Securities Auctions under Moral Hazard: Theory and Experiments[1]

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Abstract

In many settings, including venture capital financing, mergers and acquisitions, and lease competition, the structure of the contracts (debt versus equity) over which firms compete differs. Furthermore, the structure of the contract affects the future incentives of the firm to engage in value-creating activities by potentially diluting effort or investment incentives. We study, both theoretically and in the lab, the performance of open outcry debt and equity auctions in the presence of both private information and hidden effort. We show that the revenues to sellers between debt and equity auctions differ depending on the returns to entrepreneurial effort. When returns are either very low or vary high, the equity auction leads to higher expected revenues to the seller than does the debt auction. When the returns to effort are intermediate, we show that debt auctions can outperform equity auctions. We then test these predictions in a controlled laboratory setting and find broad support for the comparative predictions of the model.

1 Introduction

In many settings, competition among a few firms for some scarce asset or resource will differ both in the particulars of how the competition is conducted (auction, negotiation, etc.) as well as in the structure of the contracts over which firms are competing. For example, in bidding for oil tracts in Alaska, the form of the contracts has changed considerably over time ranging from competition in cash contracts with a fixed royalty component, to competition in pure royalty contracts, to competition in profit share contracts, and back again to cash contracts.[1] Likewise, in financing mergers and acquisitions, an acquiring firm must determine both the right "bid" to gain approval from shareholders as well as the right form of the bid in terms of the health of the balance sheet of the merged company. Again, the contractual forms vary widely ranging from pure cash acquisitions, leveraged buyouts, or equity offers like that of AOL-Time Warner. Another important area where the types of contracts are particularly rich and varied is in venture capital financing (see Kaplan and Stromberg (2003)). In this sphere, entrepreneurs are often forced to compete with one another to secure capital and management expertise from venture capital firms. The debt versus equity component of these "deals" varies widely ranging from contracts that are mainly debt with a small equity component to those that are the reverse.

While bidding for oil tracts in Alaska is undertaken as a formal auction, many of the other situations described above can (and have been) fruitfully viewed through the lens of auctions. For instance, Bulow, Huang, and Klemperer (1998) model takeovers as auctions. Bulow and Klemperer (1996) use auctions to compare the value to a takeover target of attracting one additional suitor compared to optimally negotiating with its existing suitors. While these papers abstract away from the form of the contracts (essentially all bids are in the form of cash contracts from non budget-constrained bidders), a separate literature has examined how contractual forms affect seller revenues. The earliest paper in this line, Hansen (1985),[2] examines English auctions for royalties, equity, and cash, and shows that, in a symmetric independent private values setting, a seller running an English auction obtains strictly higher revenues in an equity or royalty auction than in a cash auction. In a recent important paper, De Marzo, *et al.* (2005) generalize Hansen's model to allow for the presence of risky returns as well as to consider a much wider variety of contractual forms.

While Hansen's result suggests that the seller is always advantaged by requiring sellers to bid in the form of equity or royalties rather than in cash, Alaska's experience with such contracts suggests otherwise. The element that is present in the Alaska case but abstracted away from in the existing literature is that the form of the contract can also affect the investment and effort incentives of the winning bidder and this, in turn, can affect the value realized by the seller in a non-cash contract. This

[1] See Rothkopf and Engelbrecht-Wiggans (1992).

[2] See also Cremer (1985), Maskin and Riley (1985), Samuelson (1985), Laffont and Tirole (1987) and Hart (2001).

effect would seem extremely severe in a venture capital setting where entrepreneurial effort is clearly a key component to the ultimate success of the venture. Thus, while conducting an English auction where bids are in the form of equity is superior at extracting the available surplus from the project, it undermines the incentives of the winning bidder to undertake effort that creates value in the first place. That is, in an equity auction, the seller may end up with a larger slice of a much smaller pie compared to a debt auction, and this may not be preferred.

Outside of auction theory, an early version of this observation appears prominently in the corporate finance literature (see, for example, Jensen and Meckling (1976); Leland and Pyle (1977); and Myers and Majluf (1984) where it is pointed out that holding a larger stake in an owner-operated company may be value-reducing for investors owing to adverse incentive effects. However, this line of the literature typically abstracts away from the form of competition and uses a principal-agent framework. This matters since optimizing agents would never implement such value-reducing contracts in equilibrium in a principal-agent setting.

To summarize, the auction literature to date has mainly focused on what is essentially an adverse selection problem and ignored the incentive effects of competition in various contracts. The corporate finance line described above has mainly focused on incentive effects of various contracts and abstracted away from the microstructure of the competition leading to these contracts. Yet, in many situations, both features are present and important. To examine these situations, we study, both theoretically and through controlled laboratory experiments, how the choice between auctions for debt and equity affect the returns to the seller.

Our model differs from the standard auction theory models in the following ways: (1) Bidders can exert unobservable effort which affects the valuation of the asset being acquired.[3] As we will show, the amount of effort exerted typically depends on the outcome of the auction; meanwhile, bidding in the auction depends on the valuation of the asset. Equilibrium, of course, factors both effects in simultaneously. (2) The protection afforded by limited liability differs depending on the structure of the auction and the riskiness of the future cash flows derived from the asset being sold. This in turn affects equilibrium bidding behavior. As we show, the presence of limited liability has a qualitative effect on equilibrium bidding in debt auctions compared to the standard case of unlimited liability. This is not the case with equity auctions. To the best of our knowledge, we are the first paper to analyze equilibrium bidding in securities in the presence of unobservable effort, private information, and limited liability.

We then test the model using controlled laboratory experiments. Our experiments vary both the structure of the financing terms of the auction (debt versus equity) as well as the returns to effort (high versus low). Bidders compete in a computerized

[3] While we refer to effort throughout the paper, these efforts may be thought of more broadly as any value increasing activity whose cost is not accounted for in the contract. For example, technology improvements in extraction in the case of oil contracts.

open outcry auction using a soft (going, going, gone) ending rule. In our view, this setting closely resembles the natural auctions that arise in acquisitions and competition for venture capital financing. Furthermore, to the best of our knowledge, we are the first to examine the effects of moral hazard and the structure of contracts in laboratory auctions.

Throughout the paper, we cast the model in the form of entrepreneurs competing to secure expertise and financing from a venture capital firm. Clearly, the trade-off between surplus extraction and surplus creation is at the heart of the "negotiation dance" between entrepreneurs and VCs and therefore is an important application of the main idea of the paper. More broadly, we believe that an important independent contribution is to propose an empirically testable theory model for the interplay between *competing* entrepreneurs and VC financing agreements and to show that many of the predictions of the model are borne out in controlled laboratory experiments.

The main findings of the paper are as follows:

1. **Efficiency:** We show theoretically, that, despite the interplay between adverse selection and moral hazard present in the auctions, both debt and equity auctions succeed in selecting the higher quality business idea with probability one (Propositions 2 and 4). In the laboratory experiments, we find high efficiency levels (85.6%) for both types of auctions; however, debt auctions outperform equity auctions in this dimension (see Table 6).

2. **Incentives:** We show theoretically that equilibrium behavior in equity auctions can lead to underprovision of effort under an equity auction while effort is always optimal under a debt auction (see Lemma 1 and Proposition 3). Indeed, in our model, a debt auction is shown to be a socially optimal mechanism. The evidence we find is consistent with these differences: equity auctions undermine incentives to undertake effort as predicted by the theory although the degree to which they are undermined is lower than theory predicts. Debt auctions lead to optimal effort provision in almost all treatments (see Table 5).

3. **Extraction:** We show theoretically that, regardless of the returns to effort, equity auctions extract a greater amount of the available surplus to the VC than do debt auctions (see Proposition 5). In the laboratory experiments, we find strong evidence for the extraction effects of equity auctions (see Tables 3, 5 and 9).

   What accounts for the superior surplus extraction of equity auctions? The key is that equity auctions create *linkage* between the underlying value of the winning bidder and the payment received by the seller. In the case of a debt auction, the proceeds to the seller depend only on the incentives and project quality of the *second-highest* bidder. Since project quality is independent across bidders, there is no direct linkage. In contrast, while the sharing rule in an equity auction is determined by the project quality and incentives of the second-highest bidder, the revenues to the seller depend on the sharing rule as well as the project quality and incentives of the winning bidder—in other words, the seller's revenues are linked to the winning bidder's surplus.

4. **Extraction-Incentives Tradeoff:** We show theoretically that the linkage effect dominates when the returns to entrepreneurial effort are extreme (either very high or very low), while the incentive effect can dominate when the returns to entrepreneurial effort are intermediate (see Proposition 6). These comparative static predictions are confirmed in the laboratory experiments: equity auctions produce greater revenues than debt auctions under the low returns treatment while the revenue ranking is reversed when we raise returns to effort to lie in the intermediate case (see Tables 3 and 5).

