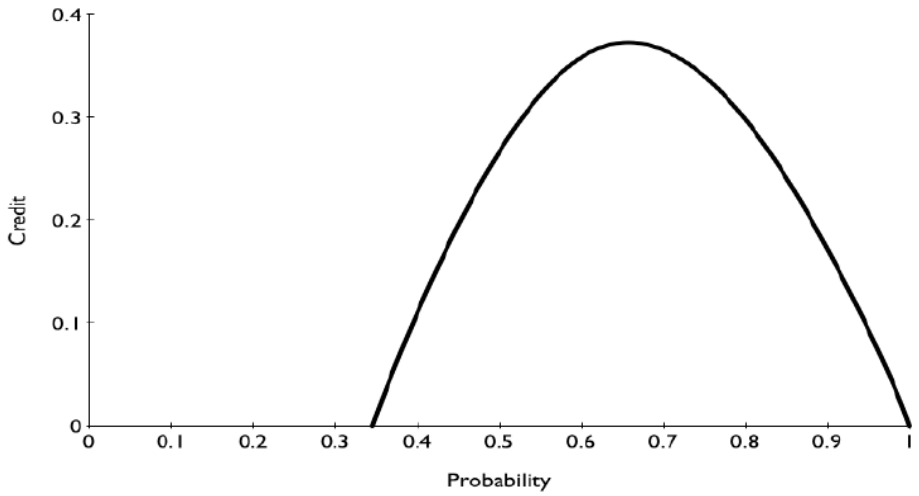

FIGURE 2.3. The relationship between the optimal credit and ρ.

Given values are drawn from a uniform distribution, then increasing the reserve price will reduce the upper and lower bounds on c because both 2.3 and *2.4* are strictly decreasing in r. Higher reserve prices will generate greater reveune for sellers when bidders snipe. Thus, a seller is less interested in offering bidders a credit as r converges towards $\underline{v}$. For bidders, higher reserve prices make sniping less profitable which increases the incentive to bid early. Using the parameters from the previous example, *Figure 2.4* shows the relationship between the optimal credit and the reserve price.

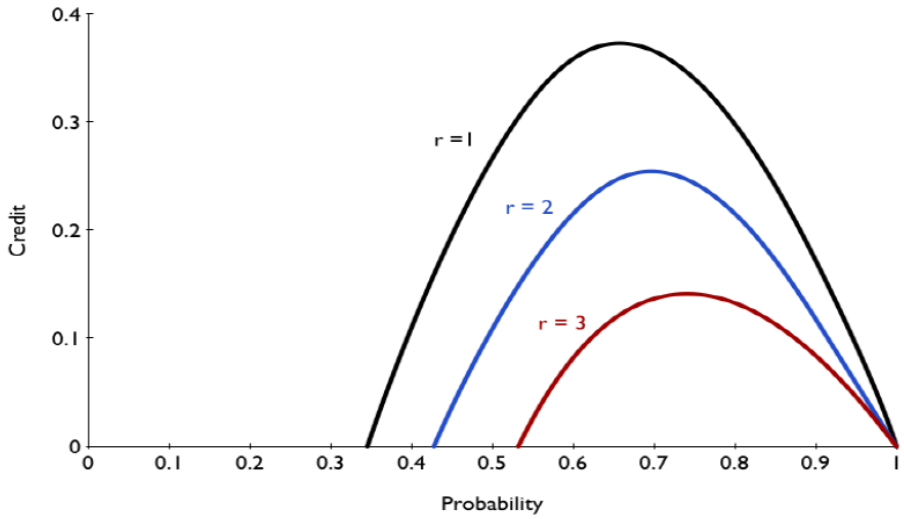

FIGURE 2.4. The relationship between the optimal credit and reserve prices.

The credit, if feasible, increases the seller's ex-ante profit but only if the bidders were sniping in the absence of the credit; see 2.4. If the bidders were not sniping, then offering a credit would yield a moderate reduction in seller profit. Assuming $\rho = 0.80$, $v_i \sim U[6, 10]$, $r = 1$, and $c^* = 0.32$ (see Example 9), *Table 2.1* shows the surplus for each party in the Credit and No Credit model when bidders follow an equilibrium bidding strategy.

Model - Strategy	Ex-Ante Seller Surplus	Surplus of Bidder with value v	Ex-Ante Bidder Surplus
NoCredit Early Bidding	\$7.33	$\frac{1}{8}\left(v^2 - 12v + 36\right)$	≈ 0.67
NoCredit - Sniping	\$5.01	$\frac{4}{25}(v-1)+$ $\frac{2}{25}\left(v^2 - 12v + 36\right)$	≈ 1.55
Credit Early Bidding	\$7.28	$\frac{1}{8}\left(v^2 - 12v + 36.1\right)$	≈ 0.68

TABLE 2.1. Surplus generated given the specified parameters from the previous example.

If the bidders are bidding early, then their surplus is slightly higher in the Credit model compared to the No Credit model because the bidder with the credit will likely not pay a price that is c above his value.[14]

The auction is efficient if no credit is offered and both bidders bid their values at the start of the auction because it gaurantees that the bidder with the highest valuation receives the good. When bidders snipe, the outcome is inefficient for two reasons. First, there is a positive probability that neither bidder will be allocated the item; this also explains the loss in welfare between early bidding and sniping. Second, there is a positive probability that the highest valued bidder will not win the auction. By construction, the optimal credit guarantees that the item will be sold which improves efficiency and raises total welfare. However, the credit does not guarantee that the bidder with the highest initial value will receive the good. The credit aids the lower valued bidder, if awarded to him, because it raises his maximum

[14]In addition, the credit causes the auction to be asymmetric. The distribution of the maximum willingness to pay of the bidder with the credit first order stochastically dominates the distribution of the bidder without the credit. Cantillon (2008) shows that in a second price auction seller(bidder) surplus is lower(higher) in the presence of asymmetries when the bidders bid their maximum willingness to pay.

bid and improves his probability of winning the good. This explains the decline in welfare from the No Credit-Early Bidding scenario to the Credit-Early Bidding scenario.

2.5 Conclusion

eBay recommends bidders submit a single, early, proxy bid equivalent to their maximum willingness to pay for the item. When all bidders follow this strategy, the outcome is efficient and it generates the greatest revenue for sellers. However, nearly all bidders do not follow eBay's recommendation. Observations from field and experimental data have shown that the majority of bidders who are bidding early will submit multiple bids, which indicates that they are gradually bidding towards their perceived valuations. Other bidders, instead of bidding early, will wait until moments before the auction's ending time to place a first bid; this strategy is commonly referred to as sniping.

The primary objective of a sniper, and any bidder, is to pay the lowest price possible. By bidding late, the sniper avoids starting a bidding war with early bidders which causes the price to remain low. If an early bidder is underbidding, then a rival bidder's best response is to snipe. Alternatively, if no early bids have been submitted, then, by waiting, a sniper may win the auction and only have to pay the public reserve price.

In auctions with snipers, prices tend to be lower which translates to lower profits for sellers. If bidders are sniping, then a mechanism which incentivizes bidders to bid early would be beneficial to the seller. The incentive mechanism proposed in this paper is a bid "credit"; it gives a single early bidder a credit which, if the bidder

wins, will reduce the price he pays by the amount of the credit. The seller incurs the cost of the price reduction but, by design, the credit is not large enough to reduce the seller's profit.

I first confirm the Ockenfels and Roth (2006) and Campbell and Zhang (2011) result that, in the absence of the credit, sniping strategies exist in symmetric Bayesian-Nash equilibria. I then use the credit to formulate a condition that destroys any equilibrium where bidders are sniping. The unique equilibrium is for each bidder to submit early bids equal to their maximum willingness to pay.

The optimal credit the seller offers must meet two necessary conditions. First, it is large enough to incentivize at least one bidder to deviate from the sniping equilibrium by placing a bid in an earlier stage. Second, it is small enough to generate greater ex-ante profit for the seller. The seller, to maximize potential profit, offers a credit just above the credit for which the bidders are indifferent between sniping and deviating from the equilibrium. The size of the credit depends on the distribution of the bidders' values, the public reserve price, and the probability of a late bid being successfully received by the auctioneer. I provide an example, using the experiment parameterization of Ariely, Ockenfels, and Roth (2005), to show it is feasible to offer credits which satisfy both conditions.

The design of the mechanism assures that the item will be allocated to a bidder in equilibrium because early bids are received by the auctioneer with certainty. However, the mechanism does not guarantee that the item will be awarded to the bidder with the highest valuation. Overall, offering a credit will restore the auction to almost full efficiency.

Some readers have inquired into what the effect would be of offering both bidders the credit, as opposed to only one. When two credits are offered in Stage 1, the

minimum credit needed to incentivieze a bidder to deviate from sniping is idenitcal to the minimum needed when only one credit is offered. The maximum credit the seller is willing to offer disappers because, in theory, bidders are bidding their maximum willingness to pay. Thus, the seller always receives the second highest value. Recall, if only one credit is offered, then the price received by the bidder could be greater than, less than, or equal to the second highest value depending on which bidder received the credit. Thus, offering two credits is more efficient than offering one.

Testing the effectiveness of credit mechanism in the laboratory is a natural extension of the research. The behavior observed in the laboratory will also shed light on whether offering more than one credit could be beneficial. Additional extensions include introducing the Buy-It-Now feature, uncertainty in the number of bidders, asymmetric bidder types, and endogenizing the reserve price.

CHAPTER 3

An Experimental Test of Early Bidding Incentives in Internet Auctions

3.1 Introduction

Over the past decade, eBay has emerged as one of the most popular Internet auction houses. eBay's marketplaces generated approximately $2 billion in revenue during its 4th quarter of 2012 while its gross merchandise volume, excluding vehicles, increased 21%. The company has grown substantially since its founding in 1995, providing services to approximately 100 million registered users all over the World.[1]

In the late 1990s and early 2000s, eBay was in direct competition with Amazon and Yahoo for seller listings and interested buyers. One way eBay differentiated itself in the market was by having its auctions end at a publicly known fixed ending time.[2] Auctions on Amazon and Yahoo, both of whom eventually succumb to eBay, would extend in length with each new bid that was placed; i.e. the auctions had a soft, variable, ending time. The heterogeneity in ending rules caused bidders to utilize

[1] This earnings data was reported by eBay Inc. in January 2013 and was summarized in an article, released by *Business Wire*, titled "eBay Inc. Reports Strong Fourth Quarter and Full Year 2012 Results".

[2] Internet auctions generally have one of two different types of ending rules: a fixed/hard-close or a soft-close. A hard close auction ends at a specific date and time regardless of whether or not bidders are still submitting bids. A soft-close auction will continue to extended in length, either by a few seconds or minutes, as bidders continue to bid. If the extended time runs out without a bid being submitted, then the auction is over. An example of an auction with a hard close is eBay and one with a soft close is Amazon, Yahoo, or, more recently, penny auctions.

different strategies for winning; ultimately, yielding significant differences in the final selling prices and seller profits between the auction houses.

The effects of ending rules on auction outcomes have been analyzed in a lab experiment by Ariely, Ockenfels, & Roth (2005, AOR henceforth). They find that final auction prices tend to be lower in treatments meant to mimic the fixed ending style of eBay auctions than in treatments with soft ending times. The appeal of lower prices likely attracted buyers to eBay which created a demand for more auction listings and sellers.

The ultimate objective of most bidders on an auction site is to acquire a "steal"; to find and retain an item at a price significantly below its valuation. One scenario that many eBay users have encountered, or know someone who has, is the following. Anna, an eBay user, has been bidding on a popular item for the past few days. Maybe other rival bidders have also placed bids, or maybe not. Regardless, she is currently the high bidder and there is less than one minute remaining in the auction. Slowly the clock ticks down to 30 seconds, then 10 seconds, and then finally "Auction Ended" appears on the screen. Initially she is excited because she has won item at a low price but upon closer inspection she realizes that she was out bid in the last 3 seconds. Ironically, the "steal" Anna thought she had found was stolen from her in the last moments of the auction.

Anna's loss was caused by a sniper. A sniper is a bidder who waits until the last moments of the auction to submit a bid; a strategy called "sniping." Sniping is unique to auctions with fixed ending times because bidders are able to anticipate the auction's end and strategically plan the placing of their bids. Ockenfels and Roth (2001, 2005) argue that a bidder will snipe to avoid engaging in a back-and-forth, price-raising, bidding war. Placing a, snipe, bid so near to the auction's ending time causes the

time remaining to be insufficient for rival bidders to respond with a new bid. AOR also observe more late bidding in eBay-like auctions than in Amazon-like auctions because Amazon's soft ending time always grants rival bidders the opportunity to react to any bid, regardless of when the bid is placed.

In field experiments conducted by Ely and Hossain (2009) and Gray and Reiley (2005), significantly lower prices are observed in auctions where the experimentalists place a snipe bid instead of a single, low, early bid. eSnipe.com, a thrid-party sniping service, provides further evidence of the benefits bidders are reaping from sniping. The company regularly advertises on its social media website that it services thousands of customers a day. It also claims to have saved its members nearly $4.5 million during November 2011.[3] Lower final prices, and bidder savings, coincide with profit losses for sellers and revenue losses for eBay who collects, as a fee, a percentage of the final price. As profit maximizers, sellers and eBay prefer for bidders to engage in competitive early bidding wars to drive up prices.

The purpose of this paper is to experimentally test a bidding mechanism, proposed by Nagy (2013), which rewards bidders for bidding early in the auction. The mechanism is designed to incentivize bidding wars, by thwarting sniping, while improving seller profit. The theoretical model presented in Nagy (2013) shows that offering early bidders a credit, simply a reduction in the final price, will eliminate sniping equilibria. In the experimental data, I observe a significant decline in the number of subjects following sniping strategies once the mechanism is introduced. In addition, I find that seller profits, or final auction prices, increase significantly when subjects who were sniping regularly no longer snipe. Before discussing the credit in more detail, it is essential to understand the mechanics of eBay and how sniping came

[3] On November 26, 2011 eSnipe.com published on its website that bidders who won auctions using the eSnipe services were willing to pay $14.5 million but due to eSnipe only paid about $10 million.

to fruition.

Bids submitted on eBay are private proxy bids, henceforth referred to as *bids*, which eBay's computer system will store and use as an upper threshold when placing bids on behalf of a bidder. The system will only bid enough for the bidder to be, if possible, the highest bidder but it will never place a bid that exceeds the bidder's threshold value.[4] eBay recommends that bidders should, to take full advantage of the proxy bidding system, submit a single early bid equivalent to their maximum willingness to pay for the item. If bidders follow this strategy, then sniping becomes nonsensical because the final price will be the same regardless of when the 'sniper' places his single bid.

There is a vast amount of auction literature and "How to" guides available to the general population that promote sniping on eBay despite eBay's recommendation against it. A seasoned bidder, on *eBay Guides*[5], writes "[sniping] is the intelligent way to bid on eBay and we recommend it to everyone, regardless of what you buy." Many who recommend sniping attribute its success to the fact that early bidders are often novices who do not understand eBay's proxy bidding system. There is a tendency for early bidders to incrementally increase their bids manually throughout the auction; a naïve bidding strategy. The frequent late bidding AOR observe is determined to be a strategic best response to naïve bidders.

Ideally a sniper wants to be the last bidder to place a bid in the auction. Thus, a sniper attempts to place a bid seconds before the auction's end. However, the

[4]For example, if bidder A submits a single bid of \$5 and bidder B submits a bid of \$3, then the computer bids only \$3.01 on bidder A's behalf. If bidder B later increases his bid to \$4, then the computer will bid \$4.01 on bidder A's behalf. In both instances, bidder A is the high bidder and the first current price is \$3.01 and the later price is \$4.01; this information is common knowledge. Bidder A's bid of \$5 is private information.

[5]See "Sniping, The Intelligent Way to Bid!", created January 2007 and updated March 2013, posted under *eBay Guides on eBay.com.*

minimum time needed to place a bid is ambiguous and varies with time of day, Internet connection speed, and eBay's server traffic. Miscalculating the time could result in the sniper's bid not being successfully received by the auctioneer; in other words, the bid is "lost". The uncertainty in relay times causes sniping to be moderately risky but the potential rewards (low prices) often outweigh these risks.

Wenyan and Bolivar (2008), from eBay research labs, observe a significant peak in bid arrival during the last five seconds of an auction. Furthermore, the researchers estimate that 61.4% of bids placed in the last minute of the auction are from snipers.[6] They also find that the winning rate of an early bidder was less than half the winning rate of a sniper.

One difficulty with analyzing field data, even data direct from the eBay research lab, is that if a sniper's bid is too late, then their bid is not observed. Thus, a lack of late bids could be misinterpreted as the absence of snipers as opposed to a failed snipe attempt. However, lab experiments can be designed in such a way that late bids are always observed by the experimenter. AOR observe approximately 50% of the subjects are placing late bids[7] when the probability of a bid being lost is 20%. The percentage grows to 80% when all uncertainty is removed. Similarly, experiments by Durham et al. (forthcoming) observe, in the baseline eBay treatment, 20% of bids being placed in the last 3 seconds of the auction and estimate that 56% of the subjects are sniping which they define as placing a winning bid in the last 3 seconds of the auction.

[6] Wenyan and Bolivar (2008) define snipers as bidders who are not bidding prior to the last minute of the auction and who are deliberately waiting. Because they have direct access to eBay's database, they are able to observe how late bids are placed, either manually or by sniping software, and the search history of users. The ability to access search history is extremely important because it allows them to determine if late bids are from snipers or from bidders unintentionally arriving late to the auction.

[7] AOR use the terms "late bidding" and "sniping" interchangeably. However, I will argue later that this is misleading because sniping is the act of waiting and bidding late.

In a simplified model of an eBay auction, Ockenfels and Roth (2006) and Nagy (2013) show that sniping can be a symmetric equilibrium as long as the probability of a bid being lost is not too large. This is in addition to the equilibrium where bidders bid their maximum willingness to pay at the beginning of the auction. However, bidders prefer the sniping equilibrium because their expected profits are higher while the seller prefers the early bidding equilibrium because prices are higher.

A mechanism designed to incentivize bidders to bid early should ignite competition and raise prices. Nagy (2013) proposes offering a credit to the first bidder who submits a bid in the auction. If the bidder wins the auction, then he receives a reduction in the final price.[8] Bidders have the incentive to reveal their identity early in hopes of obtaining the price reduction. Given that the probability of a late bid being successfully submitted is exogenous, Nagy (2013) shows that if the credit is large enough, then early bidding is a unique symmetric Bayesian-Nash equilibrium. Furthermore, the credit is designed to be beneficial to sellers by improving their revenue.

The objective of this study is to experimentally investigate whether the theoretical credit predicted by Nagy (2013) is effective at alleviating sniping behavior. I find that in the last third of the eBay-like auction treatment approximately 36% of the auctions have at least one sniper. Furthermore, as expected, sniping becomes more frequent over time. The introduction of the credit causes nearly all original snipers to place early bids in an attempt to capture the credit. The change in the snipers' behavior results in a significant increase in the efficiency of the auction. In addition, there is more overbidding in the credit treatment which suggests that the credit sparks

[8]It could be argued that once the credit is claimed there is no incentive for non-early bidders to bid and reveal their identity. This can be corrected by allowing any bidder who submitted a bid during a specific time frame at the start of the auction to be entered into a lottery for the credit, and at the end of the specified time frame the credit is randomly awarded.

competition and induces aggressive bidding. Despite the tendency to overbid, the majority of subjects are not engaging in bidding wars nor are they taking advantage of the proxy bidding system. Many subjects place small early bids and rely on a large late bid to win the auction. The inclusion of the credit causes no significant change in seller profit which is primarily due to relatively few subjects sniping in the absence of the mechanism. However, the within subject design allows me to compare differences at the subject level. Conditional on observations from the subjects who are snipers, the auctions featuring the credit produced significantly greater seller profits than the auctions without a credit.

The paper proceeds as follows. Section 3.2 introduces the model and describes the theoretical predictions. It also summarizes the necessary conditions for Nagy (2013)'s credit mechanism. Section 3.3 discusses the experimental design; specifically, the features of the auctions and the treatments. Section 3.4 offers some testable hypotheses. Section 3.5 describes the experimental procedure, followed by the experimental findings in Section 3.6 and some concluding remarks in Section 3.7.

3.2 Model and Theoretical Predictions

I begin this section by introducing the general rules and structure of an auction conducted on eBay. Adhering to eBay's most predominant features, I present a simplified two-bidder model of the auction environment using discrete bidding stages. Next, I summarize the results of Nagy (2013) for the simplified eBay model. I end by describing the Nagy (2013) credit mechanism and the necessary conditions for effectively implementing it.

3.2.1 Bidding Environment

An auction on eBay is conducted in continuous, real, time and features a known fixed ending time. The seller will choose the ending time as well as a starting minimum bid, referred to as a reserve price. Bidders are able to submit multiple (proxy) bids throughout the course of the auction. For a bidder to place a bid, the bid must meet the following two conditions. First, new bids must exceed the current price. If no bids have been placed, then the current price is the reserve price. Second, a bidder's new bid must exceed his previous bid. In other words, bidders cannot retract, or lower, old bids.

The current price is essentially the second highest bid (plus a small increment) because of the proxy bidding system.[9] Researchers, such as Lucking-Reiley (2000) and Ockenfels and Roth (2002), model eBay as a second price, continuous time, auction. At any given time during the auction, all bidders are able to observe the current price and the corresponding high bidder's ID; both of which depend on the bidders' bids. Bidders also observe a history of the auction's previous prices and high bidders. The winning bidder and final price are based on the bidders' bids at the auction's predetermined ending time. In the event of a tie, eBay's rules give precedence to the bidder who submitted the tying bid earliest.

Although bids are placed at varying times throughout the auction, each bid can be classified as having been placed in one of three stages. The first stage is an initial bidding stage where the auction receives its first bid. This bid is submitted "early" enough for rival bidders to place bids in response to it. Immediately following the

[9]The minimum increment with which a bid must exceed the price and bidder's previous bid is generally small and pre-determined by eBay. This implies that the final price will likely exceed the second highest bid by the specified increment. Relative to the current price, the minimum increment is fairly small and is likely not to have a significant effect on the price. Thus, to simplify the model, the minimum increment is omitted.

observation of the first bid is when the second stage begins. Here bidders are able to react to the first stage bid and any second stage bids; essentially a bidding war stage. The second stage ends just moments before the auction's ending time. Note that if there is never a first bid submitted which rivals can react to, then there is never a bidding war stage. The third, and final, stage is a late bidding stage. Bids placed in the third stage cannot be reacted to because there is insufficient time remaining in the auction. Thus, all third stage bids are submitted simultaneously. As previously mentioned, late bids, i.e. bids in the third stage, run the risk of not being successfully submitted to the auctioneer. However, bids in the first and second stages are submitted with certainty.

The approach of Nagy (2013) is to model eBay as a multi-stage game of incomplete information comprised of the three discrete bidding stages described above; denoted Stage 1, 2, and 3. Bids are submitted simultaneously in each stage. It is assumed that all bidders arrive simultaneously so that all have the same opportunity to bid in each stage. For the two-bidder model, there are two risk-neutral bidders in an auction for a single good; bidders are indexed by $i = 1, 2$. Let v_i denote bidder i's value for the good and assume values are drawn from a uniform distribution, $v_i \sim U[\underline{v}, \bar{v}]$ where $0 < \underline{v} < \bar{v}$. Any bid must be at least as great as the reserve price $r \in (0, \underline{v})$. Bids submitted in Stage 3 are successfully received by the auctioneer with probability $\rho < 1$.

The final price is the second highest successfully submitted bid at the conclusion of Stage 3. The highest bidder at the end of the Stage 3 is allocated the good and pays the final price to the seller. The winning bidder's profit is his value minus the price paid, and the losing bidder's profit is zero. The seller's value is normalized to 0. Thus, the seller's profit is the price she receives.

3.2.2 eBay Model

Nagy (2013), as well as Ockenfels & Roth (2001, 2006) and Campbell & Zhang (2011), show there exist multiple symmetric Bayesian-Nash equilibria. One where both bidders snipe, meaning they wait to place bids in Stage 3, and another where both bidders submit a single bid at the beginning the auction, meaning they only place bids in Stage 1.[10] The findings of Nagy (2013), when values are uniformly distributed, are summarized in the following two results.

Result 1: Sniping Equilibrium *There exists an equilibrium where neither bidder bids in Stage 1 and both bidders bid their values in Stage 3; however, if a rival deviates by bidding early, then (off the equilibrium path) bidders will bid their values in Stage 2 as a means of punishment. This result requires that the probability of a late bid being successfully received satisfies the inequality*

$$\frac{(\bar{v} - \underline{v})}{(\bar{v} + \underline{v}) - 2r} < \rho. \tag{3.1}$$

Result 2: Early Bidding Equilibrium *It is always an equilibrium for bidders to bid their true values in Stage 1.*

Result 2 is consistent with the result of Vickery (1961) for second price sealed bid auctions. Coordinating on the snipping equilibrium will yield expected profits to the bidders which are strictly greater than their profits when they bid their values early. Sniping is highly advantageous to a bidder when his bid is successfully submitted and his rival's bid is not. In this situation, the winning bidder pays only the reserve

[10] This differs slightly from Roth and Ockenfels (2001) where submitting a single early bid at any time prior to the very end of the action is an equilibrium. However, the difference is attributed to the fact that the Roth & Ockenfels (2001) model does not use discrete bidding periods.

price r. If both bids are successfully received by the auctioneer, then the outcome is identical to the outcome when both bidders bid early. If neither bid is successful, then neither bidder wins and the auction is inefficient. The sniping equilibrium does not guarantee the highest valued bidder wins the good nor does it guarantee the good will be awarded to either bidder and thus, it is inefficient. The early bidding equilibrium is ex-post efficient.

3.2.3 Credits in the eBay Model

Nagy (2013) proposes using a credit to thwart sniping behavior in these types of auctions. The mechanism incentivizes the bidders to bid early in hopes of capturing a single monetary credit. If the bidder with the credit wins the auction, then he receives a reduction in the final price. The monetary value of the credit is common knowledge and is known prior to the start of the auction.

A bidder is able to receive the credit by placing a bid in Stage 1, in other words he is an "early bidder". If both bidders submit bids in Stage 1, then the credit is randomly given to one of the two bidders. If only one bidder bids in Stage 1, then that bidder receives the credit with certainty. If neither bidder bids in Stage 1, then the credit is forfeited. After Stage 1, the auction progresses to Stage 2 if and only if a bid was placed in Stage 1; otherwise it progresses to Stage 3.

As before, the highest bidder at the end of Stage 3 wins the auction. However, the final price received by the seller will depend on whether the highest bidder has the credit. If the winning bidder does not have the credit, then the final price is the second highest bid. If the winning bidder has the credit, then the final price is the second highest bid minus the credit. The winning bidder's profit is his value minus the final price, while the losing bidder receives nothing. The seller's profit is the final

price paid by the winning bidder.

Recall, in the absence of the credit, sniping emerged as a Bayes-Nash equilibrium when ρ satisfied 3.1. The opportunity to obtain a credit, should be attractive to bidders and, if large enough, should incentivize them to deviate from waiting until Stage 3 to place a bid. However, credits are costly to the seller and thus, if too large they could generate smaller profits. Nagy (2013) formally states these contrasting constraints as a seller, upper, and a bidder, lower, boundary condition on the feasible set of credits which can be offered.

Let c denote the credit offered by the seller. The seller chooses the credit ex-ante and thus, the optimal credit is calculated based on the expected values of the highest and second highest bidders. For early bidding to be the unique symmetric Bayes-Nash Equilibrium, c must be large enough so that at least one bidder will, in expectation, receive a greater profit by deviating than by sniping. This bidder deviation constraint requires

$$c > \frac{1}{(\bar{v} - \underline{v})} \int_{\underline{v}}^{\bar{v}} \left(-(v_i - \underline{v}) + \sqrt{\rho^2 (v_i - \underline{v})^2 + 2\rho(1-\rho)(v_i - r)(\bar{v} - \underline{v})} \right) dv_i. \quad (3.2)$$

The seller is only willing to offer a credit if her ex-ante profit from offering the credit is at least equal to her profit when she does not offer one and the bidders snipe. The seller constraint requires

$$c^2 < -\rho(1-\rho)(\bar{v} - \underline{v})r + (1-\rho^2) \int_{\underline{v}}^{\bar{v}} v_i \left(1 - \frac{v_i - \underline{v}}{(\bar{v} - \underline{v})} \right) dv_i. \quad (3.3)$$

Conditional on the seller's constraint being satisfied, the seller will offer a credit just above the right-hand side of the bidders' constraint. In other words, the optimal credit, conditional on 3.3 being satisfied, is the c^* such that 3.2 holds with equality

plus $\varepsilon > 0$. Nagy's (2013) results for the credit model are summarized in the following two statements.

Result 3: Abolish Sniping *Offering a credit, c, which satisfies 3.2 and 3.3 will discourage bidders from only bidding in Stage 3; deleting equilibria where bidders snipe.*

Result 4: Early Bidding *It is an equilibrium for both bidders to bid their maximum willingness to pay in Stage 1 and Stage 2.*

The bidder who obtains the credit is willing to bid above his value because having the credit increases his maximum willingness to pay by the amount of the credit. In the credit model, early value bidding is an equilibrium if all bidders attempt to capture the credit at the start of the auction. Waiting to observe whether the rival bidder bids in Stage 1 ensures that the bidder who waited will not receive the credit; thus, there is an incentive to bid earlier. It is costless for the bidder with the credit to increase his bid in Stage 2 by c regardless of whether he is the high bidder after Stage 1.

3.3 Experiment Design

The experiment uses a within subject design where the subjects participate in two treatments during the session. The first is a baseline eBay treatment which is a replication of one of AOR's eBay treatments.[11] Immediately following the first, the second is a Credit treatment which only differs from the eBay treatment by the

[11] The treatment is identical to AOR in the design of the auctions and the values assigned to the paratmeters. The only difference is in the number of subjects used per session; AOR use 6 while I use 8.

opportunity to obtain a credit for bidding early. Both treatments will consist of an identical number of eBay-like auctions.

The auction repetition within each treatment is important because it allows for subjects to gain experience. AOR, observe very little late bidding in the first few auctions of the eBay treatment. However, as subjects gain experience, the frequency of late bidders steadily rises to 50% or 75% by the final auction depending on ρ. Their observations indicate that sniping is a strategy learned over time. Ultimately, these findings help justify using a within-subject design because I can observe if the subjects learn to snipe in the eBay treatment and then, conditional on sniping, whether the subjects continue to snipe once the mechanism is introduced.

3.3.1 Auction Environment

All subjects in the experiment will act as bidders in a series of auctions. In each auction, two randomly matched subjects compete to win a non-divisible good. Each subject has a private value for the good which is drawn independently from an uniform distribution between \$6 and \$10. The subjects' values are redrawn from the distribution at the start of each new auction.

Subjects are given the opportunity to submit a proxy bid in numerous bidding periods throughout the course of each auction. Any bid submitted by a subject must satisfy the following conditions: (i) it must be greater than or equal to the reserve price of \$1, (ii) it must be greater than the subject's current highest bid, and (iii) it must be above the current price.

Each auction is divided into three stages: an initial bidding stage (Stage 1), a reaction bidding stage (Stage 2), and a late bidding stage (Stage 3).[12] The stages do

[12]In AOR, the auction is described as having only an early stage and a late stage. Their early

not vary between the eBay and Credit treatments. Using discrete bidding stages as opposed to a timed auction allows me to maintain control of the environment and to clearly define sniping. In particular, discrete bidding stages are important to: (i) insure that early bids can be responded to and late bids cannot, (ii) create uncertainty in the relay success of late bids which is constant across all auctions and subjects, and (iii) clearly identify a subject as a sniper. The progression through the stages is similar to the progression discussed in the theoretical model.

- **Stage 1**. Stage 1 consists of a single bidding period where subjects simultaneously decide whether to submit a bid or to wait. If at least one subject submits a bid, then the auction moves to Stage 2. If neither subject submits a bid, then the auction moves to Stage 3.

- **Stage 2.** Stage 2 consists of an endogenous number of bidding periods. In each bidding period, subjects either submit a new bid or do not submit a new bid. Bids placed during each bidding period are assumed to be simultaneous. After each period, the current high bidder and price are revealed. Stage 2 ends once a bidding period passes where neither subject submits a bid; the auction then moves to Stage 3. The number of bidding periods in Stage 2 will vary between bidding pairs. By endogenizing the bidding periods, I am able to observe whether the bidders are naïvely bidding, whether they are learning, and the maximum bid they are willing to place before submitting a 'late' bid.

- **Stage 3.** Stage 3 consists of one bidding period where, like before, subjects can choose to either submit a new bid or keep their previous bid. However, bids submitted in this stage may not be successfully received by the auctioneer. The

stage would encompass both Stage 1 and Stage 2 that I use. I describe the environment using three stages, as opposed to two, to be consistent with Nagy's (2013) model.

likelihood of a successful transmission is the same for both subjects but one subject's bid being unsuccessful does not imply that his rival's bid will also be unsuccessful. Bids that are kept from Stage 2, or 1, will always be successfully transmitted to the auctioneer. After both subjects have made their decisions, the winning bidder and final price are determined.

In all bidding periods, regardless of the Stage, each subject is shown the following information: his private valuation for the good, his current bid, a record of previous high bids in the auction, and whether he is the high bidder. Subjects are never informed of their bidding partner's (or rival's) ID number.[13] Subjects are also shown the minimum bid they must submit so that the three conditions, previously listed, are satisfied. If a subject attempts to bid below their displayed minimum bid, then they are notified that the bid is invalid and they must either enter a new bid or opt not to bid. The subjects are not alerted if the bid they submit is above their value.[14] A sample screenshot of asubject's bidding screen is shown in Appendix B.3.

At the conclusion of Stage 3, the subjects are informed of whether their Stage 3 bid was successfully received by the auctioneer, if they submitted a Stage 3 bid, and the outcome of the auction. The subject with the highest successfully submitted bid wins the auction.[15] The winning subject earns his private value minus the final price, while the non-winning subject earns zero for the auction.

After reviewing the auction's outcome, the subjects are informed that they will

[13]Given the large population of bidders on eBay, it is unlikely that the same bidders will compete again in the same auction. I have considered running later sessions where the bidders identity is only revealed to his partner if he chooses to submit a bid. Treatments were the number of bidders in the auction is unknown has also been discussed as an area of future research.

[14]There is a bidding cap of $20 which is significantly about the maximum value of $10.