This suggests that competing buyers and sellers need to recognize that the form of the contracts over which they are competing affects both the seller's ability to extract surplus as well as the buyer's incentive to create surplus in the first-place. The balance between debt and equity in the forms of the resulting contracts then reflects a tradeoff between surplus extraction (via equity) and improved incentives (via debt or cash). Moreover, unlike the principal-agent setting, where the possibility of the principal taking a value-reducing share of the company is inconsistent with equilibrium, we show that when firms compete they rationally and optimally make equity offers that are *ex post* value reducing to all parties.

The remainder of the paper proceeds as follows: In section 2 we sketch the model and derive a characterization of equilibrium bidding behavior in debt and equity auctions with both private information and moral hazard. Section 3 outlines the design of the experiment. Section 4 reports the experiment results as they relate to the comparative static predictions of the theoretical model while section 5 discusses level prediction tests of the model. The structural model used in some of the estimations is contained in an appendix.

2 Theory

Consider a setting in which there are two entrepreneurs competing for resources from a venture capital firm to fund a risky project. Each entrepreneur currently operates a small business that has a commonly known and identical value of m. Each entrepreneur has access to a risky project which requires financing (and other inputs) from a venture capital firm. A venture capital firm possesses this package of resources in sufficient quantity to finance exactly one project. If an entrepreneur receives a package of resources from the VC, it then undertakes the project. The payoff from the project of entrepreneur i depends on its inherent quality (v_i) and the degree of entrepreneurial effort, $e_i \in \{0, 1\}$. In particular, suppose with probability p a project succeeds and produces cash equivalent to $v_i (1 + \delta e_i)$, where δ denoted the returns to effort. Otherwise, a project fails and pays zero to all parties.[4] Thus, when entrepreneur i undertakes a project of quality v_i and exerts effort e_i, then the payoff from the project is

$$\pi(v_i, e_i) = \begin{cases} v_i(1+\delta e_i) & \text{with} \quad \Pr = p \\ 0 & \text{with} \quad \Pr = 1-p \end{cases}$$

Let the cost of entrepreneurial effort be equal to the effort. Suppose entrepreneur i is privately informed about the quality of his or her business idea, v_i. Suppose, however, that it is commonly known that for all i, v_i is drawn from the atomless distribution F on $[\underline{v}, \overline{v}]$. In addition, an entrepreneur privately undertakes entrepreneurial effort that is personally costly. Entrepreneurial effort is not directly observable nor contractible by any outside party. Finally, suppose that the entrepreneur is protected by limited liability.

Notice that there is a trade-off between undertaking the project (even on the most favorable possible terms) and risking a failure versus retaining the "safe" outside option, m, and avoiding the costs associated with failed projects. Since our focus is on how the investment decision is affected by the structure of the negotiation between the entrepreneurs and the VC rather than whether to undertake any investment at all, we assume that the quality of any of the ideas is such that it is socially optimal to undertake the risky project. Formally, this amounts to the condition:

$$m \leq p(\underline{v} + m) \tag{1}$$

Suppose that an entrepreneur obtains VC financing on the following terms: the entrepreneur retains a fraction α_i of the company and has debt service D_i. In that case, the expected payoff to the entrepreneur is

$$EU_i = p\alpha_i(v_i(1+\delta e_i) + m - \min(D_i, v_i(1+\delta e_i) + m)) - e_i$$

In this case, the entrepreneur should optimally exert effort ($e_i = 1$) provided that

$$p\alpha_i(v_i(1+\delta) + m - \min(D_i, v_i(1+\delta) + m)) - 1 \geq p\alpha_i(v_i + m - \min(D_i, v_i + m))$$

which we may then simplify to

$$p\alpha_i(v_i\delta - (\min(D_i, v_i(1+\delta) + m) - \min(D_i, v_i + m))) \geq 1 \tag{2}$$

That is, the entrepreneur's net expected return to effort, $p\alpha_i(v_i\delta - C))$ exceeds her cost of effort, 1, where C denotes the change in debt liability associated with a successful project under high effort.

Absent the support of the VC, the value of entrepreneur i's company is simply $EU_i = m$, and the optimal amount of entrepreneurial effort is zero.

[4] We assume that the costs of a failure strictly exceed m.

Since neither the entrepreneurs' quality of ideas nor their effort is directly observable nor contractible by the VC, the key problem faced by the VC is in designing a contractual scheme with an entrepreneur to "solve" the combined adverse selection and moral hazard problems. Of course, the objective of the manager of the VC is to maximize the expected return of the investors subject to some constraints described below: Suppose that if the resources of the VC are put to neither of the two projects, then the investors of the VC withdraw their funds and the manager of the VC firm suffers infinite negative utility from suddenly becoming unemployed. Therefore, the VC cannot credibly commit not to fund one of the entrepreneurs.

We shall consider the following schemes:

1. **Equity "auction":** We will compare the above procedure with an alternative. In an equity auction, entrepreneurs compete by offering the VC fractional ownership of the company in exchange for the VC's resources. We model this as an open outcry auction—the entrepreneur offering the larger ownership share is the "winner" of the auction at the bid amount.

2. **Debt "auction":** Suppose that the entrepreneurs compete with one another by offering the VC debt contracts in exchange for VC support. Again, we model this process as an open outcry auction. The "bidder" offering the higher amount of debt repayment in exchange for the resources of the VC is the "winner" of the auction at the bid amount.

Analysis of Equilibrium in Equity Auctions

First, we consider the equity auction and determine when it is optimal for the winning entrepreneur to undertake effort.

Lemma 1 *Winning entrepreneur i should undertake effort if an only if the winning price is less than* $\frac{v_i p\delta - 1}{v_i p\delta}$

Proof. Suppose that the current "price" in the auction is $1-\alpha$. Then, if entrepreneur i won at this price, it would be optimal to undertake effort if and only if

$$p\alpha\left(v_i\left(1+\delta\right)+m\right)-1 \geq p\alpha\left(v_i+m\right)$$

or

$$1-\alpha \leq \frac{v_i p\delta - 1}{v_i p\delta}$$

■

We are now in a position to reason backwards in the auction to determine equilibrium bidding strategies. As we show below, these depend on the parameter values pertaining to the returns to effort.

Case 1. $pv_i\delta \leq 1$.

Clearly, when $v_i p\delta \leq 1$,the returns to effort are never sufficient to justify any effort "investment" on the part of the entrepreneur. In that case, the weakly dominant strategy for the entrepreneur is to bid up to the point where expected value of the company under no effort is equal to the outside option in the event no financing is obtained. Specifically, let $1-\alpha_i^0$ denote the "drop-out price; then

$$\alpha_i^0 p\left(v_i+m\right)=m$$

or

$$\alpha_i^0=\frac{m}{p\left(v_i+m\right)}$$

which is a well-defined bidding strategy by equation (1).

Case 2. $p v_i \delta>1$.

Now, for prices that are sufficiently low, the entrepreneur is willing to undertake effort. Again, consider the strategy where the entrepreneur bids up to the point where expected value of the company under positive effort is equal to the outside option in the event no financing is obtained. Specifically, let $1-\alpha_i^1$ denote the "drop-out price; then

$$\alpha_i^1 p\left(v_i(1+\delta)+m\right)-1=m$$

or

$$\alpha_i^1=\frac{m+1}{p\left(v_i(1+\delta)+m\right)}$$

which is a well-behaved bidding strategy since $p v_i \delta>1$.

Provided that $1-\alpha_i^1 \leq \frac{v_i p \delta-1}{v_i p \delta}$, then the above drop-out strategy is weakly dominant. That is, when

$$\begin{aligned}
1-\frac{m+1}{p\left(v_i(1+\delta)+m\right)} & \leq \frac{v_i p \delta-1}{v_i p \delta} \\
\frac{p\left(v_i(1+\delta)+m\right)-m-1}{p\left(v_i(1+\delta)+m\right)} & \leq \frac{v_i p \delta-1}{v_i p \delta}
\end{aligned}$$

Cross-multiplying

$$\left(p\left(v_i(1+\delta)+m\right)-m-1\right) v_i p \delta \leq p\left(v_i(1+\delta)+m\right)\left(v_i p \delta-1\right)$$

Rewriting

$$p\left(v_i(1+\delta)+m\right)\left(v_i p \delta-1\right)-\left(p\left(v_i(1+\delta)+m\right)-m-1\right) v_i p \delta \geq 0$$

Simplifying

$$(m \delta-1) v_i-m \geq 0$$

Therefore, we have shown that if $(m \delta-1) v_i-m \geq 0$, then an equilibrium in weakly dominant strategies is to bid up to a price $1-\alpha_i^1$ and exert high effort conditional on winning.