[15]In the event of a tie, precedence is given to the bidder who submitted the "tying" bid in the earliest bidding period, and if both bids were submitted in the same bidding period, then the high bidder is randomly determined.

be moving on to the next auction. All subjects participate in every auction. The subjects are always informed of how many auctions they have completed as well as their current, cumulative, earnings in the experiment. The total number of auctions in the session is indicated in the Subject Instructions; see Appendix B.1. The subjects did not learn about the credit, and the second treatment, until midway through the session.

3.3.2 eBay Treatment

The eBay treatment is comprised of the first half of the total number of auctions. Each auction transcends through the three Stages as previously described. The final price, paid by the subject with the highest bid, is the maximum of the second highest bid and the reserve price.

3.3.3 Credit Treatment

The remaining half of auctions correspond to the Credit treatment where the credit mechanism is introduced. A subject must submit a bid in Stage 1 to be eligible to receive the credit which remains constant across all auctions. There is one credit available for each bidding pair. It is likely that both subjects will bid in Stage 1; in which case, the credit will be randomly awarded, with equal probability, to one of the subjects. The allocation of the credit is observed by both subjects at the conclusion of Stage 1. The price paid by the winning subject depends on whether he has the credit. If he does not, then the rule to determine the price is identical to the rule discussed in the eBay treatment. If he does, then the price is reduced by the credit. Unused credits do not carry over to the next auction. Subjects are informed of the monetary value of the

credit during every bidding period regardless of whether the subject has the credit.

3.3.4 Parameter Assignments

In order to test the effectiveness of credits, the experiment parameter assignments must guarantee that sniping constitutes a Bayes-Nash Equilibrium in the eBay treatment; in other words, expression 3.1 must be satisfied. Given $v_i \sim U[6, 10]$ and the reserve price is \$1, sniping is a symmetric equilibrium if

$$\frac{2}{7} = \frac{(10-6)}{(10+6)-2(1)} < \rho.$$

To replicate one of AOR's eBay treatments, I let $\rho = 0.8$ which means that a Stage 3 bid will be successfully received by the auctioneer 80% of the time. Given $\rho = 0.8$, the optimal credit must satisfy condition 3.2

$$\begin{aligned} c &> \frac{2}{3}\left(-(4) + \sqrt{(.8)^2(4)^2 + \frac{8}{3}(.8)(.2)(23)}\right) \\ c &> 0.319 \end{aligned}$$

and condition 3.3

$$\begin{aligned} c^2 &< -4(.8)(.2) + (1-(.8)^2)\int_6^{10} v_2\left(1 - \frac{v_2 - 6}{4}\right)dv_2 \\ c &< 2.15. \end{aligned}$$

Seller profits are decreasing in c thus, the optimal credit the seller offers is $c^* = 0.319 + \varepsilon$ where $\varepsilon > 0$. In the Credit treatments, the subjects are offered a credit of \$0.40 which satisfies 3.2 and 3.3. This credit was chosen for mathematical simplicity;

subjects should find it easier to calculate their maximum willingness to pay by adding \$0.40 to their values as opposed to \$0.32. Given the parameter assignments, Table 3.1 presents the predicted ex-ante surplus of the subjects and the seller/experimenter.

Model - Strategy	Ex-Ante Seller Surplus	Surplus of Subject with value v	Ex-Ante Subject Surplus
NoCredit Early Bidding	\$7.33	$\frac{1}{8}\left(v^2 - 12v + 36\right)$	≈ 0.67
NoCredit Sniping	\$5.01	$\frac{4}{25}(v-1)+$ $\frac{2}{25}\left(v^2 - 12v + 36\right)$	≈ 1.55
Credit Early Bidding	\$7.28	$\frac{1}{8}\left(v^2 - 12v + 36.16\right)$	≈ 0.69

TABLE 3.1. Surplus generated given the parameter assignments and the credit of \$0.40.

3.4 Experimental Hypotheses

The baseline eBay treatment should confirm the results of AOR and it should allow subjects to learn the potential benefits of sniping. A sniper is identified as a subject who does not bid in Stage 1. This identification rule is used because of how sniping is described in *Result 1*. *Result 1* also indicates whether the sniper should place a bid in Stage 2. If the sniper's rival also does not bid in Stage 1, then both only place bids in Stage 3. Alternatively, if the sniper's rival places a bid in Stage 1, then Nagy (2013) says the sniper should react by submitting a bid in Stage 2. The result from Nagy (2013) relies of the fact that the rival who deviates, by bidding early, bids his value. However, if the subject believes his rival is naïvely bidding, then the

subject's best response is to wait until Stage 3 to bid. Thus, the presence of a sniper can be measured either by (i) a subject not bidding in Stage 1 or (ii) a subject only bidding in Stage 3. Note that a subject who satisfies (ii) also satisfies (i) but the reverse is not true. Furthermore, this definition of sniping is in-line with how sniping is described by Wenyan and Bolivar (2008).

The behavior of the subjects in the eBay treatment should be identical to the AOR eBay treatment. AOR observe sniping as a best response to subjects who are incrementally bidding. They also observe that the average number of bids prior to the last stage steadily declines, across all treatments, to approximately 1.75 bids as the subjects gain experience. The subjects do not engage in bidding wars and the subjects who bid early submit bids near the reserve price. Approximately 50% of the subjects place bids in Stage 3 by the end of the treatment. Furthermore, bids in Stage 3 converged towards the subject's value which caused the subject with the higher value to win the auction approximately 80% of the time.

The impact of the credit on bidding behavior, specifically sniping, is the primary interest of this experiment. Between the eBay and Credit treatments there should be significant differences in the frequency of subjects not bidding in Stage 1, in the earnings of the subjects, in seller profit, and in the efficiency of the auction. In the Credit treatment, I also expect to observe subjects with the credit submitting bids above their true values. Comparing across the different treatments I form the following four hypotheses.

(H1) More subjects adopt sniping strategies in the eBay treatment than in the Credit treatment.

A higher frequency of subjects choosing not to bid in Stage 1 during the eBay

treatment would confirm H1. Furthermore, sniping should become more frequent as the subjects gain experience in the eBay treatment.

(H2) Bids at the end of Stage 2 are closer to the bidders maximum willingness to pay in the Credit treatment than in the eBay treatment.

If H2 is not rejected, then I can infer that the credit causes subjects to be either engaging in bidding wars or taking full advantage of the proxy bidding system. If the change in behavior is a consequence of the subjects developing a better understanding of proxy bidding, then there should be evidence of early value bidding at the end in Stage 2 in the final auctions of the eBay treatment. In either treatment, the subjects should be submitting bids in Stage 3 that are equal to their maximum willingness to pay.

(H3) Greater seller(experimenter) profits in the Credit treatment.

Offering a credit is only beneficial to the seller if the gain in the auction price, prior to any discounts, exceeds the cost of offering a credit. An increase in the number of subjects placing Stage 1 bids and bidding above their value should improve seller profit in the Credit treatment.

(H4) Efficiency is greater in the Credit treatments than in the eBay treatments when subjects are sniping.

If subjects are sniping, then there is greater uncertainty in whether the item will be allocated to the subject who values it the most. For example, if the sniper has a higher value but his Stage 3 bid is lost, then he loses and the auction is inefficient. The credit is designed to incentivize early bidding and drive Stage 1, and Stage 2,

bids closer to the subject's value so subjects are not relying on their Stage 3 bids to win the auction. If the credit is successful, then it will mitigate the loss in efficiency due to bids being lost.

3.5 Experimental Procedure

For this study, 54 participants were divided into groups of 8 subjects (expect for one group of 6) to participate in one of 7 sessions. The subjects in each session completed 36 auctions, 18 auctions for the eBay treatment and 18 auctions for the Credit treatment. The total number of observed auction outcomes is 972 and the total number of subject observations is 1,944.

Participation in both treatments is essential because it gives subjects the ability to learn, through experience, to snipe; see AOR and Wilcox (2000). If the subjects were to participate in only one treatment, then the effect of the credit could be misinterpreted. Suppose, as predicted, sniping is not observed in the Credit treatment, then the absence of snipers could be caused by the credit or by a subject's inability to see the potential benefits of sniping. Furthermore, the credit is intended to demolish the current sniping epidemic and thus, its targeted at the bidders who are well-versed in sniping and believe it is the norm.

The subjects are randomly rematched after each auction. Random rematching is necessary to prevent subjects from predicting their rival's behavior based on past interactions. The rematching rule requires that each new auction not begin until all subjects have completed the current auction. The session ends once the participating subjects complete all 36 auctions. All auctions were computerized and were programmed using the Z-tree software, Fischbacher (2007).

The subjects used in this experiment were undergraduates recruited, via an online database, from the University of Arizona. All experimental sessions were held in the Economic Science Laboratory at the University of Arizona during January 2013 and March 2013. All participants were compensated for their voluntary participation. Upon completion of the experiment, each subject was privately paid their earnings. A subject's earnings included a show-up fee of $5 USD and their cumulative earnings from all 36 auctions at a rate of 2:1. A subject earned on average, including the $5 show-up fee, $30.50 USD.[16] A session typically lasted between 80 and 100 minutes, only one session lasted 2 hours.

3.6 Results

In this section, I will present and discuss the experimental results in the order of the four hypotheses stated previously. I will first analyze the data using the observations from all 54 subjects. I observe that some, not all, subjects are sniping in the eBay treatment. Consequently, I find that the data as a whole does not support all four hypotheses which is not surprising since the credit is designed to alter the behavior of bidders who are sniping. In order to determine whether the credit has a significant effect on the subjects who are sniping, I will repeat my analysis of the hypotheses using only the observations from the subjects who are labeled as snipers in the eBay treatment.

[16]This project was graciously funded by an ESL grant from the University of Arizona.

3.6.1 Evidence of Sniping

Recall, sniping is characterized by the act of not placing a bid in Stage 1. In the eBay treatment, I observe 23 unique subjects not bidding in Stage 1 at least once. However, not all of the 23 subjects continue to snipe in subsequent auctions as indicated by the variance in Figure 3.1. In all but one session, there is at least one subject who sniped in more than half of the auctions in the eBay treatment. Furthermore, in most sessions, there is a subject who sniped in at least 14 of the first 18 auctions. I occasionally observe a subject who will only snipe once. Nearly all one-time-snipers lose the auction they snipe in which likely discourages them from sniping again.

Approximately 22% of all auctions in the eBay treatment have at least one sniper; conditional on the auction having at least one sniper, only 5.6% have two snipers. However, almost half of all sniping takes place in the last six auctions of the eBay treatment. In these auctions, a sniper is observed in approximately 36.4% of them. The increase in non-Stage1 bidding over time is consistent with arguments that sniping and experience are positively correlated. AOR do no report how many subjects do not bid in Stage 1 because they define sniping as bidding late, i.e. placing a bid in Stage 3. Although sniping is a form of late bidding, it is better described as waiting to bid. On eBay, there is a significant amount of late bidding by snipers, who are strategically waiting to bid, and by early bidders who are placing bids in response to being outbid late in the auction. Thus, AOR's experimental definition of sniping as simply placing a bid in Stage 3 is inaccurate and incomplete because it does not specify whether the bidder bids in Stage 1 or Stage 2.[17]

[17] When referencing AOR, their Stage 1 corresponds to both my Stage 1 and Stage 2 and their Stage 2 corresponds to my Stage 3.

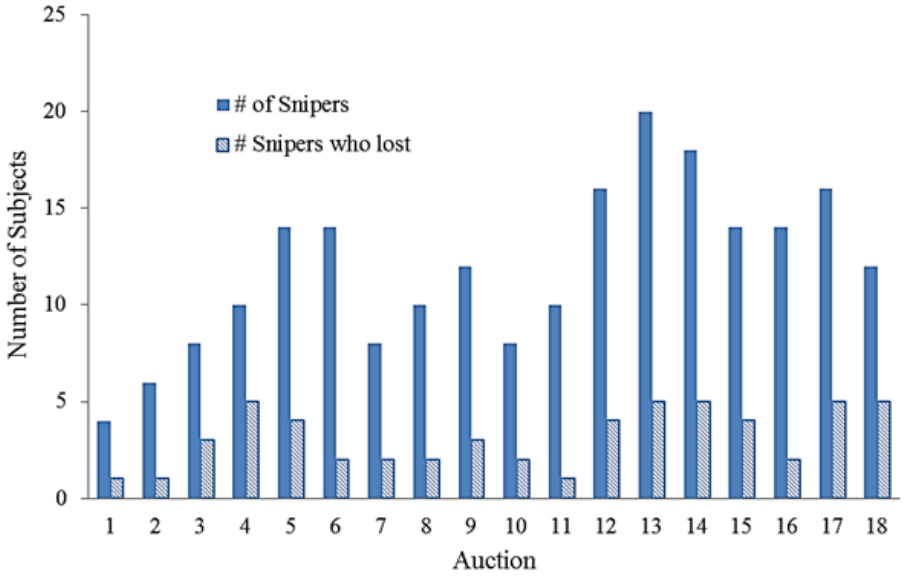

FIGURE 3.1. Number of subjects who snipe by auction in the eBay treatment.

Hypothesis H1 predicts that sniping will be more frequent in the eBay treatment than in the Credit treatment. There are 113 observations of subjects not bidding in Stage 1 during the eBay treatment verses only 14 observations in the Credit treatment. Aggregating at the subject level, the difference in the frequency of sniping between the two treatments is shown to be significant using a Wilcoxon signed ranks test ($p < 0.001$). Thus, the data supports H1.

Table 3.2 displays the marginal effects from a probit regression in which the dependent variable is 1 if a subject does not bid in Stage 1, in other words the subject snipes, and 0 otherwise. The *p-values* corresponding to each explanatory variable are shown in the parenthesis. *Treatment* is a binary dummy variable that takes on the value of 1, or 0, for observations occurring during the Credit, or eBay, treatment. The first column in Table 3.2 shows that being in the Credit treatment reduces the probability of sniping by 10.19%; the effect is highly significant and shows support

for H1.

Column II of Table 3.2 controls for other variables which may influence the probability a subject will snipe. *WinsFromSnipe* is a running total of the number of auctions, prior to the current auction, which the subject has won and sniped in. If a subject never snipes, then *WinsFromSnipe* will always be zero for the subject. The number of previous auction wins that resulted from the subject sniping has a small, but significant, positive effect on whether the subject will snipe again. The variable *Value* is the subject's assigned value for the item. The negative sign on *Value* indicates that a subject with a higher value is less likely to snipe. Although the effect from *Value* is not significant, the negative sign is predicted by Nagy (2013) who shows that the bidder with the higher value will deviate from the sniping equilibrium before his lower-valued rival. If a bidder believes his value is lower than his rival's value, then sniping is more beneficial to him because it gives him a positive probability of winning the auction. If the bidder with the lower value were to bid early, then his rival will do the same. Consequently, assuming both bidders are behaving as theory predicts and bidding their values, the low valued bidder will lose the auction with certainty. There is little change in the marginal effect of the treatment dummy when other explanatory variables are included in the model. Thus, the results in Table 3.2 indicate that sniping is less likely in the Credit treatment.

Dependent Variable: Probability a subject does not bid in Stage 1		
	I	II
Treatment	-10.19% (0.000)	-10.15% (0.000)
WinsFromSnipe		0.65% (0.120)
Value		-0.14% (0.295)

TABLE 3.2. Marginal effects from a probit regression.

3.6.2 Bidding Behavior

Early Bidding: Behavior in Stage 1 & 2

In each auction of the eBay treatment, the majority of subjects submit a bid in Stage 1. Conditional on the subject placing a Stage 1 bid, average Stage 1 bids steadily decline from $4.50 to $3.50 over time. In addition, average bids in Stage 1 as a percentage of (the subjects') values steadily decline in the eBay treatment from 58% to 41%. The observation of subjects placing smaller, positive, Stage 1 bids as they gain experience is counterintuitive. Researchers argue that bidders who submit low initial bids and then increase their bids throughout the auction are following a naïve bidding strategy that is a consequence of inexperience. Thus, I would anticipate a rise in the average bid placed in Stage 1 as subjects become more familiar with the proxy bidding system.[18]

In the Credit treatment, the credit is always given to a subject in every auction and thus, there is never an auction where neither subject opted not to bid in Stage 1. In the Credit treatment, 99.3% of Stage 1 bids are greater than zero. Furthermore,

[18] AOR do not report the average first bids of the subjects in their experiment. Thus, no direct comparisons can be made between the behavior they observe and the behavior I observe.

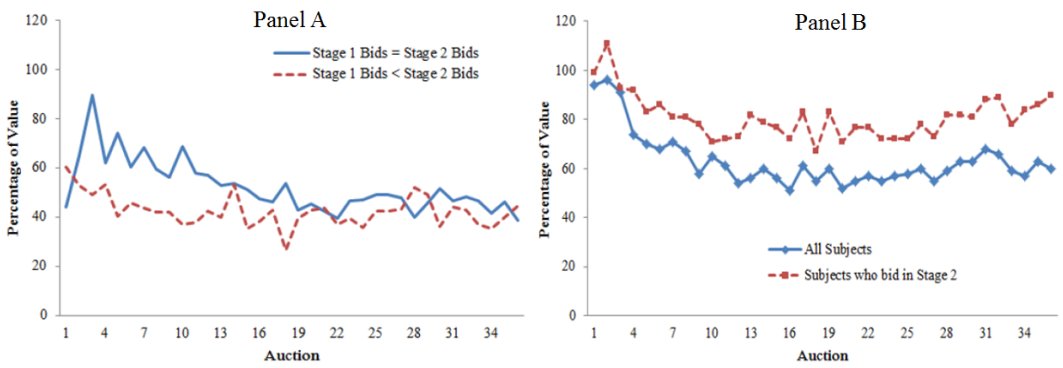

FIGURE 3.2. Average Stage 1 bids (Panel A) and average Stage 2 bids (Panel B) as a percentage of value over time.

average Stage 1 bids are approximately $3.40 for all auctions which is equivalent to the average (positive) Stage 1 bid in auction 18, the last auction in the eBay treatment. The downward trend in Stage 1 bids that is observed in the eBay treatment does not continue in the Credit treatment. It appears that by auction 18 most non-sniping subjects have adopted a comfortable bidding strategy which they continue to use for the remainder of the session. Thus, by the end of the eBay treatment there is very little learning taking place.