Suppose that $(m \delta-1) v_i-m<0$, in that case, $1-\alpha_i^1>\frac{v_i p \delta-1}{v_i p \delta}$. Therefore, the bidding strategy must change once the price $\frac{v_i p \delta-1}{v_i p \delta}$ is exceeded. In particular, for all prices $1-\alpha>\frac{v_i p \delta-1}{v_i p \delta}$. It is not optimal to exert effort. In that case, the drop out condition is exactly as in case 1. It may be readily shown that $1-\alpha_i^0 \geq \frac{v_i p \delta-1}{v_i p \delta}$ if and only if $(m \delta-1) v_i-m<0$. To summarize

Proposition 1 *In a equity auction, an equilibrium in weakly dominant strategies is for bidder i to drop out at price* $1-\alpha_i$ *where*

$$\alpha_i = \begin{cases} \frac{m+1}{p(v_i(1+\delta)+m)} & \text{if } \; pv_i\delta > 1 \text{ and } (m\delta-1)\,v_i - m \geq 0 \\ \frac{m}{p(v_i+m)} & \text{otherwise} \end{cases}$$

Together with the effort strategy in Lemma 1, this comprises a symmetric subgame perfect equilibrium in undominated strategies in an equity auction.

We now argue that the equity auction has the property that the higher valued idea is funded with probability one. To see this, suppose that $v_1 > v_2$. There are two cases to consider:

Case 1. $pv_1\delta \leq 1$ or $(m\delta - 1)\,v_1 - m < 0$.

In that case the bidding functions α_1 and α_2 are identical and strictly decreasing in v_i; hence entrepreneur 1's project is funded.

Case 2. $pv_1\delta > 1$ and $(m\delta - 1)\,v_1 - m \geq 0$.

If $(m\delta - 1)\,v_2 - m \geq 0$ and $pv_1\delta > 1$, then α_1 and α_2 are identical and strictly decreasing functions of v_i; hence entrepreneur 1's project is funded. Otherwise, entrepreneur 2 drops out at price

$$\begin{aligned} \alpha_2 &= 1 - \frac{m}{p\,(v_2+m)} \\ &< 1 - \frac{m}{p\,(v_1+m)} \\ &\leq 1 - \frac{m+1}{p\,(v_1\,(1+\delta)+m)} \\ &= \alpha_1 \end{aligned}$$

where the strict inequality follows from the fact $v_1 > v_2$ and the weak inequality follows from the fact that $(m\delta - 1)\,v_1 - m \geq 0$. Therefore, entrepreneur 1's project is funded.

Hence, we have shown that

Proposition 2 *In an equity auction under the equilibrium in weakly dominant strategies given in Proposition 1, the higher valued idea is funded with probability one.*

What is the expected return to the VC under this auction? There are three possibilities to consider, either (i) the winning entrepreneur exerts high effort and the price is set as though high effort will be undertaken; (ii) the winning entrepreneur exerts low effort and the price is set as though low effort will be undertaken; or (iii) the winning entrepreneur exerts high effort and the price is set as though low effort will be undertaken. The fourth possibility, a price set as though high effort will be undertaken followed by a low effort choice from the winning entrepreneur is inconsistent with subgame perfect equilibrium. The expected return in each of the possibilities is as follows:

(i)

$$\begin{aligned} ER_{equity} &= \left(1 - \frac{m+1}{p\left(v_2\left(1+\delta\right)+m\right)}\right) p\left(\left(v_1\left(1+\delta\right)\right)+m\right) \\ &= \frac{v_1\left(1+\delta\right)+m}{v_2\left(1+\delta\right)+m} \times \left(pv_2\left(1+\delta\right)-\left(1-p\right)m-1\right) \end{aligned}$$

(ii)

$$\begin{aligned} ER_{equity} &= \left(1 - \frac{m}{p\left(v_2+m\right)}\right)\left(p\left(v_1+m\right)\right) \\ &= \left(\frac{p\left(v_2+m\right)-m}{p\left(v_2+m\right)}\right)\left(p\left(v_1+m\right)\right) \\ &= \frac{v_1+m}{v_2+m} \times \left(pv_2-\left(1-p\right)m\right) \end{aligned}$$

(iii)

$$\begin{aligned} ER_{equity} &= \left(1 - \frac{m}{p\left(v_2+m\right)}\right) p\left(\left(v_1\left(1+\delta\right)\right)+m\right) \\ &= \frac{v_1\left(1+\delta\right)+m}{v_2+m} \times \left(pv_2-\left(1-p\right)m\right) \end{aligned}$$

Using Proposition 1, we now determine the parameter values in which each of the three possibilities arise.

Remark 1 *If* $pv_2\delta > 1$ *and* $(m\delta - 1)v_2 - m \geq 0$*, then the winning entrepreneur exerts high effort and the price is set in anticipation of high effort.*

If either (a) $pv_1\delta \leq 1$*; or (b)* $pv_1\delta > 1$*,* $(m\delta - 1)v_1 - m < 0$*, and* $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p\delta}$*, then the winning entrepreneur exerts low effort and the price is set in anticipation of low effort.*

Otherwise, the winning entrepreneur exerts high effort and the price is set in anticipation of low effort.

Case 1: $pv_1\delta \leq 1$ then $\langle low, low\rangle$
Case 2: $pv_1\delta > 1$
Case 2a: $pv_2\delta > 1$ and $(m\delta - 1)v_2 - m \geq 0$ then $\langle high, high\rangle$
Case 2b: $(m\delta - 1)v_1 - m < 0$ and $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p\delta}$ then $\langle low, low\rangle$
Case 2c: $(m\delta - 1)v_1 - m < 0$ and $1 - \frac{m}{p(v_2+m)} \leq \frac{v_1 p\delta - 1}{v_1 p\delta}$ then $\langle high, low\rangle$
Case 2d: $(m\delta - 1)v_1 - m \geq 0$ and $(m\delta - 1)v_2 - m < 0$ or $pv_2\delta \leq 1$ then $\langle high, low\rangle$

Analysis of Equilibrium in Debt Auctions

Next, we turn to debt auctions. Before proceeding, it is useful to establish several preliminary facts about equilibrium bidding in a debt auction. As above, define D_i^1 to be an equilibrium bid from an entrepreneur who expects to undertake positive effort if awarded the financing. Let D_i^0 be likewise defined for an entrepreneur who expects to undertake no effort if awarded the financing.

Lemma 2 *In any equilibrium of a debt auction,* $D_i^1 \leq v_i(1+\delta)$ *and* $D_i^0 \leq v_i$.

Proof. Suppose to the contrary that $D_i^1 > v_i(1+\delta)$. In that case, the expected payoff to the entrepreneur in the event that she "wins" and is awarded the financing is

$$\begin{aligned} E\pi_i &= p\left(v_i(1+\delta) + m - \min\left(D_i^1, v_i(1+\delta)+m\right)\right) - 1 \\ &\leq m - 1 \\ &< m \end{aligned}$$

Therefore, it is a profitable deviation for the entrepreneur simply to stop bidding before reaching this price. An identical argument establishes the claim for $D_i^0 \leq v_i$. ■

Thus, for a given level of effort, it is a weakly dominant strategy to bid up to a debt level that leaves the entrepreneur indifferent between obtaining funding and not. That is, D_i^1 solves

$$p\left(v_i(1+\delta) + m - D_i^1\right) - 1 = m$$

Or, equivalently

$$D_i^1 = v_i(1+\delta) - \frac{1}{p} - \frac{1-p}{p}m \tag{3}$$

Likewise D_i^0 solves

$$D_i^0 = v_i - \frac{1-p}{p}m \tag{4}$$

Lemma 3 *Undertaking effort is optimal if and only if* $D_i^1 \geq D_i^0$.

Proof. Suppose to the contrary that $D_i^1 \geq D_i^0$ and undertaking effort was not optimal. In that case, the expected payoff from undertaking effort for a bid D_i^0 is at least m; whereas, by construction, it is exactly equal to m in the case of undertaking no effort. This is a contradiction. Suppose to the contrary that $D_i^1 < D_i^0$ and undertaking effort is optimal. In that case, the expected payoff undertaking no effort and bidding D_i^1 is strictly greater than m while undertaking effort and bidding D_i^1, by construction, produces expected payoff equal to m. This is a contradiction. ■

It can be shown that $D_i^1 \geq D_i^0$ if and only if

$$v_i \geq \frac{1}{\delta p}$$

To summarize

Proposition 3 *In a debt auction, an equilibrium in weakly dominant strategies is for bidder i to bid according to*

$$D_i = \begin{cases} v_i(1+\delta) - \frac{1}{p} - \frac{1-p}{p}m & \text{if} \quad v_i \geq \frac{1}{\delta p} \\ v_i - \frac{1-p}{p}m & \text{otherwise} \end{cases}$$

We now argue that the debt auction has the property that the highest valued idea is funded with probability one. To see this, suppose that $v_1 > v_2$. There are three cases to consider:

Case 1. $v_2 \geq \frac{1}{\delta p}$.

In that case, D_1 and D_2 are identical and strictly decreasing functions of v_i; hence entrepreneur 1's project is funded.

Case 2. $v_1 < \frac{1}{\delta p}$.

In that case, D_1 and D_2 are identical and strictly decreasing functions of v_i; hence entrepreneur 1's project is funded.

Case 3. $v_1 \geq \frac{1}{\delta p}$ and $v_2 < \frac{1}{\delta p}$.

In that case, $D_1 > D_1^0 > D_2^0 = D_2$. Hence entrepreneur 1's project is funded.