The number of subjects increasing their bids in Stage 2 declines significantly throughout the course of the eBay treatment. Excluding subjects who snipe, in auctions 1-4, more than 67% of the subjects bid in Stage 2 while in auctions 15-18, fewer than 43% of the subjects increase their bids in Stage 2. This observation combined with the decline in Stage 1 bids suggests that non-snipers are not incrementally bidding. Figure 3.2-A displays the average bid submitted in Stage 1 as a percentage of values, conditional on the Stage 1 bid being positive. The dashed(solid) line represents the average for subjects who did(did not) increase their bids in Stage 2; both exhibit a slight downward trend despite the different starting points. Furthermore,

regardless of the subjects' strategy in Stage 2, the average Stage 1 bid relative to values appears to be converging towards 43%. As expected, the subjects who do not increase their bids in Stage 2 submit a Stage 1 bid that is a greater percentage of their value than the subjects who do increase their bids in Stage 2. A Wilcoxon signed ranks test confirms that there is a significant difference between the dashed and solid line in the eBay treatment; $p = 0.0012$.

During the Credit treatment, there is little variation in the number of subjects who place bids in Stage 2. Averaging over all auctions in the Credit treatment, approximately 44% of subjects do not place a Stage 2. The lack of Stage 2 bidding suggests that the majority of subjects are not engaging in bidding wars despite both the subject and their rival bidding in Stage 1. Furthermore, similar to the eBay treatment, subjects are not bidding their values in Stage 1. The average Stage 1 bids as a percentage of values for subjects who do not increase their bids in Stage 2 is a mirror image of the average percentages for the subjects who do increase their bids; see auctions 19 to 36 in Figure 3.2-A**.** A paired t-test indicates that in the Credit treatment, the average Stage 1 bids of the subjects who place bids in Stage 2 are significantly different from the average Stage 1 bids of the subjects who do not bid in Stage 2; $p = 0.0213$.[19] However, subjects who increase their bids in Stage 2 are, on average, willing to bid closer to their values in Stage 2.

Figure 3.2-B displays the average highest Stage 2 bid as a percentage of (the subjects') maximum willingness to pay. In the eBay treatment, a subject's maximum willingness to pay is his value. The solid line represents the averages for all subjects while the dashed line represents the averages for only the subjects who bid in Stage 2. In either case, the data shows that the subjects are not bidding their values by the

[19] A Shapiro-Wilk test for normality fails to reject the null hypothesis that each data set is normally distributed; the p-values are 0.382 and 0.215.

end of Stage 2. However, subjects who are bidding in Stage 2 submit bids closer to their values than subjects who do not bid. The downward trend during auctions 1-10 suggests that subjects are bidding further from their values as they gain experience.

In the Credit treatment, a subject's maximum willingness to pay is his value plus the credit if he has the credit or his value if he does not. Figure 3.2-B shows a slight upward trend in average highest Stage 2 bids as a percentage of maximum willingness to pay during the Credit treatment. The trend is driven solely by subjects who are increasing their bids in Stage 2 because there is little variation in Stage 1 bids. The relatively higher bids in the Credit treatment may be due to subjects overvaluing the price reduction. An alternative explanation is that the credit causes subjects to become more invested in winning the item and thus, they bid higher in Stage 2 to improve their chances of winning in the event that their Stage 3 bid is lost.

The number of bidding periods in Stage 2 indicates the number of bids placed prior to Stage 3. Over time, the average number of bidding periods in Stage 2 declines to approximately 4 periods per auction; see Figure 3.3. The drop during the eBay treatment is caused by the decline in the number of subjects increasing their bids in Stage 2 and by the increase in the number of snipers. AOR observe a similar downward trend but they see the average number of bidding periods declining from 4 per auction to approximately 2.5. In the Credit treatment, the average number of bidding periods remains constant around 4 per auction despite there being fewer subjects sniping. The insignificant change from the end of the eBay treatment (auctions 11-18) to the Credit treatment suggests that the credit does not cause subjects to engage in bidding wars.

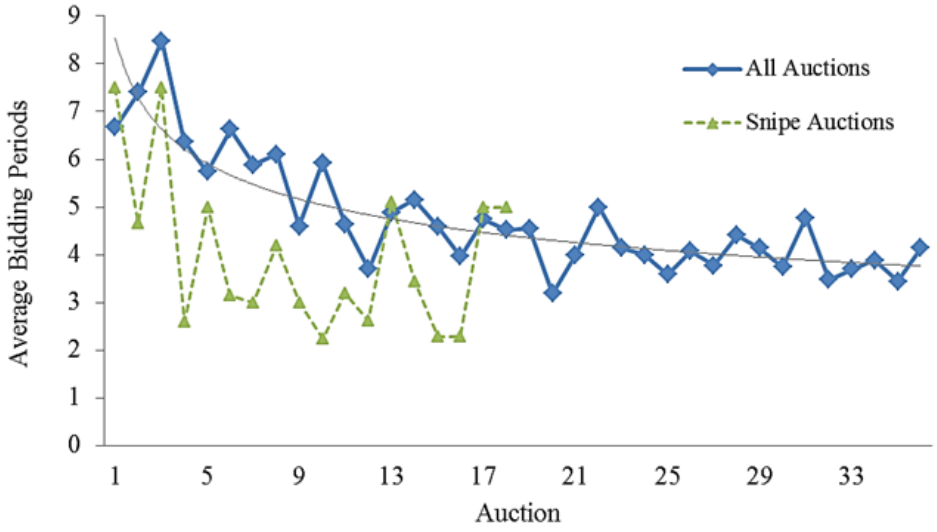

FIGURE 3.3. Average number of bidding periods per auction over time.

Late Bidding: Behavior in Stage 3

The average Stage 3 bid, including lost bids, as a percentage of (the subjects') values is over 90% for every auction in the eBay treatment. Averaging over all auctions in the eBay treatment, Stage 3 bids are approximately 96.5% of values. AOR also observe Stage 3 bids being, on average, at least 90% of values; however, they observe bids be equivalent to the subjects' values by auction 15 which I do not see. During the eBay treatment, the number of subjects who do not bid in Stage 3 declines from approximately 22 subjects (40%) in the early auctions, to 11 (20%) in the later auctions, and finally to only 6 subjects (11%) in auction 18.[20] Note, if a subject chooses not to bid in Stage 3 then their Stage 3 bid is identical to their Stage 2 bid. Subjects appear to be relying on their Stage 3 bids to win the auction. Furthermore, there is a clear positive relationship between experience and late bidding. AOR

[20]If I were to use AOR's definition of sniping (bidding in Stage 3), then I would observe almost 90% of the subjects sniping by the last auction in the eBay treatment.

observe a flatter downward trend in Stage 3 bidding where the percentage of subjects not bidding in Stage 3 declines from approximately 60% in auction 1 to 50% in auction 18.

The number of subjects who do not bid in Stage 3 varies randomly throughout the Credit treatment but the number is consistently between 15 and 21 subjects; approximately 28% to 39% of subjects. Averaging over all auctions in the Credit treatment, 17.5 subjects per auction do not bid in Stage 3 which is almost identical to the average of 15.8 subjects per auction in the eBay treatment.

After adjusting for the credit, subjects are submitting Stage 3 bids closer to their maximum willingness to pay in the Credit treatment than in the eBay treatment. The average Stage 3 bid, including lost bids, as a percentage of maximum willingness to pay is over 94% in each auction of the Credit treatment. The average for all auctions in the Credit treatment is approximately 97.5%. Interestingly, the average Stage 3 bid relative to the subjects' willingness to pay is over 100% for the subjects with the credit in only auction 36 but for subjects without the credit it is over 100% in nine of the auctions[21].

In conjunction with higher bidding in Stage 3, there are significantly more auctions with overbidding in the Credit treatment. Aggregating over all sessions, approximately 40% of the auctions in the eBay treatment had at least one subject bidding more than their value compared to 64% of the auctions in the Credit treatment. Just over half of the overbidding in the Credit treatment is by subjects who receive the credit and recognize the advantage it gives them in the market. More importantly, the remaining half of overbidding is from subjects without the credit. Similar overbidding in private value second price auctions is observed in the laboratory by Kagel

[21] Auctions 22, 26-28, 30-33, and 35.

and Levin (1993).

The subject with the credit wins the auction, on average, approximately 60% of the time and consequently, a subject without the credit wins approximately 40% of the time. The subject with the lower value receives the credit 44.86% of the time and conditional on receiving the credit, wins the auction 28.9% of the time. This explains why the average earnings for subjects who do not receive the credit is slightly lower than the average earnings for subjects who do receive the credit. There are only 41 occurrences of the credit causing the subject with the lower value, compared to his rival, to have a maximum willingness to pay above his rival's value. Of those occurrences, the subject with the credit won 22 of the auctions. In the remaining 19 auctions, the losses are caused primarily by low Stage 3 bids as opposed to bids being lost or the rival overbidding.

3.6.3 Seller Profit

Seller profit in the eBay treatment is the final auction price; recall the price is the maximum of the second highest bid and the reserve price. In the Credit treatment, seller profit depends on whether the subject with the highest bid has the credit. If the subject does not have the credit, then seller profit is the final auction price. If the subject does have the credit, then seller profit is the final auction price minus the credit. Figure 3.4 shows that average seller profits in the eBay and Credit treatments are not significantly different; this implies a rejection of H3. The averages for all auctions are displayed in Table 3.4.

The data collected from the experiment can be represented as a panel-data set where time is represented by auctions and individual subject observations can be identified using group numbers and subject IDs. Table 3.3 displays the results of a

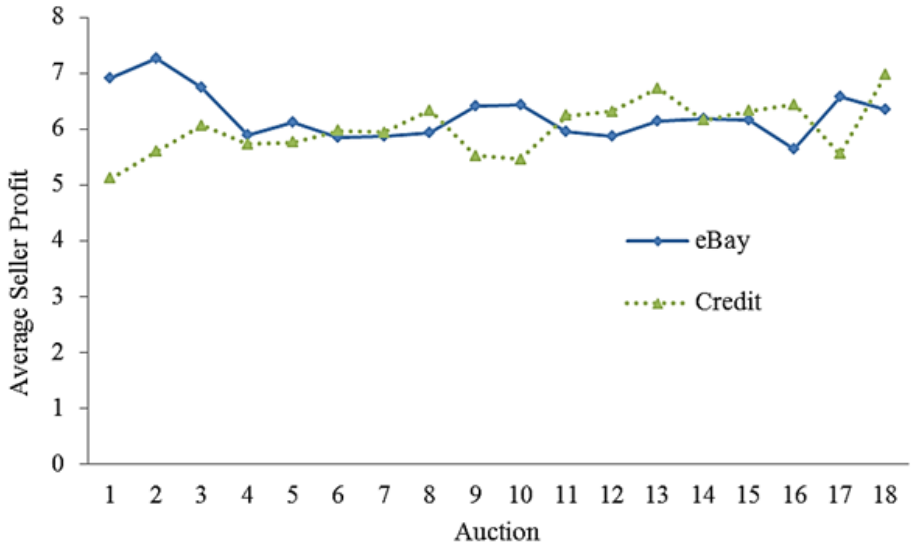

FIGURE 3.4. Average seller profit over time. (Credit averages correspond to auctions 19-36.)

series of regressions using fixed effects for individual subjects where the dependent variable is seller profit. A fixed effects model, as opposed to a random effects model, is appropriate because the explanatory variables are likely to be correlated across subjects. The only exceptions are the winning subject's value and the non-winning subject's bid being lost; both are randomly determined. However, a subject is able to avoid losing his bid by keeping his Stage 2 bid in Stage 3 as opposed to submitting a new bid. A subject's choice to keep his bid is directly correlated with an individual bidding strategy and thus, a lost bid is not necessarily a random event.

Controlling for no other factors, Column I of Table 3.3 shows that the availability of the credit has a negative effect on profit, rejecting H3, but the effect is insignificant at the 85% level. The negative sign is somewhat expected given the lack of sniping observed in the eBay treatment. Table 3.1 indicated that if bidders were not originally sniping in the eBay, then seller surplus will decline when a credit is offered. Thus,

Dependent Variable: Seller Profit	I	II FE	III FE	IV FE
Treatment	-.227 (0.162)	0.20 (0.143)	0.19 (0.147)	0.26 (0.042)
Stage2BidPeriods		0.16 (0.000)	0.15 (0.000)	0.16 (0.000)
LoserLostBid		-3.39 (0.000)	-3.30 (0.000)	-3.29 (0.000)
SniperWins		-0.45 (0.171)	-0.34 (0.282)	
WinnerValue			0.44 (0.000)	0.40 (0.000)
WinnerStage1Bid				0.12 (0.000)
Constant	6.23	6.05	2.36	2.15

TABLE 3.3. Regression results relating to seller profit with subject fixed effects in II, III, and IV.

comparisons between seller profit should be made conditional on whether the subjects were originally snipers; this idea will be explored in section 3.6.5.

In addition to *Treatment*, seller profit may depend on other explanatory variables. The impact of the non-winning subject's bid being lost in Stage 3 is represented by the variable *LoserBidLost;* it takes on the value of 1 if the bid was lost and 0 otherwise. Bidding wars are expected to drive up prices so the number of Stage 2 bidding periods are included in the regressions. In addition, I include two different variables to capture the impact a sniper will have on seller profit. The first captures whether the winning bidder is a sniper and the second is the winning bidder's Stage 1 bid.

Columns II and III in Table 3.3 include the dummy variable *SniperWins,* which takes on the value of 1 if a sniper won the auction and 0 otherwise. There is little difference between model II and III in terms of both the significance and the mag-

nitude of the coefficients on the explanatory variables. In opposition to Column 1, *Treatment* has a positive and significant (at the 85% level) effect on seller profits. A sniper winning the auction causes profit to decline by \$0.45 but the effect is slightly insignificant. The non-winning subject's Stage 3 bid being lost has the largest, negative, effect on seller profit which is not surprising when the majority of subjects are relying on their Stage 3 bids to win the auction.

Column III includes the winning subject's value in the model, *WinnerValue*, which is likely to be positively correlated with seller profit. Note that including a subject's value as an explanatory variable does not meet the assumptions of the fixed effects model but I choose to report the results as a check for robustness. Including *WinnerValue* causes a large, but expected, decrease in the constant term. In addition, the coefficient on *SniperWins* becomes less significant and has a smaller impact on profit.

An alternative measure for capturing the impact of sniping on profits is to use the explanatory variable *WinnerStage1Bid*; it takes on the value of 0 if the subject is sniping. The coefficient on *WinnerStage1Bid*, shown in Column IV of Table 3.3, implies that for every \$1 increase in the winning bidders first bid, seller profit increases by \$0.12. The ability for bidders to receive a credit increases seller profit by \$0.26; note that this takes into account the \$0.40 cost of offering the credit. However, the impact of the credit on profit is even greater when a sniper from the eBay treatment chooses not to snipe in the Credit treatment. Converting a sniper causes profits to increase by at least \$0.38, \$0.12 from the effect of bidding at least \$1 in Stage 1 and \$0.26 from the treatment effect. All explanatory variables, including *Treatment*, are highly significant.

As mentioned in the previous subsections, subjects, on average, are submitting

Auction	% of Seller Surplus Captured	Average Seller Profit
eBay	84.1	\$6.23
Credit	82.1	\$6.01

TABLE 3.4. Differences in seller profitability between the two treatments.

bids in Stage 3 that are less than their maximum willingness to pay. Thus, the seller is likely to not be capturing all her available surplus. Table 3.4 shows the percentage of total surplus received by the seller as a percentage of the surplus that would be obtained if subjects were bidding their maximum willingness to pay prior to Stage 3. The insignificant difference between the eBay and Credit treatments is, again, likely caused by relatively few subjects sniping in the eBay treatment.

3.6.4 Efficiency

The efficiency of an auction is measured by whether the bidder with the highest value for an item retains the item. There is debate on whether this measure of efficiency, in reality, is pertinent to auction houses. If, for example, eBay is concerned about insuring the bidder with the highest value will always win the auction, then it should consider an alternative sealed-bid auction design. However, efficiency may be indirectly important to auction houses because it is important to the bidders and sellers it wants to attract. Bidders who value fairness may be drawn to more efficient auction houses because the final outcomes are the "right" ones. Efficiency is likely to also be important to sellers because it should correlate with higher prices and thus, generate greater seller surplus.

Auction	% of Efficient Auctions	% of Total Surplus Captured
eBay	68.3	96.2
Credit	78.8	97.9

TABLE 3.5. Differences in auction efficiency between the two treatments.