Hence, we have shown that

Proposition 4 *In a debt auction under the equilibrium in weakly dominant strategies given in Proposition 3, the higher valued idea is funded with probability one.*

What is the expected return to the VC under this auction? The expected payoff to the VC when $v_1 > v_2$ is as follows:

Case 1. $v_2 \geq \frac{1}{\delta p}$.

$$ER_{debt} = p\left(v_2(1+\delta) - \frac{1}{p} - \frac{1-p}{p}m\right)$$

Case 2. $v_2 < \frac{1}{\delta p}$.

$$ER_{debt} = p\left(v_2 - \frac{1-p}{p}m\right)$$

2.1 Revenue Comparisons

Proposition 5 *Suppose that (i) $\delta p v_1 \leq 1$ or (ii) $\delta p v_1 > 1$ and $\delta p v_2 < 1$. Then, for all realizations, $v_1 > v_2$, the equity auction yields greater revenues to the VC than does the debt auction.*

Proof. Notice that under either conditions, entrepreneur 2 bids in the debt and equity auctions anticipating undertaking zero effort. Hence,

$$ER_{debt} = pv_2 - (1-p)m$$

while

$$ER_{equity} \geq \frac{v_1 + m}{v_2 + m} \times (pv_2 - (1-p)\,m)$$

Differencing these expressions one obtains

$$\begin{aligned} ER_{equity} - ER_{debt} &\geq \frac{v_1 + m}{v_2 + m} \times (pv_2 - (1-p)\,m) - (pv_2 - (1-p)\,m) \\ &> (pv_2 - (1-p)\,m) - (pv_2 - (1-p)\,m) \\ &= 0 \end{aligned}$$

■

Proposition 6 *Suppose that $\delta p v_1 > 1$ and $(m\delta - 1)\,v_2 - m \geq 0$ or (ii) $\delta p v_2 < 1$. Then, for all realizations, $v_1 > v_2$, the equity auction yields greater revenues to the VC than does the debt auction.*

Proof. Notice that, when $\delta p v_2 > 1$ and $(m\delta - 1)\,v_2 - m \geq 0$, then under both the equity and debt auctions, high effort is undertaken and the price is set anticipating high effort. Hence

$$ER_{debt} = pv_2\,(1+\delta) - (1-p)\,m - 1$$

while

$$ER_{equity} = \frac{v_1\,(1+\delta) + m}{v_2\,(1+\delta) + m} \times (pv_2\,(1+\delta) - (1-p)\,m - 1)$$

Differencing these two expressions, one obtains

$$\begin{aligned} &ER_{equity} - ER_{debt} = \\ &\quad \frac{v_1\,(1+\delta) + m}{v_2\,(1+\delta) + m} \times (pv_2\,(1+\delta) - (1-p)\,m - 1) - (pv_2\,(1+\delta) - (1-p)\,m - 1) \\ &\quad > (pv_2\,(1+\delta) - (1-p)\,m - 1) - (pv_2\,(1+\delta) - (1-p)\,m - 1) \\ &\quad = 0 \end{aligned}$$

■

The main lesson from the proposition is that, when the returns to effort are either sufficiently high that undertaking high effort is still profitable in an equity auction or so low that undertaking effort is not optimal in either auctions, then the equity auction always outperforms the debt auction.

Finally, we consider the intermediate cases. Here, the trade-off is more complicated. Entrepreneur 2 will bid as though high effort will be undertaken in the debt auction and as though low effort will be undertaken in the equity auction. For the equity auction, the expected revenues also depend on whether entrepreneur 1 undertakes effort. That is, whether $\delta \geq \frac{1}{v_1} + \frac{1}{m}$.

As we shall see below, the revenue ranking in this case depends heavily on the gap between v_1 and v_2. For future reference define

$$\Delta = \frac{(v_2 + m)(p\delta v_2 - 1)}{(pv_2 - (1-p)m)}$$

Proposition 7 *Suppose that* $\delta p v_2 > 1$, $(m\delta - 1) v_1 - m < 0$, *and* $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p\delta}$. *Then*

If v_1 *and* v_2 *are "close"; that is* $v_1 - v_2 < \Delta$, *the debt auction yields greater revenues to the VC than does the equity auction.*

If v_1 *and* v_2 *are not close, that is,* $v_1 - v_2 \geq \Delta$, *the equity auction yields greater revenues to the VC than does the debt auction.*

Proof. Under the above conditions, the price in the debt auction is set in anticipation of high effort and high effort is undertaken while the price in the equity auction is set in anticipation of low effort and low effort is undertaken. Thus, the revenue comparison is as follows:

$$ER_{debt} = (pv_2(1+\delta) - (1-p)m - 1)$$

while

$$ER_{equity} = \frac{v_1 + m}{v_2 + m} \times (pv_2 - (1-p)m)$$

Differencing these two expressions

$$ER_{equity} - ER_{debt} = \frac{v_1 + m}{v_2 + m} \times (pv_2 - (1-p)m) - (pv_2(1+\delta) - (1-p)m - 1)$$

The sign of this expression depends on whether

$$v_1 \geq v_2 + \Delta$$

■

Proposition 8 *Suppose that* $\delta p v_2 > 1$, $(m\delta - 1) v_2 - m < 0$, *and either (a)* $(m\delta - 1) v_1 - m \geq 0$, *or (b)* $1 - \frac{m}{p(v_2+m)} \geq \frac{v_1 p\delta - 1}{v_1 p\delta}$. *Then*

If v_1 *and* v_2 *are "close"; that is* $v_1(1+\delta) - v_2 < \Delta$, *the debt auction yields greater revenues to the VC than does the equity auction.*

If v_1 *and* v_2 *are "not close", that is,* $v_1(1+\delta) - v_2 \geq \Delta$, *the equity auction yields greater revenues to the VC than does the debt auction.*

Proof. Under the above conditions, the price in the debt auction is set in anticipation of high effort and high effort is undertaken while the price in the equity auction is set in anticipation of low effort and high effort is undertaken. Thus, the revenue comparison is as follows:

$$ER_{debt} = (pv_2(1+\delta) - (1-p)m - 1)$$

while

$$ER_{equity} = \frac{v_1 (1 + \delta) + m}{v_2 + m} \times (pv_2 - (1 - p) m)$$

Differencing these two expressions

$$ER_{equity} - ER_{debt} = \frac{v_1 (1 + \delta) + m}{v_2 + m} \times (pv_2 - (1 - p) m) - (pv_2 (1 + \delta) - (1 - p) m - 1)$$

The sign of this expression depends on whether

$$v_1 (1 + \delta) \geq v_2 + \Delta$$

■

Despite the complexity of the parameter conditions, the results of the last two propositions are intuitive: When v_1 is sufficiently high relative to v_2, the equity auction outperforms the debt auction simply by linking the payment received by the VC to v_1. In the case where only low effort is undertaken, the required gap for this effect to dominate is Δ whereas, when the incentive diluting effect of the equity auction is not a concern (as in Proposition 4), the required gap between v_1 and v_2 falls in proportion to the returns to effort—to $\Delta - \delta v_1$. In contrast, the VC obtains little benefit from linking its payment received to the value of v_1 when the valuations of the two entrepreneurs are relatively equal. In that case, the superior incentive effects of the debt auction dominate.

3 Experimental Design

3.1 General

The experiment consisted of 14 sessions conducted at the University of California at Berkeley Experimental Social Sciences Laboratory (XLab) during the Spring 2004 semester. Eight subjects participated in each session, and no subject appeared in more than one session. Subjects were recruited from a distribution list comprised of primarily economics, business and engineering undergraduate students. Participants received a show-up fee of $3 and an additional performance based pay of $0-$40 for a session lasting around 2 hours.

All sessions started with subjects being seated in front of a computer terminal and given a set of instructions, which were then read aloud by the experimenter. Throughout the session, no communication between subjects was permitted and all choices and information were transmitted via the computer terminal.

The session then consisted of three phases of 12 periods each. During the first and last phase subject participating as "entrepreneurs" bid with debt while in the second phase "entrepreneurs" bid with equity. Thus. the sequence of sessions is Debt, equity, Debt.

At the beginning of each period, subjects were randomly assigned to groups of four. Within each group a single unit of funding was sold at an English auction. Each subject received an independently and identically draw from a uniform distribution with a support of 0 to 100, which corresponded to the value of project (if it is funded) to the entrepreneur. Each entrepreneur then submitted bids in a computerized outcry process subject to improvement rule (this mechanism mirrors the one used by large art auction houses as Christie's and Sotheby's). The period ended if no new bids arrived in a period of 15 seconds, during which subjects received a "going, going, gone" warning message. Each bid included two elements – a price and an effort decision. While the former is standard, the later denotes entrepreneur's decision whether or not they would opt to increase the value of the project (i.e. exert effort) by incurring a known cost. While the benefit resulting from exerting effort accrued to the project being financed, the cost was borne completely by the bidder. The terminal provided a calculator which allowed subjects to compute their earnings given different inputs of winning bids and effort decisions.

At the start of each period subjects were endowed with ten points each. During the debt auctions, bids were interpreted as points. Thus, winning bid earnings were equal to ten points plus private and effort values minus bid and effort cost. During the equity auction, bids were interpreted as *percentage* points. Thus, winning bid earnings were equal to 100 minus percentage point bid times 10 points plus private value, effort value, minus effort cost[5]. Losing bid earned ten points. At the end of each period, subjects' earnings were calculated and displayed on their interface.

3.2 Discussion of the design

The experiment was designed around two treatments: security type (debt / equity) and returns to effort (low / high). The main purpose of this design is to test the revenue ranking predictions. When effort returns are low, the moral hazard problem is immaterial and equity auctions yield higher revenues to the seller than debt auctions. On the other hand, when effort returns are high, the moral hazard problem becomes sizable and debt auctions yield higher revenues to the seller. The auction type treatment was implemented across subjects so that some sessions were parametrized with low returns to effort while other sessions were parameterized with high returns to effort. The auction type treatment was implemented within subjects so that each subject participated in both debt and equity auctions.

One contribution of the study is to model the auction in the lab as a computerized ascending bid English (or open outcry) auction. Thus, our work builds on earlier *oral* English auctions using a similar design (see, for instance, Coppinger, Smith, and Titus, 1980 as well as McCabe, Rassenti, and Smith, 1990). A key difference between our design and these earlier studies is that our design retains the anonymity of bidder identities. Other laboratory implementation of the English auction (see, for

[5] Notice that effort costs are borne solely by the entrepreneur.

instance, Kagel, Harstad and Levin,1987) retain anonymity but use a so-called clock auction design, where bidders need only decide at what price to drop out. For many situations, the outcry form of the English auction is a more natural form. This mechanism has a number of advantages over the commonly used first and second price sealed bid auctions. First, it is familiar to subjects and thus easy to understand. Since the securities with which subjects bid are somewhat non-standard, we believed that an intuitive mechanism was important. Second, while English auction is theoretically equivalent to the canonical sealed bid auctions, the strategies in the former are substantially simpler, making it less prone to potential cognitive biases. Third, this auction mechanism is invariant to risk preferences (see for example Riley and Samuelson (1981), and Maskin and Riley (1984)). Previous studies suggested that deviations from risk-neutrality may be consequential for results obtained in under sealed bid auctions (see Kagel (1995) for a review of this literature).

We parametrized the experiment such that in the "low returns" sessions the effort value was low enough to make it unprofitable for player, in either the debt or equity auctions, to exert effort. In the "high returns" sessions, effort was optimally exerted by the winning bidder in all debt auction instances but only in small fraction of equity auctions. For simplicity, we kept the cost of effort the same for all sessions. The specific return-to-effort values were determined so as to generate a powerful test of the revenue ranking predictions while making bidders decisions manageable in terms of their complexity. Given the real-time nature of the auction, we wanted to avoid cases were theoretical effort choice switches during the bidding process.

To summarize, each session was conducted using one of the two effort conditions ("low returns" or "high returns"). Under both treatments, outside value, m, was equal to 10, private value of the project, v_i, was drawn from a uniform distribution with support of $[0, 100]$, and the cost of effort , c, was equal to 20.[6] Returns to effort, δ, were set to 0.1 in the "low" case, and to 1.3 in the "high" case. These parameters were chosen such that the expected loss from socially inefficient effort choice in the equity auctions overweighted the expected benefits arising from linking the revenues to the highest private value. The effort returns needed to be sufficiently high to induce effort exertion in the debt case but not high enough to induce effort exertion in the equity bidding case.

The equilibrium predictions for each type of auction under each treatment is given in table 1. The table provides mean predictions of sellers' revenues (in points), normalized revenues and effort decisions, which are defined below:

- **Revenues:** This is simply a measure of the revenues obtained by the seller in a given auction (measured in the experimental points).

- **Normalized Revenues:** Since the valuations of each of the bidders are drawn randomly, there may be variations in revenues that are purely driven by the

[6] The experiment tests the deterministic version of the model discussed in the Theory section; that is, probability of the high node state is 1.

realizations of the draws. A more useful measure of the performance of an auction is the fraction of the maximum theoretically possible surplus captured by the seller. To take a simple example, suppose that the surplus available in auction A was \$10 and the seller received \$7. In auction B, the available surplus was \$5 and the seller obtained \$4. Then, even though the revenues from auction B, measured in levels, are lower than those under auction A, the percentage of surplus captured by the seller is higher. Thus, given the variation across auctions in the available surplus, this measure of auction performance seems useful.

- **Effort choices:** The measure for effort indicates whether the winning bidder chose to pay the costs required to "upgrade" the asset. We code this as "1" if effort was exerted in a given round of the experiment and "0" otherwise.

Table 1: Theoretical Predictions for Revenues, Normalized Revenues, and Effort Choices

Revenues

Returns to effort	Security: *Debt*	Security: *Equity*
Low	60.21	79.94
High	117.17	80.00

Normalized Revenues

Returns to effort	Security: *Debt*	Security: *Equity*
Low	75.6%	99.6%
High	71.0%	49.0%

Effort choices

Returns to effort	Security: *Debt*	Security: *Equity*
Low	0.0%	0.0%
High	100.0%	14.0%

4 Comparative Static Results

4.1 Overview

We start by presenting descriptive statistics from the experiment, which are provided in table 2. The table is divided into four columns reflecting the four different treatment "cells" in the experiment. The first two columns correspond to the low returns cases – under the debt and equity bidding. The next two columns correspond to the high return cases under both security types.

There are roughly twice as many rounds under the equity columns as there are under the debt columns[7]. This is because of our ABA design where debt auctions occur both at the beginning and at the end of each experimental session.

The rationale behind this design is as follows. Pilot studies suggested that subjects' learning was much easier in going from debt to equity auctions than vice-versa.

[7]It is not exactly twice because of a technical problem that forced early termination of one of the high return sessions.

Table 2: Descriptive Statistics

	Low returns		High returns	
	Debt	**Equity**	**Debt**	**Equity**
Number of sessions	9		5	
Number of participants	72		40	
Total number of rounds played	216	108	108	60
Total number of market instances	416	216	209	120
Total number of bids	3,132	1,855	1,442	690

Since we are interested in equilibrium behavior, we decided to start the sessions with rounds of debt auctions that serve to familiarizing subjects with the bidding process. The results suggest that most of the learning process is completed by round six. To illustrate that, we split all debt rounds into four groups of six rounds each: 1-6, 7-12, 25-30 and 31-36,[8]. We constructed a number of measures that capture the dynamics of bidding activity: bidding intensity (average number of bids per round), overbidding (average amount by which winning bidder overbid relative to the theoretical predictions), and inefficiency (the fraction of times the funding was not provided to the highest venture value). The results are presented separately for the low and high return sessions in Figures 1 and 2.

In both the low and the high return variants dramatic decrease in inefficiency and overbidding, from the initial rounds (1-6) to the subsequent rounds (7-12 and 25-36), is observed. We do not find similar changes when comparing the first and second half of the third phase rounds (rounds 25-30 vs. 31-36).

Further, the intensity of bidding seems to be fairly stable across rounds in the both variants, while there is a downward (upward) trend in the high (low) returns variant. These results suggest that presentation effects are immaterial since the debt auction rounds conducted just *before* the equity auction rounds appear to be indistinguishable from the debt auction rounds conducted immediately *after* the equity auction rounds. To summarize, it appears that learning takes place during the initial rounds but the process stabilizes halfway into the first phase of rounds.