The first column of Table 3.5 presents the percentage of auctions in which the winning subject had a value greater than their rival's value. The eBay auctions are efficient approximately 68.3% of time. This result is in line with the 70% auction efficiency AOR and Durham et al. (forthcoming) observe. Only a small portion of the efficiency loss is due to bids in Stage 3 being "lost". During the eBay treatment, a new Stage 3 bid was lost 17.3% of the time; or 119 bids out of 688. Of the 119 Stage 3 bids that were lost, only 25 bids would have generated a gain in efficiency. Thus, inefficiencies are caused by poor bidding strategies as opposed to Nature's bad luck. Introducing the credit results in a significant 10% improvement in auction efficiency. Although H4 specifies an improvement in efficiency with respect to auctions in the eBay treatment where a subject is sniping, the significant increase suggests that the data will support H4 because theory predicts auctions with snipers are more inefficient than those without snipers.

Table 3.6 displays the marginal effects of a probit regression using the probability the auction results in an efficient outcome as the dependent variable. The dependent variable takes on the value of 1 if the auction is efficient and 0 if it is inefficient. The p-values corresponding to the independent variables are shown in parenthesis. Column I of Table 3.6 indicates that the true effect of the treatment with no controls. Being in the *Treatment* causes the probability the high valued subjects wins the

Dependent Variable: Probability the auction is efficient			
	I	II	III
LoserLostBid		-2.94% (0.498)	-2.43% (0.573)
Treatment	9.94% (0.000)	9.16% (0.002)	7.56% (0.011)
LoserBid:Value		30.79% (0.000)	31.38% (0.000)
SniperWins		-9.09% (0.158)	-10.96% (0.008)
#Stage2BidPeriods			-0.92% (0.010)

TABLE 3.6. Marginal effects of a probit regression relating to auction efficiency.

auction to be 9.94% more likely; the marginal effect is highly significant. This result provides support for H4.

However, within each session there is a large learning/sequence effect between the two treatments. To ensure that the *Treatment* variable is not capturing these effects I show the results of two additional regressions. In the additional models, I include explanatory variables which are likely to be correlated with subject bidding behavior and auction efficiency. The variable *LoserBid:Value* is the non-winning subject's Stage 3 bid as a fraction of the subject's value. If non-winning subjects are bidding closer to their maximum willingness to pay, then it should be more likely that the auction yields an efficient outcome. All regressions include this explanatory variable along with the *Treatment* dummy and the *LoserLostBid* dummy.

A quick comparison of columns II and III in Table 3.6 shows little variation in the significance and marginal effects of the variables *LoserLostBid* and *LoserBid:Value.* As previously mentioned, lost bids are likely not to be the cause of inefficiencies which is confirmed by the small and highly insignificant effect from the variable *LoserLost-*

Bid. The negative sign on *LoserLostBid* is also expected because the majority of subjects are bidding significantly less than their maximum willingness to pay in Stage 2 and are focusing on their bids in Stage 3. Thus, the Stage 3 bid of the higher valued subject being lost could easily result in the subject losing the auction and an inefficient outcome. *LoserBid:Value* has a large and highly significant positive marginal effect which is predicted. A non-winning subject submitting a bid closer to their value would improve the probability of the auction being efficient by approximately 31%.

The second column of Table 3.6 includes the dummy variable *SniperWins* in the regression. A sniper will reduce the probability of the auction being efficient by approximately 9.09%. The negative effect is expected because if the subject with the lower values snipes, then it improves his chances of winning. The auction taking place with the credit, represented by *Treatment*, has a positive and highly significant effect on efficiency. Specifically, offering a credit increases the likelihood that the auction is efficient by 9.16%.

The third column of Table 3.6 includes the number of bidding periods in Stage 2 as a measure of bidding wars. Bidding wars are characterized by a higher number of bidding periods during Stage 2 of the auction as subjects repetitiously place bids to manually out-bid their opponent by the lowest possible bid. However, the inclusion of the number of bidding periods has a small but significant marginal effect of the probability of the auction yielding an efficient outcome[22]. Including the number of Stage 2 bidding periods has little impact on the marginal effects or significance of the other independent variables. The *Treatment* effect declines slightly to 7.56% while the marginal effect from *SniperWins* becomes more negative.

[22] The negative sign on the marginal effect is unexpected but could be a consequence of the subjects submitting Stage 2 bids that are (on average) less than half their values. Thus, despite engaging in bidding wars, the subjects are relying mostly on their bids in Stage 3 to win the auciton.

Overall, the *Treatment* dummy remains significant across all regressions, even when controlling for sniping, which provides support for hypothesis H4.

3.6.5 Experienced Snipers

At the beginning of the results section, I reported that there were 23 unique subjects who, in at least one auction, did not bid in Stage 1 during the eBay treatment. Many of these subjects adopt a "trial and error" approach to sniping. The subjects would attempt to snipe for the first time but either their Stage 3 bid would be lost or they would lose the auction and as a result, many choose never to snipe again. However, not all subjects are one-time snipers. In most sessions, there is at least one subject who snipes in at least 14 of the 18 auctions in the eBay treatment. The subjects who are sniping repeatedly do so regardless of whether the snipe always results in a win.

In this section, I will direct my attention to the set of subjects who repeatedly snipe in the eBay treatment because the credit is designed to specifically target the behavior of these subjects. The set of snipers contains one bidder from Session 3, two bidders from Sessions 1, 4, 6, and 7, and three bidders from Session 5; a total of 12 bidders who placed 111 snipe bids. I anticipate observing significant differences across the two treatments in regards to the auction outcomes and the subjects' bidding behavior when I condition on the subjects being snipers.

Table 3.7 displays the results of a probit regression using subject fixed effects with the dependent variable being the probability a subject snipes. The explanatory variables used are identical to those in the probit regression displayed in Table 3.2; however using a fixed effects specification causes all observations for non-sniping subjects to be dropped. Conditional on sniping in the eBay treatment, the true negative

Dependent Variable: Probability a subject does not bid in Stage 1		
	I (FE, Snipers)	II (FE, Snipers)
Treatment	-15.31% (0.000)	-19.53% (0.000)
WinsFromSnipe		1.06% (0.001)
Value		-0.52% (0.072)

TABLE 3.7. Marginal Effects of a rrobit regression relating to the probability an experience sniper snipes.

effect from being in the Credit treatment is magnetized to 15.31% and remains highly significant.

Column II of Table 3.7 includes controls for various factors that may impact a subject's bidding strategy as they gain experience. The marginal effects from *SnipeWins* and *Value* are again small in magnitude and have the expected sign. However, unlike in Table 3.2, conditioning on the subjects being snipers causes both effects to be significant. Most importantly, the negative marginal effect from the treatment dummy remains highly significant which provides further support for H1.

Throughout this section I will make reference to two different types of auctions within the eBay treatment. The first are Snipe auctions which denote an auction in which the subject places a snipe bid. The second are NoSnipe auctions which are the auctions where the bidder places a positive bid in Stage 1.

Sniper Response to Credit

The purpose of the Credit treatment is to evaluate whether the appeal of a price reduction will discourage snipers from bidding late. Thus, it is natural to focus on

how the experienced snipers in the eBay treatment responded to the early bidding incentive.

For these bidders, the average Stage 1 bid in the Credit treatment was \$1.95 which is significantly lower than the average, non-zero, Stage 1 bid of \$3.58 in the eBay treatment (Wilcoxon signed ranks test, $p = 0.0121$). The average number of bidding periods in Stage 2 in the eBayNoSnipe, eBaySnipe, and Credit auctions was 5.97, 4.64, and 3.68 respectively. Differencing across subjects using a Wilcoxon signed ranks test indicates that there is a significant difference in the number of bidding periods between eBayNoSnipe and Credit ($p = 0.047$) but no significant difference between eBaySnipe and Credit ($p = 0.638$).

Interestingly after not bidding in Stage 1, each of the twelve snipers adopt one of only two strategies in Stage 2. In the eBay treatment, approximately half of the snipers do not place bids in Stage 2; I will refer to these subjects as "non-punishing snipers", or NPsnipers. I will refer to the subjects who did place a bid, or bids, in Stage 2 as "punishing snipers", or Psnipers. The subjects never mix between the punishing and non-punishing strategies; each adopts one and uses it for every auction they snipe in. Recall, theory predicts that if a subject's rival deviates and bids early, then the subject should punish his rival by bidding his value in Stage 2.

In the eBay treatments, the Psnipers submit a highest bid in Stage 2 that is on average 76.5% of their value. The same subjects, in the Credit treatment, submit a highest bid in Stage 2 that is on average 64% of their value. In the Credit treatment, the subjects who are NPsnipers submit a highest bid in Stage 2 that is on average 18% of there value. The NPsnipers are submitting early bids near the reserve price only in an attempt to capture the credit. After observing the allocation of the credit, these subjects are waiting until Stage 3 to place another bid. This low bidding behavior

along with the decline in the number of bidding periods, see Figure 3.3, implies that these snipers are unwilling to engage in bidding wars.

In the eBay treatment, a Psniper outbid his rival 54% of the time but he had the lower value in almost two-thirds of the auctions he won. The introduction of the credit causes the percentage of wins to decline slightly to 51.9%. However, the proportion of auction wins by Psnipers where they had the lower value declines significantly to 12.5%; a consequence of non-snipers overbidding, or bidding closer to their maximum willingness to pay, in the Credit treatment. In the eBay treatment, a NPsniper outbid his rival 45.6% of the time and he had a value lower than his rival's value in only one-third of the auctions. The percentage of auctions won increases to 50% when the credit is introduced.

Figure 3.5 shows the average earnings for each subject during the eBay treatment, when they sniped or did not snipe, and during the Credit treatment.[23] Differencing across subjects, a paired t-test for dependent samples indicates that the mean earnings during Snipe auctions are strictly greater than those during NoSnipe auctions ($p = 0.127$) but the means are not statistically different between the Snipe auctions and the Credit auctions ($p = 0.871$).[24] Readers should be cautious in the validity of these results because this type of testing will not eliminate the sequence effects from the experience gained within the two treatments.

[23] Sniper 12's average earnings from auction where he did not snipe were extremely negative because he and his rival both drove their bids up to $20 in the first auction. Sniper 12 was the first to bid $20, which was the maximum bid allowed, and thus, paid a price of $20 which was significantly higher than the subject's value. This was the only observation where both subjects in the auction placed bids equal to the maximum bid of $20.

[24] A Shapiro-Wilk test for normality confirms that the data is normaly distributed for each specification at a 90% confidence level.

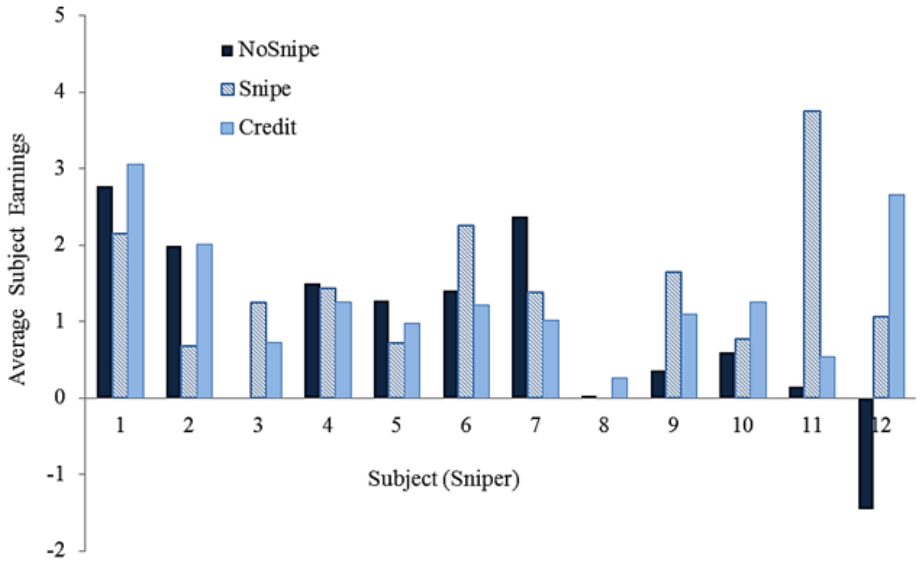

FIGURE 3.5. Average subject earnings for only subjects who sniped in the eBay treatment.

Seller Profit

Previous comparisons of average seller profit between the eBay and Credit treatments showed the two treatments were indistinguishable. Figure 3.6 shows average seller profits for the Credit, eBaySnipe, and eBayNoSnipe auctions over time using all subject observations. The averages for all auctions are displayed in Table 3.8. A paired t-test for dependent samples[25] indicates that profits obtained during the Credit auctions are significantly greater than those obtained during the eBaySnipe auctions ($p = 0.131$). Thus, conditional on there being a sniper in the auction, I find support for hypothesis H3; the Credit treatment generates greater seller profit. Average seller profit in the eBaySnipe auctions is significantly less than average seller profit in the eBayNoSnipe auctions ($p = .0413$) which is consistent with arguments that sniping

[25] A Shapiro-Wilk test for normality (H_0 : Data is normally distributed) confirms that the data is normaly distributed for each specification at a 99% confidence level. For eBayNoSnipe, eBaySnipe, and Credit the p-values are 0.792, 0.328, and 0.624 respectively.

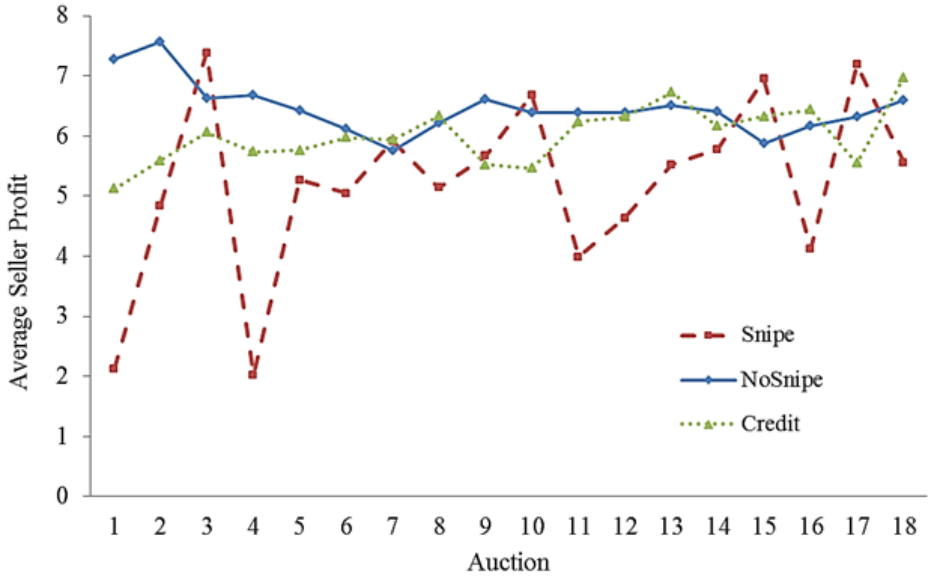

FIGURE 3.6. Average seller profit over time conditional on the presence of a sniper. (Credit averages correspond to auctions 19-36.)

reduces auction prices, or seller profits.

Table 3.8 displays the surplus captured by the seller as percentage of the ex-post surplus the seller would receive if subjects were bidding their maximum willingness to pay. As expected, the seller captures the least amount of surplus in auctions where at least one bidder is sniping. The credit mechanism is able to recapture some of the lost profit/surplus but not as much as the theory predicted.

Table 3.9 reports the results of an OLS regression and shows that conditioning on the subjects being snipers reverses the effect of the treatment on seller profit. Although the sign on *Treatment* is positive, it is also relatively insignificant and thus, it can not support the predictions made in H3. Column III of Table 3.9 confirms the previous result that profit loss is driven primarily by lost bids in Stage 3.

Auction	% of Seller Surplus Captured	Average Seller Profit
eBayNoSnipe	87.5	\$6.47
eBaySnipe	72.3	\$5.21
Credit	82.1	\$6.01

TABLE 3.8. Differences in average seller profitability for each type of auction.

Dependent Variable: Seller Profit	I All Subjects	II Snipers	III Snipers (FE)
Treatment	-.227 (0.162)	0.387 (0.250)	0.32 (0.184)
Stage2BidPeriods			0.21 (0.000)
LoserLostBid			-3.18 (0.000)
Constant	6.23	5.94	5.07

TABLE 3.9. Regression results relating to seller profit in auctions with experienced snipers.

Auction Efficiency

If an auction is efficient when the subject with the higher value receives the item, then the eBayNoSnipe auctions are efficient approximately 70% of the time. Efficiency drops to 60.8% in the eBaySnipe auctions where I observe a sniper winning 53% of the auctions while having a value greater than his rival's value only 43% of the time. Recall, during the Credit treatment the auctions were efficient approximately 79% of the time which is significantly greater than the efficiency of the Snipe auctions. The difference in efficiency between the Snipe and NoSnipe auctions is also due to differences in the non-sniping subjects Stage 2 and Stage 3 bids. In Snipe auctions, the non-sniping subjects place Stage 2 bids that are on average 51% of their value and a Stage 3 bid that is 82% while in NoSnipe auctions, the non-sniping subjects' average Stage 2 bids are 70% of their values and the average Stage 3 bids are 92%. Thus, subjects adopt significantly different strategies when competing against a rival who is bidding early.

An alternative method for evaluating auction efficiency is to analyze the total surplus generated ex-ante. Figure 3.7 displays the total surplus generated by each of the three types of auctions as a percentage of the total surplus generated in a second price auction where bidders bid their values. For the eBay treatment, I calculate the maximum surplus by summing the lower value of the two subjects for all auctions. For the Credit treatment, I assume the subject with the credit bids his value plus the credit and I use the adjusted maximum willingness to pay when calculating maximum surplus. The differences between the percentages in the eBaySnipe, eBayNoSnipe, and Credit auctions are fairly small. This may be a consequence of the values being drawn from a distribution with a relatively small support, \$6 and \$10. As a baseline for comparison I randomly allocate the good to one of the two subjects in each auction

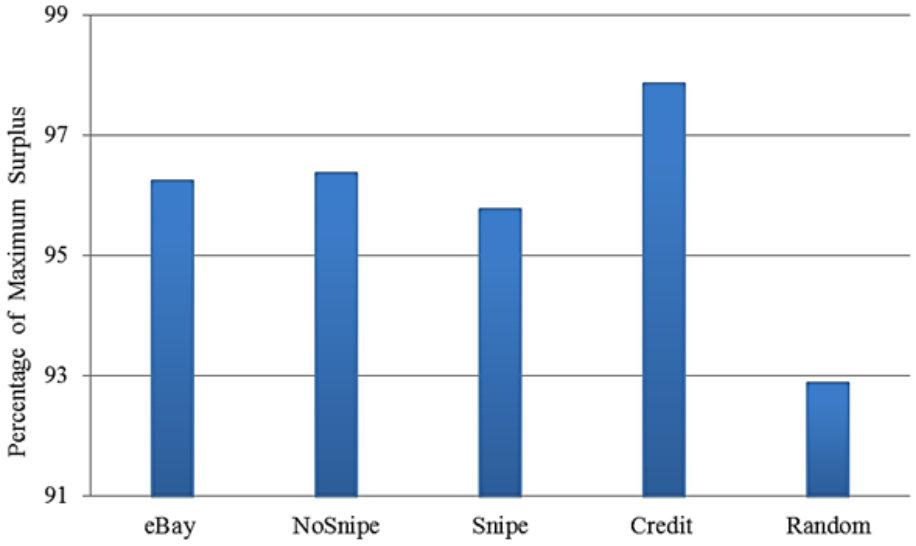

FIGURE 3.7. Total surplus captured by the auction as a percentage of the maximum surplus attainable.

and calculate the total surplus generated as a percentage of the maximum obtainable in the auctions. Randomly allocating the item captures approximately 93% of total surplus which is only 3% less than the total surplus captured when the subjects are able to follow their own bidding strategy in the eBay treatment. Using 93% as a reference point, the approximate 2% gain in efficiency from the eBaySnipe auctions to the Credit auctions is more substantial and confirms H4. The increase is likely explained by overbidding in the Credit treatment.

3.7 Conclusion

When bidders in auctions with fixed ending times, like those on eBay, follow the recommended strategy of bidding their maximum willingness to pay at the start of the auction, final prices and seller revenue tend to be highest. This strategy yields an efficient outcome by guaranteeing the bidder with the highest value wins the item.

However, not all bidders adhere to this strategy. Bidders are frequently seen placing bids in the very last seconds of an auction; i.e. sniping. Snipers attempt to place bids as near to the ending as possible and thus, snipers run the risk of their bids not being successfully transmitted to the auctioneer. However, if the bid is successful, then a winning sniper may pay a price significantly below the price he would have paid if he instead bid early. Consequently, sniping reduces seller profits. If a seller anticipates snipers in the auction, then a mechanism which incentivizes bidders to bid early would be beneficial. Nagy (2013) proposes a bidding mechanism that offers early bidders a price reduction, i.e. credit, if they win the auction.

In the baseline eBay treatment, I observe trends in the data that are consistent with the previous research by Ariely, Ockenfels, and Roth (2005) but on a different scale. Relative to their findings, I observe subjects submitting higher early bids and placing a greater number of bids throughout the auction. Over time, positive early bids are further from the subjects' values which indicates that the subjects are not taking advantage of, or do not understand, proxy bidding.

The primary purpose of this paper is to experimentally test the effectiveness of Nagy's (2013) bidding mechanism at reducing, or eliminating, sniping in eBay-like auctions. In the eBay treatments there are 113 observations of sniping verses only 14 observations in the Credit treatment; a significant difference. Furthermore, the credit is shown to have a highly significant negative marginal effect on the probability a bidder snipes. As the subjects gain experience, sniping becomes more frequent; approximately 36% of the auctions in the last third of the eBay treatment have at least one sniper. If I restrict attention to a subset of subjects who I identify as experienced snipers, then the marginal effect grows in magnitude. Thus, credits are effective at reducing the amount of sniping in auctions with fixed ending times.

Of equal importance is the impact the credit has on seller profits. Aggregating across all observations, there is little difference in seller profit between the two treatments. The insignificance is not surprising since the majority of subjects are not sniping. A total of 23 subjects, out of a total of 54, snipe at least once but only 12 subjects snipe repeatedly. The credit is designed to improve seller profit relative to profit when bidders are sniping. A comparison of average seller profit in auctions during the eBay treatment with a sniper and in auctions during the Credit treatment shows a significant increase in profit when credits are offered. The gain in seller profit translates into greater profits for eBay because the auction house collects a final portion of the seller price. In addition, the credit improves auction efficiency in respect to capturing a greater portion of the maximum surplus available and in allocating the item to bidder with the highest value more often. More overbidding in the Credit treatment than in the eBay treatment also explains the improvement in seller profit and auction efficiency. Furthmore, the ability of the credit to spark more aggresive bidding improves its attractivness to sellers.

While the aggregate data suggests that bidders are responsive to the credit I do have some concerns. First, when the credit becomes available most of the original snipers adopt a strategy of submitting a low early bid to capture the credit and then wait until the last stage of the auction to bid; a modified sniping strategy. Ideally, the snipers' rivals should recognize this and submit a bid equal to their maximum willingness to pay prior to the last stage. However, I instead observe a greater number of bidders learning to adopt a similar strategy of relying heavily on late bids to win the auction. The subjects not recognizing the precautionary benefits of the proxy bidding system is a second area of concern. It suggests that late bidding strategies cannot be fully expunged on eBay until bidders are fully educated on proxy bidding.

APPENDIX A

Incentivizing Early Bidding Using Credits in Internet Auctions

A.1 Proof of Proposition 1

Proof. [ ] In Stage 3, bidder i's bid is successfully received with probability ρ. Bidder i's bid, b_i^3, is only relevant if his bid is successfully received. Assume bidder 2 follows the strategy of bidding $\beta^3(v_2, h^2) = v_2 \ \forall h^2 \in H^2$ and both bidders bid prior to $t = 3$ according to some symmetric sequence of bidding functions $\{\beta^1, \beta^2\}$. Let bidder 1 at $t = 3$ bid b_1^3 when his value is v_1.

Suppose bidder 1 observes h^2 where $w^2 = \{\emptyset\}$, which implies neither bidder has bid prior to $t = 3$. Bidder 1's expected payoff at $t = 3$, conditional on h^2, is

$$\pi_1(b^3, v_1, h^2 = \{..., (r, \emptyset)\}) = \rho^2 \Pr(b_1^3 > v_2)(v_1 - v_2) + (1 - \rho)\rho(v_1 - r)$$

With probability ρ^2 both bidders are able to bid; bidder 1 wins if and only if $b_1^3 > b_2^3 = v_2$. With probability $\rho(1 - \rho)$ bidder 2 is unable to bid but bidder 1 is, bidder 1 wins and pays the reserve price. Bidder 1 maximizes his expected profit when he maximizes the probability he wins when both bidders are able to bid, so $b_1^3 = v_1$.

Suppose according to $\{\beta^1, \beta^2\}$ bidders bid prior to $t = 3$ so $w^2 \neq \{\emptyset\}$. The bidders' strategies are symmetric prior to $t = 3$ so either both bidders bid in Stage 1 and not in Stage 2 or both bid in both Stages 1 and 2. Let $b_i^{\bar{t}} = \max\{\beta^t(v_i, h^{t-1}) \mid \beta^t(v_i, h^{t-1}) =$

$a_i^t\}$, the highest bid submitted by bidder i such that the strategy defined placed bid is equivalent to the recorded action of the bidder. If h^2 is such that $w^2 = 2$ then $b_1^{\bar{t}} < b_2^{\bar{t}}$. Bidder 1's profit function reduces to

$$\pi_1(b^3, v_1, h^2 = \{..., (b_1^{\bar{t}}, 2)\}) = \begin{array}{c} \rho^2 \Pr(b_1^3 > v_2)(v_1 - v_2) \\ +\rho(1-\rho) \Pr(b_1^3 > b_2^{\bar{t}})(v_1 - b_2^{\bar{t}}) \end{array}$$

Maximizing with respect to b_1^3 implies that $b_1^3 = v_1$ in order to maximize $\Pr(b_1^3 > v_2)$ and $\Pr(b_1^3 > b_2^{\bar{t}})$. If h^2 is such that $w^2 = 1$ then $b_1^{\bar{t}} > b_2^{\bar{t}}$. Bidder 1 always wins if bidder 2's bid is unsuccessfully received since bids are weakly increasing in t, thus $\Pr(b_1^3 > b_2^{\bar{t}}) = 1$. Bidder 1's profit function is then

$$\pi_1(b^3, v_1, h^2 = \{..., (b_2^{\bar{t}}, 1)\}) = \rho^2 \Pr(b_1^3 > v_2)(v_1 - v_2) + \rho(1-\rho)(v_1 - b_2^{\bar{t}}).$$

Maximizing with respect to b_1^3 implies that $b_1^3 = v_1$ in order to maximize $\Pr(b_1^3 > v_2)$.

For all possible histories bidder 1 's best response is to bid his value at $t = 3$ when bidder 2 bids his value; and vice versa. □

A.2 Proof of Theorem 2

Proof. [ ] Assume bidder 2 follows the strategy $\beta_2^t(v_2, h^{t-1}) = v_2 \ \forall h^{t-1} \in H^{t-1}$ and $\forall\ t > 0$. The objective is to show that bidder 1's best response is the same strategy. It has been shown that in any symmetric equilibrium $\beta_i^3(v_i, h^2) = v_i \ \forall h^2 \in H^2$, so bidder 1 will bid his value in (or by) Stage 3. Working backwards, consider bidder 1's best response in stages $t < 3$. If bidder 1 does not bid in Stages 1 or 2 then $h^2 = \{(r, 2), (r, 2)\}$ and his expected profit is $\rho^2 \Pr(v_1 > v_2)(v_1 - v_2)$. If, instead,

bidder 1 bids $b_1^t > r$ in Stage t then his expected profit is $\Pr(b_1^t > v_2)(v_1 - v_2)$,which is maximized when $b_1^t = v_1$. Given bidder 2's strategy, bidder 1 always prefers bidding v_1 early since $\rho < 1$. Furthermore, bidder 1 bids in Stage 1, as opposed to waiting for Stage 2, because precedence is given to the earlier bidder in the event of a tie. Thus a best response to $\beta_2^t(v_2, h^{t-1}) = v_2 \ \forall h^{t-1} \in H^{t-1} \forall \ t$ is $\beta_2^t(v_2, h^{t-1}) = v_1 \ \forall h^{t-1} \in H^{t-1}$ $\forall \ t > 0$. Hence $\beta^t(v_i, h^t) = v_i \ \forall h^t \in H^t \ \forall \ t > 0$ is a symmetric equilibrium. □

A.3 Proof of Theorem 3

Proof. [ ] By *Proposition 1* $\beta_i^3(v_i, h^2) = v_i \ \forall h^2 \in H^2$, so bidder 1 will bid his value in (or by) Stage 3. If bidders snipe then they each submit a single bid at $t = 3$ which is successfully transmitted with probability ρ. Bidder 1's expected profit in equilibrium when both bidders follow β_i^{snipe} is $\rho(1-\rho)(v_1 - r) + \rho^2 \int_{\underline{v}}^{v_1} (v_1 - v_2) g(v_2) dv_2$. Bidder 1 can only win if he is able to bid in Stage 3. The first term in bidder 1's expected payoff corresponds to his payoff when bidder 2's is unable to bid in Stage 3 and the second term corresponds to when bidder 2 is able to bid. Suppose bidder 1 deviates and does not snipe. If bidder 1 bids early then bidder 2's strategy is to also bid early; furthermore, bidders maximize their expected profit by bidding v_i as shown in Theorem 1. If bidder 1 deviates his expected profit is $\int_{\underline{v}}^{v_1} (v_1 - v_2)\, g(v_2) dv_2$. Bidder 1 prefers to not deviate if

$$\int_{\underline{v}}^{v_1} (v_1 - v_2)\, g(v_2) dv_2 < \rho(1-\rho)(v_1 - r) + \rho^2 \int_{\underline{v}}^{v_1} (v_1 - v_2) g(v_2) dv_2$$

which simplifies to

$$\frac{\rho}{1+\rho} > \frac{1}{v_1 - r} \int_{\underline{v}}^{v_1} (v_1 - v_2) g(v_2) dv_2.$$

The problem is symmetric for bidder 2. This condition is strictly increasing in v_1 and thus, if a bidder with value $\overline{v}$ is willing to follow β_i^{snipe}, then a bidder with any value is willing to follow β_i^{snipe}. Setting $v_1 = \overline{v}$, the previous condition simplifies to

$$\frac{\rho}{1+\rho} > \frac{1}{\overline{v} - r} \int_{\underline{v}}^{\overline{v}} G(v_2) dv_2.$$

□

A.4 Proof of Proposition 6

Proof. [ ] Assume bidder 2 bids truthfully in the last stage and bids according to the bidding function $\beta^3(v_2, h^2 \mid \kappa) = v_2 + c1_{(\kappa=2)}$ $\forall h^2 \in H^2$. Let b_1^t denote bidder 1's bid in stage t when $\kappa \neq 1$ and let $b_{1,\kappa}^t$ denote bidder 1's bid in stage t when $\kappa = 1$. Suppose, in Stage 3, bidder 1 bids b_1^3 or $b_{1,\kappa}^3$ depending on κ. Assume prior to $t = 3$ both bidders bid according to the sequence of bidding functions $\{\beta^1, \beta^2\}$.

Case 1- No high bidder: Suppose bidders observe $h^2 \in \{...(r, \emptyset)\}$ which implies neither bidder bid at $t = 1$, nor $t = 2$, so $\beta_i^1(\cdot) = 0$ $\forall i$ and consequently neither will receive the credit. Bidder 1 wins the auction if he is able to bid in Stage 3 and $b_1^3 \geq v_2$. Bidder 1's expected payoff in the last stage is

$$\rho^2 \int_{\underline{v}}^{b_1^3} (v_1 - v_2) g(v_2) dv_2 + (1-\rho)\rho(v_1 - r).$$

Maximizing with respect to b_1^3 yields the F.O.C.

$$\rho^2 (v_1 - b_1^3) g(b_1^3) = 0$$

and in equilibrium $b_1^3 = \beta^3(v_1, h^2 \mid \kappa \neq 1)$ so $\beta^3(v_1, h^2 \mid \kappa \neq 1) = v_1$. If $h^2 \in \{...(r, \emptyset)\}$ then bidder 1 should bid his value so $\beta^3(v_1, h^2 \mid \kappa) = v_1$ when $\kappa = \emptyset$; in this case bidder 1 is never able to receive the credit so his optimal bid if $\kappa = 1$ cannot be derived.

Case 2- High bidder: Like in *Proposition 1*, suppose bidders follow symmetric bid functions $\{\beta^1, \beta^2\}$ prior to $t = 3$ so that $w^2 \neq \{\emptyset\}$. Let $b_i^{\bar{t}(i)} = \max\{\beta^t(v_i, h^{t-1} \mid \kappa \neq i) \mid \beta^t(v_i, h^{t-1} \mid \kappa \neq i) = a_i^t\}$ and $b_{i,\kappa}^{\bar{t}(i)} = \max\{\beta^t(v_i, h^{t-1} \mid \kappa = i) \mid \beta^t(v_i, h^{t-1} \mid \kappa = i) = a_i^t\}$ be the highest bids, conditional on κ, submitted by bidder i such that the strategy defined bid is equivalent to the recorded action of the bidder; $\bar{t}(i)$ denotes the stage of bidder i's of the most recent submitted bid.[1]

Suppose bidder 1 observes $h^2 = \{...(b_2^{\bar{t}(2)}, 1)\}$ then $b_1^{\bar{t}(1)} > b_2^{\bar{t}(2)}$. With probability $(1-\rho)$ bidder 2 is unable to bid at $t = 3$ so bidder 1 wins the auction with certainty. If bidder 2 is able to bid then bidder 1 wins only if $(b_1^{\bar{t}(1)}, b_{1,\kappa}^{\bar{t}(1)}) > \beta^3(v_2, h^2 \mid \kappa)$ when he is unable to bid, or if $(b_1^3, b_{1,\kappa}^3) > \beta^3(v_2, h^2 \mid \kappa)$ when his is able to bid. Bidder 1's expected profit will depend on whether or not he has the credit. If he has the credit, $\kappa = 1$, his expected profit is

$$\rho^2 \int_{\underline{v}}^{b_{1,\kappa}^3} (v_1 + c - v_2) g(v_2) dv_2 + (1-\rho)(v_1 + c - b_2^{\bar{t}(2)})$$
$$+(1-\rho)\rho \int_{\underline{v}}^{b_{1,\kappa}^{\bar{t}(1)}} (v_1 + c - v_2) g(v_2) dv_2$$

maximizing with respect to $b_{1,\kappa}^3$ yields the F.O.C.

$$\rho^2 (v_1 + c - b_{1,\kappa}^3) g(b_{1,\kappa}^3) = 0.$$

[1] Assuming that if $i \in \kappa$ bidder i then follows the strategy $\beta^{\bar{t}}(v_i + c, h^{\bar{t}-1}, \kappa)$ as opposed to $\beta^{\bar{t}}(v_i, h^{\bar{t}-1}, \kappa)$ slightly alters the bidder's expected profits but does not change the derived results.