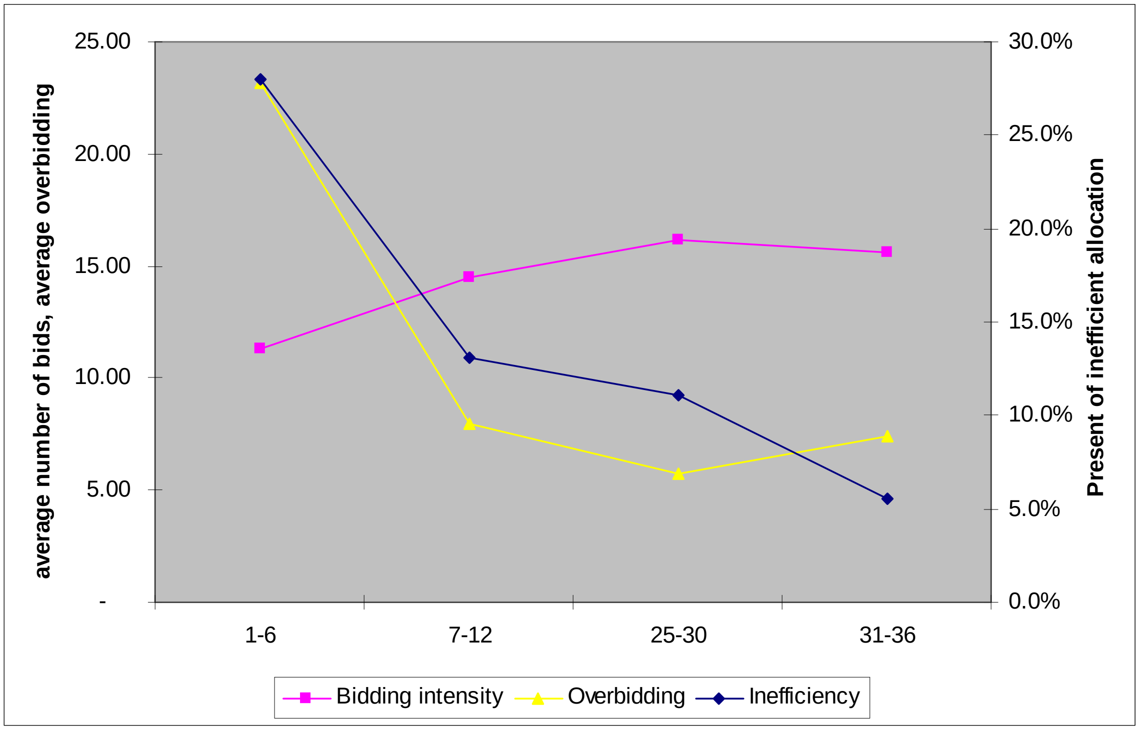
Pooled Results

As a first cut, the table below pools all of the sessions under each treatment (excluding rounds 1-12) thus allowing a direct comparison with the theory predictions of Table 1.

As Table 3 shows, the revenue ranking predicted by the theory is borne out in the pooled data. Moreover, the deleterious impact of the equity auction on incentives is likewise borne out in the pooled data. Of course, all of this is merely suggestive. Clearly, one would want to control for interdependence effects within a session, learning effects, as well as utilize additional details for the predictions of the theory, such as

[8]Recall that in rounds 13 through 24 we use share auctions.

Figure 1: Average Bidding Intensity, Overbidding and Inefficiency in Low Returns Treatments



efficient sorting and optimal bidding, before drawing conclusions. In the succeeding sections, we take a closer look at the performance of the theory while adding various controls.

4.2 Comparative Static Predictions

As we saw in Table 1, for the parameter values presented in the experiment, the theory model suggests that we test the following four hypotheses about comparative static effects on revenues and effort choices:

Hypothesis 1: When returns to effort are low, revenues and normalized revenues are higher in equity auction than in a debt auction.

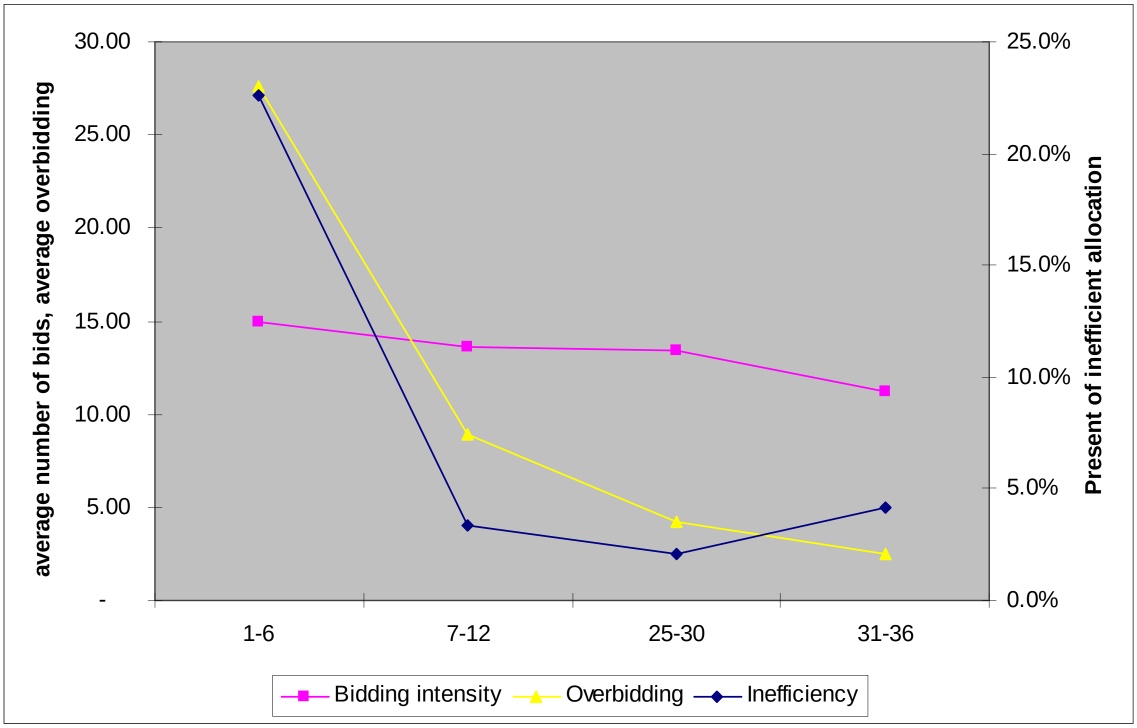
Hypothesis 2: When returns to effort are high, revenues and normalized revenues are higher in a debt auction than in a equity auction.

Hypothesis 3: When returns to effort are low, the effort choice is the same under debt and equity auctions.

Hypothesis 4: When returns to effort are high, more effort is undertaken under a debt auction than under a equity auction.

We examine these hypotheses under a variety of specifications and ways of handling the data and find strong support for all four hypotheses regardless of the han-

Figure 2: Average Bidding Intensity, Overbidding and Inefficiency in High Returns Treatments



dling of the data or the particular specification employed.

Session Level Analysis First, we examine the four hypotheses using the *session* as the unit of observation. The justification for this handling of the data is that, since subjects participated in multiple rounds, interacted with one another, and learned over the course of the experiment, arguably the observations should not be treated as independent. Thus, an extremely conservative view of the data is that each session constitutes a unit of observation. In terms of our experiments, this leaves us with only 14 data points (9 obtained in the low returns condition and 5 obtained in the high returns condition).[9]

Since we used a within-subjects design to compare auction forms, we can examine how changing the auction form affects each of the performance measures by differencing the average revenues, normalized revenues and efforts for equity versus debt auctions session by session. The results of this are reported in Table 4 above. In that table, we test the null hypothesis that each of the three performance measures are equal the same across auction forms against the one-sided alternative implied by

[9]Because of the learning effects highlighted in the previous section, we omit the first twelve rounds of data in constructing observations at the session level. The exception is session 1 where, due to a computer glitch, rounds 25-36 were not completed. For that session, we used rounds 1-12 instead.

Table 3: Observed Revenues, Normalized Revenues, and Effort Choices

Revenues

Returns to effort	Security: Debt	Security: Equity
Low	61.81	71.00
High	114.99	90.46

Normalized Revenues

Returns to effort	Security: Debt	Security: Equity
Low	77.6%	88.5%
High	69.7%	55.4%

Effort choices

Returns to effort	Security: Debt	Security: Equity
Low	7.5%	2.3%
High	96.2%	21.7%

Observations pooled over all sessions.

hypotheses 1-4 using a Mann-Whitney sign test.

According to hypothesis 1, equity auctions should produce higher revenues (or normalized revenues) compared to debt auctions in the low returns sessions. As Table 4 shows, in 8 of the 9 sessions, the average revenues were in the predicted direction. The differences are statistically significant at the 2 percent level.

Hypothesis 2 predicted that the revenue ranking would reverse in the high returns sessions. As the table shows, average revenues were higher under debt auctions compared to equity auctions in all 5 sessions. Once again, the difference in revenues is statistically significant—this time at the 3% level.

Hypothesis 3 suggests that there should be no difference in effort choices across the two auction forms for the low returns sessions. Notice that, in 2 of the sessions, higher average effort is undertaken in an equity auction than in a debt auction. The reverse is true for 2 sessions as well, while for the remaining 5 sessions, average effort is exactly the same under the two auction forms. Taken together, this suggests no difference in average effort undertaken across auction forms. Formally, we fail to reject the null hypothesis of a zero treatment effect at the 68 percent level.

Hypothesis 4, however, predicts that in high returns treatments, equity auctions would undermine effort choices relative to debt auctions. The data in Table 4 strongly supports this prediction. In all 5 sessions, average effort is lower under an equity auction than under a debt auction and the differences are considerable. Formally, we find the differences in effort are statistically significant at the 3% level.