In equilibrium $b^3_{1,\kappa} = \beta^3(v_1, h^2 \mid \kappa = 1)$, and thus

$$\beta^3(v_1, h^2 \mid \kappa = 1) = v_1 + c$$

If bidder 1 does not have the credit, $\kappa \neq 1$, then his expected payoff is

$$\rho^2 \int_{\underline{v}}^{b_1^3 - c} (v_1 - v_2 - c) g(v_2) dv_2 + (1-\rho)(v_1 - b^{\bar{t}(2)}_{2,\kappa})$$
$$+(1-\rho)\rho \int_{\underline{v}}^{b_1^{\bar{t}(1)} - c} (v_1 - v_2 - c) g(v_2) dv_2.$$

Maximizing with respect to b_1^3 yields the F.O.C.

$$\rho^2 (v_1 - (b_1^3 - c) - c) g(b_1^3 - c) = 0$$

and in equilibrium $b_1^3 = \beta^3(v_1, h^2 \mid \kappa \neq 1)$; thus bidder 1's optimal bid in the last stage is

$$\beta^3(v_1, h^3 \mid \kappa \neq 1) = v_1.$$

Suppose bidder 1 observes $h^2 = \{...(1, b_1^{\bar{t}(1)})\}$ then $b_2^{\bar{t}(2)} \geq b_1^{\bar{t}(1)}$. Bidder 1 can only win the auction if his is able to submit a bid in Stage 3. If only bidder 1 is able to bid at $t = 3$ and $(b_1^3, b_{1,\kappa}^3) > \beta^{\bar{t}}(v_2, h^{\bar{t}-1} \mid \kappa)$ then he wins and pays $\beta^{\bar{t}}(v_2, h^{\bar{t}-1} \mid \kappa)$; note bidder 1 does not observe $b_2^{\bar{t}(2)}$. Similar to before, suppose that bidder 1 has the credit; his expected payoff is

$$\rho^2 \int_{\underline{v}}^{b^3_{1,\kappa}} (v_1 + c - v_2) g(v_2) dv_2 + (1-\rho)\rho \int_{\underline{v}}^{\beta^{(\bar{t})^{-1}}(b^3_{1,\kappa})} (v_1 + c - \beta^{\bar{t}}(v_2, h^{\bar{t}-1} \mid \kappa \neq 2)) g(v_2) dv_2.$$

Maximizing bidder 1's expected payoff with respect to $b^3_{1,\kappa}$ gives the F.O.C.

$$\begin{array}{c} \rho^2(v_1+c-b^3_{1,\kappa})g(b^3_{1,\kappa})+ \\ (1-\rho)\rho\Omega\left(v_1+c-\beta^{\bar{t}}\left(\beta^{(\bar{t})^{-1}}(b^3_{1,\kappa},h^{\bar{t}-1}\mid\kappa\neq 2)\right)\right)g(\beta^{(\bar{t})^{-1}}(b^3_{1,\kappa},h^2\mid\kappa\neq 2)) \end{array} = 0$$

where $\Omega=\frac{\partial}{\partial b^3_{1,\kappa}}\beta^{(\bar{t})^{-1}}(b^3_{1,\kappa},h^2\mid\kappa\neq 2)$. The F.O.C. reduces to

$$\begin{array}{c} \rho^2(v_1+c-b^3_{1,\kappa})g(b^3_{1,\kappa})+ \\ (1-\rho)\rho\Omega\left(v_1+c-b^3_{1,\kappa}\right)g(\beta^{(\bar{t})^{-1}}(b^3_{1,\kappa},h^2\mid\kappa\neq 2)) \end{array} = 0;$$

rearranging the terms and given $b^3_{1,\kappa}=\beta^3(v_1,h^3\mid\kappa=1)$ in equilibrium, bidder 1's optimal bid in the last stage is

$$\beta^3(v_1,h^2\mid\kappa=1)=v_1+c.$$

Suppose instead that bidder 1 does not have the credit; his expected payoff is

$$\begin{array}{c} \rho^2\int_{\underline{v}}^{b^3_1-c}(v_1-v_2-c)g(v_2)dv_2+ \\ (1-\rho)\rho\int_{\underline{v}}^{\beta^{(\bar{t}(2))^{-1}}(b^3_1)}(v_1-\beta^{\bar{t}(2)}_2(v_2,h^{\bar{t}(2)-1}\mid\kappa=2))g(v_2)dv_2 \end{array}.$$

Maximizing with respect to y gives the F.O.C.

$$\begin{array}{c} \rho^2(v_1-(b^3_1-c)-c)g(b^3_1-c)+ \\ (1-\rho)\rho\Omega(v_1-\beta^{\bar{t}(2)}\left(\beta^{(\bar{t}(2))^{-1}}(b^3_1,h^{\bar{t}(2)-1}\mid\kappa=2)\right)g(\beta^{(\bar{t}(2))^{-1}}(b^3_1,h^{\bar{t}(2)-1}\mid\kappa=2)) \end{array} = 0$$

where $\Omega=\frac{\partial}{\partial b^3_1}\beta^{(\bar{t}(2))^{-1}}(b^3_1,h^{\bar{t}(2)-1}\mid\kappa=2)$. As before, the F.O.C. can be reduced to

$$\begin{array}{c} \rho^2(v_1-b^3_1)g(b^3_1-c)+ \\ (1-\rho)\rho\Omega(v_1-b^3_1)g(\beta^{(\bar{t}(2))^{-1}}(b^3_1,h^{\bar{t}(2)-1}\mid\kappa=2)) \end{array} = 0$$

where rearranging the terms and given in equilibrium $b^3_1=\beta^3(v_1,h^2\mid\kappa\neq 1)$ the

optimal bid for bidder 1 in the last stage is $\beta^3(v_1, h^2 \mid \kappa \neq 1) = v_1$.

If bidder 2 bids according to $\beta^3(v_2, h^2 \mid \kappa) = v_2 + c1_{(\kappa=2)}\ \forall h^2 \in H^2$ then bidder 1's optimal strategy is to bid according to $\beta^3(v_1, h^2 \mid \kappa) = v_1 + c1_{(\kappa=1)}\ \forall h^2 \in H^2$; thus in any symmetric equilibrium $\beta^3(v_i, h^2 \mid \kappa) = v_i + c1_{(\kappa=i)}\ \forall h^2 \in H^2\ \forall i$. □

A.5 Proof of Theorem 7

Proof. [ ] Assume that bidder 2 follows the proposed strategy and value bids early by following the strategy $\beta^t(v_2, h^{t-1} \mid \kappa) = v_2 + c1_{(\kappa=2)}\ \forall h^{t-1} \in H^{t-1}\ \forall t > 0$. By *Proposition 6* bidder 1 will follow $\beta^3(v_1, h^2 \mid \kappa) = v_1 + c1_{(\kappa=1)}$ in Stage 3 but he must decide whether or not he will bid before Stage 3. Let b_1^t denote bidder 1's bid in stage t when $\kappa \neq 1$ and let $b_{1,\kappa}^t$ denote bidder 1's bid in stage t when $\kappa = 1$.

If bidder 1 chooses not to bid at $t = 1, 2$ then $\kappa \neq 1$ and his expected profit is $\rho^2 \int_{\underline{v}}^{v_1} (v_1 - v_2 - c) g(v_2) dv_2$. Working backwards through the stages consider bidder 1's optimal bid at $t = 2$. Suppose bidder 1 does not bid in Stage 1, consequently $\kappa \neq 1$ and $h^1 = \{(r, 2)\}$, then by not bidding in Stage 2 his profit is shown above. However, if he instead bids b_1^2 in Stage 2 his expected profit is

$$\rho \int_{\underline{v}}^{v_1} (v_1 - v_2 - c) g(v_2) dv_2 + (1 - \rho) \int_{\underline{v}}^{b_1^2 - c} (v_1 - v_2 - c) g(v_2) dv_2.$$

Maximizing with respect to b_1^2 yields the F.O.C. $(1-\rho)(v_1 - (b_1^2 - c) - c) g(b_1^2 - c) = 0$. In equilibrium $b_1^2 = \beta^2(v_1, h^1, c \mid \kappa \neq 1)$ implying $\beta^2(v_1, h^1, c \mid \kappa \neq 1) = v_1$ when $h^1 = \{(r, 2)\}$. By bidding v_1 in Stage 2 bidder 1 earns a profit of $\int_{\underline{v}}^{v_1} (v_1 - v_2 - c) g(v_2) dv_2$ which is strictly greater than the profit he earns by not bidding, hence bidder 1 prefers bidding in Stage 2 over not bidding.

If instead bidder 1 chooses to bid b_1^1at $t = 1$ then he is equally likely to receive

the credit. Consider the case when $\kappa \neq 1$ and $h^1 = \{(p^1, 1)\}$, which implies $b_1^1 > v_2$. By not submitting a new bid at $t = 2$, $b_1^2 = b_1^1$, bidder 1's profit is $\rho \int_{\underline{v}}^{v_1 - c} (v_1 - v_2 - c) g(v_2) dv_2 + (1 - \rho) \int_{\underline{v}}^{b_1^1 - c} (v_1 - v_2 - c) g(v_2) dv_2$. If instead bidder 1 bids in Stage 2 then he will bid b_1^2 to maximize his expected profit of $\rho \int_{\underline{v}}^{v_1 - c} (v_1 - v_2 - c) g(v_2) dv_2 + (1 - \rho) \int_{\underline{v}}^{b_1^2 - c} (v_1 - v_2 - c) g(v_2) dv_2$. Maximizing with respect to b_1^2 yields the F.O.C. $(1 - \rho)(v_1 - (b_1^2 - c) - c) g(b_1^2 - c) = 0$. In equilibrium $b_1^2 = \beta^2(v_1, h^1 \mid \kappa \neq 1)$, thus bidder 1's optimal bid when $h^1 = \{(p^1, 1)\}$ is $\beta^2(v_1, h^1 \mid \kappa \neq 1) = v_1$. Bidder 1's profit from bidding is at least as great as his profit from not bidding because bids are weakly increasing in t, meaning $b_1^1 \leq b_1^2 = v_1$. Suppose instead $\kappa \neq 1$ and $h^1 = \{(p^1, 2)\}$, which implies $b_1^1 < v_2$. If bidder 1 does not increase his bid in stage 2 then his profit is $\rho \int_{\underline{v}}^{v_1 - c} (v_1 - v_2 - c) g(v_2) dv_2$. If he instead chooses to bid then his bid b_1^2 will maximize profits identical to those when $h^1 = \{(p^1, 1)\}$, indicating bidder 1's optimal bid when $h^1 = \{(p^1, 2)\}$ is $\beta^2(v_1, h^1 \mid \kappa \neq 1) = v_1$. Bidder 1's profits from bidding v_1 are at least as great as those from bidding b_1^1; thus bidder 1 prefers to bid in Stage 2 $\forall h^1 \in H^1$ when $\kappa \neq 1$. Bidder 1's decision when $\kappa = 1$ follows a similar argument. If bidder 1 chooses not to increase his bid in Stage 2 then regardless of h^1 his profit is $\rho \int_{\underline{v}}^{v_1 + c} (v_1 + c - v_2) g(v_2) dv_2 + (1 - \rho) \int_{\underline{v}}^{b_1^1} (v_1 + c - v_2) g(v_2) dv_2$. If he instead submits a new bids when $h^1 = \{(p^1, 1)\}$ then his optimal bid $b_{1,\kappa}^2$ maximizes $\rho \int_{\underline{v}}^{v_1 + c} (v_1 + c - v_2) g(v_2) dv_2 + (1 - \rho) \int_{\underline{v}}^{b_{1,\kappa}^2} (v_1 + c - v_2) g(v_2) dv_2$. Maximizing with respect to $b_{1,\kappa}^2$ gives the F.O.C. $(1 - \rho)(v_1 + c - b_{1,\kappa}^2) g(b_{1,\kappa}^2) = 0$; in equilibrium $b_{1,\kappa}^2 = \beta^2(v_1, h^1 \mid \kappa = 1)$ thus bidder 1's optimal bid when $h^1 = \{(p^1, 1)\}$ is $\beta^2(v_1, h^1 \mid \kappa = 1) = v_1 + c$. The bidder's maximization problem is identical when $h^1 = \{(p^1, 2)\}$. Bidder 1's profits from bidding $v_1 + c$ in Stage 2 are greater than or equal to his profits of bidding b_1^1, indicating bidder 1 prefers to bid. Hence bidder 1's optimal bidding strategy in Stage 2, given bidder 2's strategy, is $\beta^2(v_1, h^1 \mid \kappa) = v_1 + c 1_{(\kappa = 1)}$ $\forall h^1 \in H^1$.

It was shown that bidder 1 prefers to bid in Stage 1 and potentially earn a credit; continuing to work backwards through the auction the next step is to determine his optimal bid b_1^1 in Stage 1 when bidder 2 bids v_2. Recall that when bids are placed in Stage 1 bidders are not aware of whether or not they have the credit. So long as $b_1^1 \geq r$ bidder 1's expected profit is $\int_{\underline{v}}^{v_1+c}(v_1+c-v_2)g(v_2)dv_2$ if he has the credit or $\int_{\underline{v}}^{v_1-c}(v_1-v_2-c)g(v_2)dv_2$ if he doesn't because Bidder 1follows $\beta^2(v_1, h^1 \mid \kappa) = v_1 + c1_{(\kappa=1)}$ in Stage 2, which occurs with certainty. However, in the event of a tie for the high bidder precedence goes to the bidder who's bid was submitted in the earlier stage hence $\beta^1(v_1, h^0 \mid \kappa) = v_1$ is a best response to $\beta^1(v_2, h^0 \mid \kappa) = v_2$.

Suppose bidder 1 follows a similar strategy of bidding early but does not bid truthfully and bids as if his value were x; such that $\beta^t(x, h^t \mid \kappa) = x$ and $\beta^t(x+c, h^t \mid \kappa) = x + c \ \forall t$. Bidder 1's is equally likely to win the credit. If $1 \in \kappa$ then he wins the auction when $x + c > v_2$ and he pays v_2. Note that if $1 \in \kappa$ and he is the high bidder with his first bid $\beta^1(x, h^0 \mid \kappa) = x$, which implies $x > v_2$, then bidding again, $\beta^t(x+c, h^t \mid \kappa)$, does not benefit nor harm him. If $1 \notin \kappa$, then bidder 1 only wins if $x > v_2 + c$ and he pays $v_2 + c$. Note since the bidding strategy with the credit is simply an affine transformation of the bidding strategy without the credit, merely the addition of c, I combine both cases into a similar profit maximization problem. Bidder 1 earns an expected profit at time $t > 1$ of

$$\frac{1}{2}\int_{\underline{v}}^{x+c}(v_1+c-v_2)g(v_2)dv_2 + \frac{1}{2}\int_{\underline{v}}^{x-c}(v_1-v_2-c)g(v_2)dv_2.$$

Maximizing with respect to x yields the F.O.C.

$$\frac{1}{2}\left[(v_1-x)g(x+c) + (v_1-x)g(x-c)\right] = 0$$

and thus $x = v_1$. Bidder 1's expected profit from bidding early is $\frac{1}{2}\int_{\underline{v}}^{v_1+c}(v_1 + c - v_2)g(v_2)dv_2 + \frac{1}{2}\int_{\underline{v}}^{v_1-c}(v_1 - v_2 - c)g(v_2)dv_2$.