Market Level Analysis In the preceding analysis, we excluded the first twelve rounds owing to learning effects and treated the session as the unit of observation. Yet, this leaves unanswered the question of how important these learning effects (or their exclusion) are to the conclusions with respect to hypotheses 1-4. Moreover, the preceding analysis examined the results effectively pairwise across auction forms for a given high or low returns treatment. It is of some interest to examine the strength of the interaction terms against the level effects of the high or low returns treatment itself. For these reasons, we now examine the four hypotheses using the interaction

Table 4: Session Level Results

Session	Type	Change in Revenues	Change in Normalized Revenues	Change in Effort Choice
1	High Returns	-38.65	-16.5%	-75.0%
2	High Returns	-24.03	-9.6%	-58.3%
3	High Returns	-21.50	-14.5%	-66.7%
4	High Returns	-31.54	-21.0%	-95.8%
5	High Returns	-27.21	-15.5%	-83.3%
Sign test (p-value)		*0.031*	*0.031*	*0.031*
6	Low Returns	-3.31	-2.7%	0.0%
7	Low Returns	12.14	12.8%	0.0%
8	Low Returns	10.66	8.1%	0.0%
9	Low Returns	14.84	18.5%	-8.3%
10	Low Returns	4.20	4.6%	12.5%
11	Low Returns	12.81	24.9%	0.0%
12	Low Returns	1.97	5.1%	4.2%
13	Low Returns	17.95	14.9%	0.0%
14	Low Returns	6.72	7.6%	-4.2%
Sign test (p-value)		*0.020*	*0.020*	*0.688*

In this table, we subtract the average levels (within session) of revenues, normalized revenues and fraction of effort choice in the debt rounds (25-36) from the average levels in the equity rounds (13-24)

of a group of subjects in a particular "market" as the unit of observation. Since these markets took place over time during the experiment, this lets us isolate some learning effects on market outcomes. Moreover, by pooling across auction type and returns treatment, we are able to separately identify level from interaction effects present in the data.

While the differences shown are significant using parametric and non-parametric tests that use mean levels across samples obtained from the two security types, we examine the robustness of the four hypotheses using regression analysis. In what will follow we take a slightly less conservative view of the data and treat each "round" of the experiment as an observation, while explicitly incorporating the fact that errors are possibly subject to autocorrelation and/or heteroskedasticity within each session. Indeed, it is precisely this sort of worry about session effects that suggested pooling by session in the first place. However, clustering by session might, theoretically, allay this concern somewhat. Further, using regression analysis allows us to explicitly control for various types of learning effects (and which motivated omitting the first six rounds from the session level analysis above).

Specifically, we run the following regression:

$$measure_{st} = \beta \left(auction\ form_t \times agency\ effects_s \right) + \gamma_t X_{st} + \varepsilon_{st} \tag{5}$$

where $measure_{st}$ denotes one of the three measures of auction performance given above for round t of session s. The variable $auction\ form_t$ is equal to one if an equity auction occurred in period t and zero if a debt auction occurred in that period. The variable $agency\ effect_s$ is equal to zero if returns to effort are low and it is equal to one if returns to effort are high, in a given session s. The matrix X_{st} is a matrix of controls for learning effects over the course of a session. Specifically, we add a linear and squared time trends. Additionally, the matrix X_{st} includes a control, $learning_{st}$, which is equal to the number of previous rounds conducted within the same security type, in period t, session s. For instance, if period t were the kth period in which a equity auction was run, then the value of the learning control would be equal to k (rather than t). This accounts for the fact that learning may occur at different rates for different auction forms. Thus,

$$\gamma X_{st} \equiv \gamma_1 t + \gamma_2 t^2 + \gamma_3 learning_{st}$$

Of course, we continue to be concerned that past market interactions could affect current market interactions as subjects in a given session repeatedly interact. To allow for possible heteroskedasticity and autocorrelation of market outcomes in a given session, we regress the various measures of revenues and effort on the X variables and cluster by session. We obtain the following coefficient estimates summarized in Table 5.[10]

Table 5: Results from Market Level Regressions: Revenues, Normalized Revenues and Effort Choices

	β_0	β_1	β_2	β_3	γ_1	γ_2	γ_3	R^2
Revenues	61.770 (10.79)	10.794 (2.18)	53.344 (21.97)	−33.881 (−7.78)	−.2994 (−0.37)	.01116 (0.56)	.00346 (0.01)	0.3195
Normalized revenues	.8120 (20.51)	.1267 (3.13)	−.0786 (−4.16)	−.2456 (−6.31)	−.0068 (−1.43)	.00019 (1.75)	.00032 (0.08)	0.1768
Effort choice	.168144 (2.67)	.0126 (0.33)	.8831 (35.35)	−.6895 (−9.82)	−.0101 (−1.42)	.00019 (1.19)	−.00593 (−1.32)	0.6838
$N = 961$								

The t-values, reported in parentheses, derived using robust standard errors clustered by session

[10]We also ran an alternative specification where we included session level fixed effects and used robust standard errors. The results of this specification yield quantitatively similar estimates and precisions. The results are available upon request to the authors.

To see how the regression coefficients bear on the hypotheses listed above, it is helpful to write out the interaction terms explicitly. That is, all else equal,

$$\begin{gathered}measure_{st} = \beta_0 + \beta_1 auction\ form_t + \beta_2 agency\ effects_s + \\ \beta_3 auction\ form_t \times agency\ effects_s + \varepsilon_{st}\end{gathered}$$

There are four cases we need to consider, {debt, low returns}, {equity, low returns}, {debt, high returns}, and {equity, high returns}. Since *auction form* takes on the value of zero in the case of debt auction and *agency effects* takes on the value of zero when returns to effort are low, we obtain that in the:

- {debt, low returns}, $\overline{measure} = \beta_0$
- {equity, low returns}, $\overline{measure} = \beta_0 + \beta_1$
- {debt, high returns}, $\overline{measure} = \beta_0 + \beta_2$
- {equity, high returns}, $\overline{measure} = \beta_0 + \beta_1 + \beta_2 + \beta_3$

Therefore, the differences in average levels of the dependent measure when comparing equity and debt auctions in the low returns case, $\overline{measure}_{\{\text{equity,low returns}\}} - \overline{measure}_{\{\text{debt,low returns}\}}$, is equal to β_1. Likewise, the difference in between the equity and debt auctions in the high returns case, $\overline{measure}_{\{\text{equity,high returns}\}} - \overline{measure}_{\{\text{debt,high returns}\}}$, is equal to $\beta_1 + \beta_3$.

According to Hypothesis 1, when returns to effort are low, equity auction should yield higher revenues and normalized revenues than debt auctions. Thus, β_1 is predicted to be positive when the dependent variables are revenues or normalized revenues. Indeed, we find that this coefficient is estimated to be positive (61.77 for revenues and 0.812 for normalized revenues) and statistically different from zero (at the 1% level). Hypothesis 2 suggests that in the high returns case, debt auctions should yield higher revenues and normalized revenues than do equity auction, implying that $\beta_1 + \beta_3 < 0$. We find that this sum is negative for both revenues (-23.087) and normalized revenues (-0.1189) with statistical significance of 1%.

Hypothesis 3 predicts that effort decisions should be the same across the auction forms when returns to effort are low. That is, estimated β_1 in the effort choice regression should not be significantly different from zero. Indeed, the results suggest that the value of this coefficient (.0126) is indistinguishable from zero at conventional significance level. According to hypothesis 4, effort choices should be significantly different across the security forms when returns to effort are high. The results strongly support the hypothesis. We find that estimated $\beta_1 + \beta_3$ is negative (-9.49) and significant at confidence level of 1%.

The coefficients that capture across-rounds and within-security-form-learning do not appear to be statistically different from zero. Nonetheless, the sign of the linear round trend coefficient in the revenues and normalized revenues regressions appear to be positive. This is consistent with the intuition that learning decreases overbidding, resulting in lower revenues to the seller. The effect of within-auction-form seem to be negligible in the presence of time trend variables. The results suggest that while learning probably takes place, the process' effects are not significant when considering the complete set of rounds.

Summary

The session and market level data strongly supports the comparative static implications of the theory model. When returns to effort are low, equity auctions significantly outperform debt auctions; however, the reverse is true when the returns to effort are high. The key distinction in the revenue ranking is that competition in equity auctions undermines effort incentives and, as we saw above, leads to significant reductions in effort levels of the winning bidder.

5 Level Predictions of the Theory

While it is reassuring that the comparative static predictions of the model are borne out, the model also offers more detailed predictions about the levels of winning bids, the distribution of scare venture capital funding across firms, and about effort choices as a function of the current bid level. We investigate these questions in this section.

5.1 Efficient Sorting

Recall that we have a number of theorems indicating that the adverse selection problem is perfectly solved by either debt or equity auctions, irrespective of the returns to effort. We first examine differences in efficiency at the market level. In Table 6 below, we display the fraction of outcomes in terms of the ordering of the qualities of the projects of the highest and second highest bidder for each of the treatments. For example, the upper left-hand corner of the table displays a contingency table for debt auctions under the low returns treatment. The rows show the ranking in terms of project quality of the winning bidder while the columns display the rank of the losing bidder placing the highest bid. The theory predicts that all observations should occur where the winning bidder has the highest quality project.

As the table illustrates, the modal outcome in each of the treatments corresponds exactly to this prediction; however, perfect sorting does not arise for any of the treatments. Sorting in debt auctions is extremely efficient—the highest quality project is funded 88% of the time under low returns and 92% of the time under high returns. In contrast, equity auctions are less efficient—the highest quality project is funded only 69% of the time under low returns and 73% of the time under high returns.