Suppose instead bidder 1 only bids late, where by *Proposition 6* he bids $\beta^3(v_1, h^2 \mid \kappa) = v_1$, then he loses out on the credit and conditional on his bid being successfully transmitted with probability ρ he only wins if $v_1 > v_2 + c$. Bidder 1's expected profit in the last stage of the auction is

$$\rho \int_{\underline{v}}^{v_1-c} (v_1 - v_2 - c)g(v_2)dv_2.$$

Bidder 1 prefers bidding early if

$$\rho < \frac{1}{2}\left(1 + \frac{\int_{\underline{v}}^{v_1+c} G(v_2)dv_2}{\int_{\underline{v}}^{v_1-c} G(v_2)dv_2}\right)$$

which is always true since $\int_{\underline{v}}^{v_1+c} G(v_2)dv_2 \geq \int_{\underline{v}}^{v_1-c} G(v_2)dv_2$, so the term in parentheses is greater than (or equal to) 2, and $\rho < 1$. Thus folding back the payoffs of the auction, given bidder 2's strategy, bidder 1 prefers to bid early and attempt to capture the credit as oppose to wait. And so $\forall t$ $\beta^t(v_i, h^t \mid \kappa) = v_i$ if $i \notin \kappa$ and $\beta^t(v_i + c, h^t \mid \kappa) = v_i + c$ if $i \in \kappa$ is a symmetric equilibrium. □

A.6 Proof of Proposition 8

Proof. [ ] When both bidders snipe they follow the strategy

$$\beta^{snipe} : \begin{cases} \beta^1(v_i, h^0 \mid \kappa) = 0 \\ \beta^2(v_i, h^1 \mid \kappa) = v_i + c1_{(\kappa=i)} & \forall h^1 \in H^1 \\ \beta^3(v_i, h^2 \mid \kappa) = v_i + c1_{(\kappa=1)} & \forall h^2 \in H^2 \end{cases}$$

The expected profit to bidder 1 when he and bidder 2 follow β^{snipe} is

$$\rho^2 \int_{\underline{v}}^{v_1} (v_1 - v_2) g(v_2) dv_2 + \rho(1-\rho)(v_1 - r).$$

If bidder 1 were to deviate and bid early at $t < 1$, he captures the credit, and bidder 2 responds by bidding his value in Stage 2. Using *Theorem 7*, bidder 1 maximizes his profits from deviating is he bids v_1 in Stage 1 and $v_1 + c$ in Stage 2. Bidder 1's expected profit if he deviates is

$$\int_{\underline{v}}^{v_1+c} (v_1 + c - v_2) g(v_2) dv_2.$$

Bidder 1 earns a higher payoff from deviating if

$$\begin{aligned} \int_{\underline{v}}^{v_1+c} (v_1 + c - v_2) g(v_2) dv_2 &> \rho^2 \int_{\underline{v}}^{v_1} (v_1 - v_2) g(v_2) dv_2 + \rho(1-\rho)(v_1 - r) \\ \int_{\underline{v}}^{v_1+c} G(v_2) dv_2 &> \rho^2 \int_{\underline{v}}^{v_1} G(v_2) dv_2 + \rho(1-\rho)(v_1 - r). \end{aligned}$$

By assuming $v_i \sim U[\underline{v}, \bar{v}]$, the inequality above can be rewritten as

$$\rho(1-\rho)(v_i - r) + \frac{\rho^2 (v_i - \underline{v})^2}{2(\bar{v} - \underline{v})} < \frac{((v_i + c) - \underline{v})^2}{2(\bar{v} - \underline{v})}.$$

Bidder i deviates if $c > -(v_i - \underline{v}) + \sqrt{\rho^2 (v_i - \underline{v})^2 + 2(\bar{v} - \underline{v})\rho(1-\rho)(v_i - r)}$ and the bidder with the highest value deviates, in expectation, if

$$c > \frac{2}{3} \left(-(\bar{v} - \underline{v}) + \sqrt{\rho^2 (\bar{v} - \underline{v})^2 + \frac{3}{2}(\bar{v} - \underline{v})\rho(1-\rho)(2\bar{v} + \underline{v} - 3r)} \right).$$

□

APPENDIX B

An Experimental Test of Early Bidding Incentives in Internet Auctions

B.1 Subject Instructions

Once in the experimental lab, the students were directed to a computer station where a set of instructions, a questionnaire, and a closed manila envelope labeled "Open only when prompted to do so." were sitting. All subjects participating in the experiment received an identical set of paper Instructions which they could refer back to at any time during the experiment. The instructions were unknowingly divided into two parts. Part I was exposed upon arrival; it related to the eBay treatment and the experiment in general. Part II was hidden inside the manila envelope; it related to the Credit treatment.

Part I of the instructions discussed the general structure of the auctions, how to place bids, and how profits were calculated. The subjects were given time to read over the instructions on their own and then attempt a basic questionnaire to check their understanding of the experiment/instructions. The instructions were then read aloud and the answers to the questionnaire were discussed. Before starting the experiment, the subjects had the opportunity to ask general questions relating to the instructions.

After all subjects completed the first half of the auctions, i.e. the eBay treatment, a window on the computer prompted each to stop and open the envelope sitting on

the table. The subjects were directed to read the short set of instructions on their own. Part II of the instructions were not read aloud. The subjects were asked if they had any questions; if not, then they were instructed to continue with the experiment.

B.1.1 Part I - eBay Treatment

The purpose of this session is to study decision making in an auction market. During this session you will participate in a series of auctions.

In each auction there will be exactly two bidders: you and one other bidder, called your "rival". After each auction you will be randomly repaired with another bidder. It is possible that you will be paired with the same bidder in later auctions.

The object you are bidding for, in each auction, is an artificial good. The monetary value you have for the good is a randomly selected experimental dollar amount between \$6.00 and \$10.00. All values on that interval are equally likely.

Your value for the good will be given to you at the start of each auction; it will be displayed on the computer screen for the entire auction. Your value will change between auctions. Having a high value in the first auction does not imply you will have a high value in the next auction.

At the end of the auction,

- If you win the auction with a price of \$$p$, then you earn a profit of your value minus \$$p$. [The price will be discussed in more detail later.] If the price exceeds your value, then you earn a negative profit.

- If you do not win the auction, then your profit is zero.

In order to win the auction you will have to submit a bid or bids

How To Bid

In each auction you will have at least two opportunities to bid.

The bidder with the highest bid is the "high bidder".

The current price is the second highest bid. In other words, if you are the high bidder, then the current price is your rival's bid.

If both bidders submit the exact same bid then the bidder who submitted their bid earliest is the high bidder. If both bidders submit identical bids at the exact same time, one of the bids/bidders is chosen randomly to be the earlier bidder (and the higher bidder).

Example:

1. Bidder 1 submits a bid of \$8.

   Bidder 2 submits a bid of \$4.40.

   Bidder 1 is the higher bidder and the price is \$4.40.

2. Bidder 1 submits a bid of \$6.50.

   Bidder 2 submits a bid of \$6.40.

   Bidder 1 is the higher bidder and the price is \$6.40.

The price is public information to you and your rival, but your bid is kept secret.

The price will never be below the reserve price of \$1.00.

Each auction consists of at least two bidding periods; the exact number will depend on your actions and your rival's actions. In each bidding period you will have the opportunity to submit a bid. You can submit bids multiple times during the auction, regardless of whether or not you are the high bidder.

Whenever you submit a bid, it must satisfy the following three conditions

- It must be greater than or equal to the minimum starting bid (reserve price) of $1.00.
- It must exceed the current price.
- It must exceed the bid you submitted before (if any).

In each bidding period, the minimum you must bid will be displayed on the screen. If the bid you attempt to submit is not high enough you will be prompted to enter a higher bid.

The computer acts on your behalf as a "proxy bidder." It always stores (or remembers) your highest bid from a previous bidding period in the auction. The computer will bid for you, but only enough so that you will be the highest bidder. However, if your rival bids more than your highest bid then the computer will only bid up to the highest bid you placed; it will never bid more than the bid you submitted. The computer is there to help you.

Example:

First Bidding Period: Bidder 1 submits a bid of $8 and Bidder 2 submits a bid of $4.40. Outcome: Bidder 1 is the high bidder and the current price is $4.40

Second Bidding Period: Bidder 1 does not submit a new bid and Bidder 2 increases his bid from $4.40 to $7.

Outcome: The computer remembers Bidder 1's bid of $8 from the first period. Bidder 1 remains the high bidder because $8 > $7. The current price is $7.

Third Bidding Period: Bidder 1 does not submit a new bid and Bidder 2 increases his bid from $7 to $8.50.

Outcome: The computer remembers Bidder 1's bid of \$8 from the first period. Bidder 2 becomes the high bidder because \$8.50 > \$8. The current price is \$8.

If neither bids in any later bidding periods, then the final outcome of the auction is bidder 2 wins and pays \$8.

Note: Had bidder 2 bid \$8.50 in the first bidding period (and bidder 1 still bid \$8) and neither bids in any later periods, then the final outcome of the auction is bidder 2 wins and pays \$8. This outcome is identical to the previous.

During each bidding period you will have the following information: whether or not you are the high bidder, the current price, as well as a history of all the prices from the previous bidding periods during the auction.

Each auction will consist of TWO STAGES, which will now be described.

Stage 1

Stage 1 consists of at least one bidding period. In each bidding period, both bidders will have the opportunity to submit new bids or wait (not submit a new bid). Bids are submitted with 100% probability.

- If a bidder chooses to submit a new bid that bid must satisfy the three conditions listed previously.
- If a bidder chooses to not submit a new bid, then the computer will use your highest bid it stored, from a previous bidding period, to determine if you are the high bidder.

The first bidding period always occurs. Bidding periods will continue to occur after the first period so long as either you or your rival bidder submits a NEW bid.

If both you and your rival decide to NOT submit a new bid in the same bidding period, then the auction moves to Stage 2.

Before the next bidding period starts an intermediate screen will be displayed indicating whether either bidder submitted a new bid and whether or not you will be moving on to the next stage.

Stage 2

Stage 2 will have only one bidding period. In this bidding period, all bidders will have the opportunity to submit a new bid or keep their current bid.

Bids are successfully received by the experimenter with probability 80%.

In other words there is 20% chance that a new bid you submit in Stage 2 will be lost and not received by the experimenter. If your bid is lost, then the computer will remember your highest bid from Stage 1 and will use it to determine if you are the high bidder.

If you kept your bid, then it cannot be lost.

After you and your rival make your decisions, the auction is over.

The bidder with the highest (not lost) bid wins the auction. The final price is the second highest bid. The high bidder will earn an experimental profit of his value minus the price, while the losing bidder will earn an experimental profit of zero.

The outcome of the auction and your experimental profit will be revealed to you and then the next auction will begin.

There will be a total of 36 auctions.

Bidding Screen

What will you see on the screen will be a series of boxes which will have a similar layout to the boxes shown below.

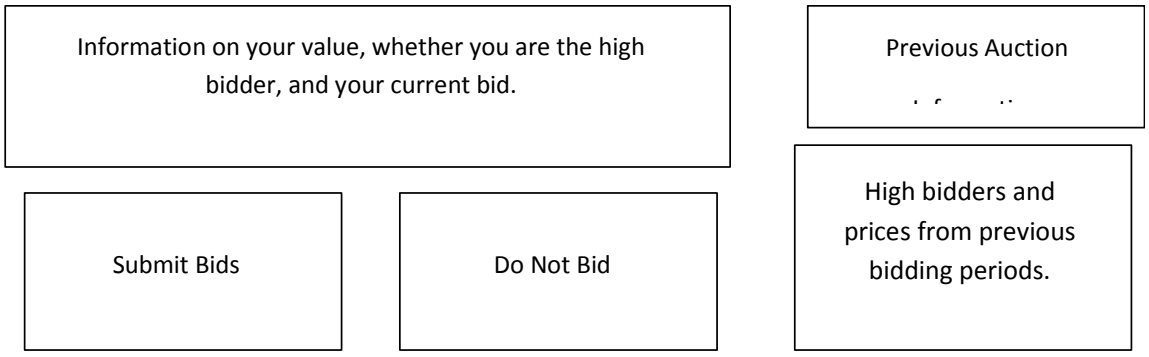

FIGURE B.1. Instructions: Bidding Screen Layout

Summary – In each auction: Values are between \$6.00 and \$10.00. Reserve Price is \$1.00.

The computer will help you by acting as your "proxy bidder" and only bidding enough so that you are the highest bidder. [If you bid \$6 but only needed to bid \$4 to outbid your rival, then the computer will only bid \$4.]

Stage # 1	Bidding Period #1	Bidding Periods after #1
Actions	Submit a Bid or Wait to Bid	Submit a new bid. Do not submit a new bid.
Occurrence	Always	Only if you or your rival bid in the previous bidding period.
Probability bid is successfully submitted to the experimenter	100%	100%

FIGURE B.2. Instructions: Stage 1 Summary

Stage #1 ends if there is a bidding period where both you and your rival do NOT submit a new bid. The auction then moves to Stage #2.

Stage #2	Last Bidding Period
Actions	Bid or Keep Bid
Occurrence	Always
Probability bid is successfully submitted to the experimenter	80%

FIGURE B.3. Instructions: Stage 2 Summary

Winning Bidder: bidder with the highest (not lost) bid at the end of Stage #2

Final Price: the second highest (not lost) bid at the end of Stage #2.

Experimental Profit: If you win, then you earn your value minus the price. If you lose, then you earn zero.

B.1.2 Part II - Credit Treatment

Everything described in Part I of the experiment carries over to Part II.

Short Summary:

- Each bidder's value is a random dollar amount between \$6.00 and \$10.00.
- Each auction consists of a Stage 1 and a Stage 2.
- Stage 1 has at least one bidding period, where bids are successfully received by the experimenter 100% of the time.
- Stage 2 has only one bidding period, where bids are successfully received by the experimenter 80% of the time.
- The bidder with the highest bid (at the end of Stage 2) wins the auction.

- The price the winning bidder pays is equal to the loser's (rival bidder) bid.
- The reserve price is $1.00.

However, for the next 18 auctions, each bidder will have an opportunity to receive a **credit** which will reduce the price you pay if you win the auction. **Only one bidder** can receive the credit.

If the winning bidder has received the credit, then the price he/she pays is the loser's bid minus the credit. If the winning bidder did NOT receive the credit, then the price he/she pays is the loser's bid.

Example: Suppose Bidder 1 wins the auction and Bidder 2's highest bid was $6.50, so the price is $6.50. If Bidder 1 received a credit of $0.40, then the original price of $6.50 is reduced by $0.40 and Bidder 1 only pays $6.10.

To receive the credit you must submit a bid in the first period of Stage 1.

- If only Bidder 1 submits a bid in the first bidding period, then Bidder 1 receives the credit.
- If both Bidder 1 and Bidder 2 submit bids in the first bidding period, then the credit is randomly given to one of the bidders (with equal probability).

If neither bidder bids in the first bidding period, then the credit disappears and neither bidder can receive the credit for the remainder of the auction.

Credits cannot be saved for later auctions.

At the start of each new auction the credit will always be available, regardless of the outcome of the previous auction.

The amount of the credit will be the same throughout all auctions. **The credit is $0.40.**

There are 18 auctions remaining in the experiment.

B.2 Subject Questionnaire

Auction Comprehension Questionnaire – Fill in the Blanks

Auction 1: Reserve Price (minimum starting bid) is $ 1.00

Bidding Period	Bidder 1's Bid	Bidder 2's Bid
1	$5.99	$7.12
2	$7.00	Doesn't Bid
3	Doesn't Bid	Doesn't Bid
4	$8.99	$9.00

TABLE B.1. Subject questionnaire auction example #1.

After bidding period 1:

Highest Bidder is bidder _____ Current Price is _____

After bidding period 2:

Highest Bidder is bidder _____ Current Price is _____

After bidding period 3:

Highest Bidder is bidder _____ Current Price is _____

Which bidding period(s) take place in Stage 1? _____

Which bidding period(s) take place in Stage 2? _____

If both bidders' bids are successfully received by the experimenter in Stage 2 then

Bidder _____ wins the auction. Final Price is _____ .

If only bidder 1's bid is successfully received by the experimenter in Stage 2 then

Bidder _____ wins the auction. Final Price is _____ .

Auction 2: Reserve Price (minimum starting bid) is $ 1.00

Bidding Period	Bidder 1's Bid	Bidder 2's Bid
1	Doesn't Bid	Doesn't Bid
2	$6.21	$7.50

TABLE B.2. Subject questionnaire auction example #2.

Bidding Period 1 takes place in Stage _____ .

Bidding Period 2 takes place in Stage _____ .

If only bidder 1's bid is successfully received by the experimenter in Stage 2 then

Bidder _____ wins the auction. Final Price is _____ .

If bidder 1 has a value of $6.50, then his profit is _____ .

If both bidders' bids are successfully received by the experimenter in Stage 2 then

Bidder _____ wins the auction. Final Price is _____ .

If bidder 1 has a value of $6.50, then his profit is _____ .

B.3 Screenshots

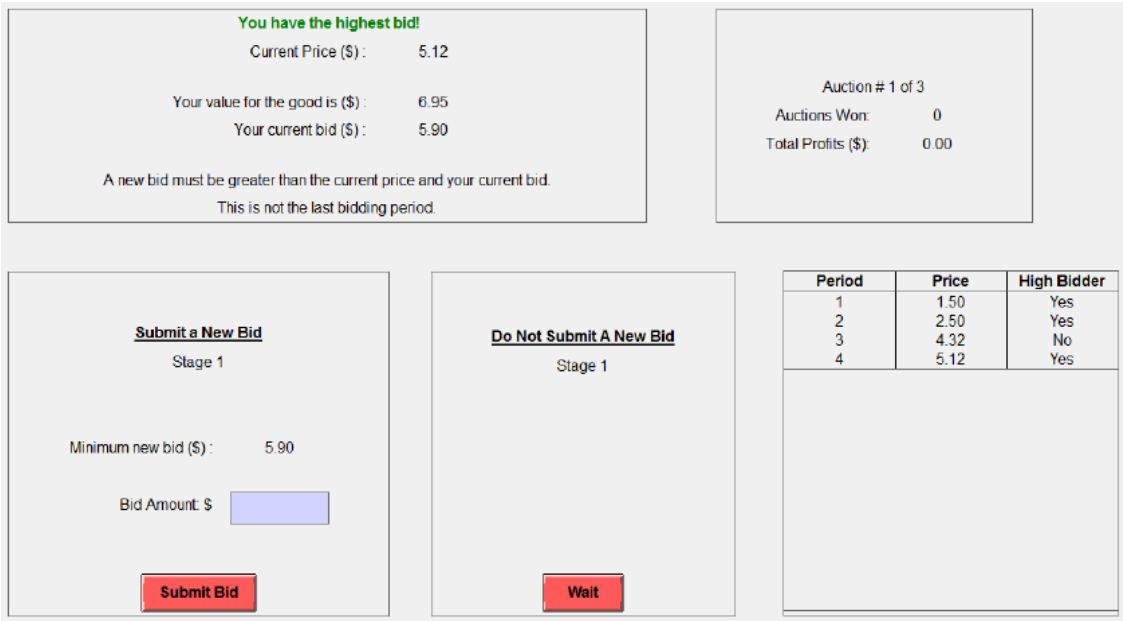

FIGURE B.4. Screenshot of eBay treatment bidding screen.

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