Table 6: Efficient Sorting

			Project Quality Rank of Highest Losing Bidder					
			Low Returns			High Returns		
			1	2	3-4	1	2	3-4
Project Quality Rank of Winning Bidder	Debt	1	0%	76%	12%	0%	82%	10%
		2	7%	0%	3%	6%	0%	1%
		3-4	1%	0%	1%	2%	0%	0%
	Equity	1	0%	53%	16%	0%	55%	18%
		2	15%	0%	8%	16%	0%	4%
		3-4	5%	1%	0%	3%	4%	0%

Percentages in each cell expressed as a fraction of total realizations under the given treatment.

It is possible that the misallocations observed in Table 6 are the product of learning effects rather than systematic differences across treatments. To examine this possibility, we use a probit model to estimate the probability that the highest quality project is funded across auction forms and effort returns conditions. To estimate this model, we once again use the specification in the right-hand side of equation (5). We use a binary left-hand side variable for $measure_{it}$, which we code as "1" when the winner of the auction is the bidder with the highest v_i in the market and "0" otherwise. The coefficient estimates of the marginal effects of each of the factors on the probability of an efficient allocation for this specification are reported in Table 7 below.

Table 7 shows that the differences across treatments observed in Table 6 are not purely due to learning effects. While learning does improve efficiency at about a 2 percent rate per round of the experiment, the coefficients associated with the different treatments remain significant even after accounting for these effects. In particular, consistent with Table 6, equity auctions achieve efficient sorting about 15% less often than do debt auctions. Furthermore, auctions under the high returns treatment (regardless of security type) deliver efficient allocations about 8% more often.

One possible explanation for the efficiency differences is that bidding errors by bidders with the highest and second highest quality projects might trigger an inefficient outcome. Under this view, when the gap between the optimal bid for the bidder with the highest quality project is close to that for the bidder with the second highest quality project, then inefficiency is more likely. Notice that the average gap between the theoretical highest and second highest bidders differs substantially across treatments. Specifically, the average gaps in the debt auctions were 19.8 points (under low returns) and 48.7 points under high returns. The average gaps in the equity auctions were 4.7 points (under low returns) and 4.1 points (under high returns). This ranking among gaps is qualitatively consistent with the results presented in Table 7. However, a more detailed examination of this hypothesis leads us to discount it. Specifically, the "gap hypothesis" suggests that if we add the gap as an additional right-hand side variable in the probit analysis above, it should have a positive coefficient and strong

Table 7: Probit Estimates of Allocative Efficiency

Parameter	$d\Pr(y)/dx$	z-value
Equity Auction Dummy	$-.1563$	-2.81^{**}
High Returns dummy	.0840	2.54^{*}
Equity Auction×High Returns dummy	$-.0758$	-1.35
Round number	.0203	2.87^{**}
Round number squared	$-.0003$	-1.96
Within-auction form round number	$-.0036$	-0.72
Baseline probability of efficient allocation: 0.8549 $N = 961$		

Statistical significance is denoted by *for 5% level and by **for 1% level.

explanatory power. We performed this analysis and observed that the coefficient on gap was -0.0005 – neither statistically nor economically significant.

An alternative explanation for the efficiency differences across the two auction forms is that they differ in their cognitive complexity. In particular, bidding errors may arise more frequently in equity auctions than in debt auctions and this, in turn would lead to lower efficiency. It is not clear how one formalizes this idea of differences in cognitive complexity. For instance, the equilibrium in both debt and equity auctions occurs in weakly dominant strategies; thus from the standpoint of the rationality requirements of the solution concept, the two auctions are equally complex.

Efficient Sorting - Losing Bidder

In addition to predicting that the highest quality project would receive funding, it follows from the fact that bidding strategies are monotone that the highest losing bid should be placed by the bidder with the second-highest quality project. Indeed, since in the absence of jump-bidding (which we shall discuss later), the highest losing bidder effectively sets the price for the winner of the auction (modulo the bid increment), the project quality of the highest losing bidder is closely related to the revenues to the VC. Returning to Table 6, we observe that under debt auctions, conditional on awarding funding to the highest quality project, the highest losing bid comes from the bidder with the second-highest quality project fully 86% of the time under low returns and 89% of the time under high returns. In contrast, we observe that under equity auctions, conditional on efficient allocation, the highest losing bid comes from the bidder with the second-highest quality project 77% of the time under low returns and 75% of the time under high returns.

In addition to the sorting conditions, VC revenues also depend on the effort choice of the winning entrepreneur. As we saw, for debt auctions under high and low returns, these choices closely conformed to the theory prediction. This, combined with the efficient sorting results explains why observed revenues for these auctions were close to the levels predicted by the theory. In the case of equity auctions under low returns, effort choices again corresponded to the theory; thus, the shortfall in revenues compared with the theory prediction can mainly be explained by inefficient sorting.

5.2 Weak Dominance

In addition to the sorting property, the theory also predicts that bidders will follow weakly dominant strategies. This has differing implications for the winning and highest losing bidders. For the winning bidder, weak dominance implies that the payoffs to the winner should (weakly) exceed the payoffs from the outside option. Similarly, weak dominance implies that losing bidders should not submit bids which, if accepted, would result in payoffs below their outside option. An additional, and perhaps more interesting implication of dominance for the case of losing bidders is that the losing bidder should not be able to improve payoffs over the value of the outside option by submitting a bid in excess of that of the winning bidder. That is, "improved" bids by losing bidders should not be profitable.

To examine these implications, we have classified auction results for the winning and losing bidders under each treatment into a 3×3 matrix. Rows or columns labeled "-1" correspond to bids yielding payoffs strictly below the outside option for the winning and highest losing bidder respectively. Rows or columns marked "1" correspond to bids where, in the case of the winning bidder, his or her payoffs exceeded her outside option or, in the case of the losing bidder, where an "improved" bid over and above that of the winning bidder would still yield payoffs in excess of the outside option. Finally, rows and columns marked "0" correspond to bids where, in the case of the winning bidder, his or her payoffs were equal to her outside option or, in the case of the losing bidder, where the current bid was (weakly) profitable but no "improved" bid would yield payoffs in excess of the outside option. The results of this exercise are displayed in Table 8.

Winning Bidders

The first implication of weak dominance implies that one should see no observations in the "-1" rows of the table above. On the other hand, if bidders are mainly motivated by the love of simply winning the auction or subject to "bidding fever" leading to buyer's remorse, then we would expect to find a considerable number of dominance violations. As the table shows, for debt auctions, there is little evidence of these types of behavior: fewer than 5 percent of outcomes in a given treatment involve dominance violations by winning bidders. In contrast, there are considerably

Table 8: Bidding Relative to Outside Option

			Highest Losing bid					
			Low Returns			High Returns		
			-1	0	1	-1	0	1
Winning bid	Debt	-1	1%	4%	0%	0%	1%	1%
		0	1%	16%	1%	1%	7%	0%
		1	9%	66%	2%	13%	71%	6%
	Equity	-1	0%	14%	0%	2%	8%	0%
		0	1%	42%	1%	8%	39%	2%
		1	4%	36%	2%	7%	32%	3%

Percentages in each cell expressed as a fraction of total realizations under the given treatment. The indicators "-1," "0," "1" denote negative, zero, and positive surplus bids, respectively.

more dominance violations in equity auctions—up to 14% in the case of low returns. Notice, however, that the bulk of these violations occur when the highest losing bidder has not made a similar type of bidding mistake. Were love of winning or bidding fever responsible for these mistakes, one might have speculated that the resulting bidding war would have propelled both the winning and highest losing bidders into dominance violations, yet that does not seem to be the case. Increased dominance violations by winning bidders in equity auctions may simply be further evidence that such auctions are simply more cognitively complex than are debt auctions.

An important difference between debt and equity auctions concerns the surplus available to winning bidders. Recall that, for a given effort level, equity auctions leave lower bidder surplus than do debt auctions. Thus, one should expect that winning bidders would be indifferent (have outcomes in the "0" rows) more frequently than under debt auctions. One can readily see this in the table. Conditional on the winner not having a dominance violation, winning bidders obtained positive net surplus 81% of the time for debt auctions with low returns and 92% of the time for debt auctions with high returns. This contrasts sharply with equity auctions where winning bidders obtained positive net surplus only 49% of the time under low returns and only 46% of the time under high returns. In short, consistent with the theory prediction, equity auctions are far more effective than debt auctions at capturing available surplus from bidders.

Losing Bidders

As with winning bidders, dominance implies that the highest losing bidder should not submit an unprofitable bid. That is, no observations should lie in the "-1" columns of the table. As is apparent, this is not the case. For debt auctions, at least 11% of submitted bids by the highest losing bidder violate dominance. There are somewhat fewer dominance violations for equity auctions (5% in the case of low returns), but still significantly more than for winning bidders. It is interesting to note that most of the violations occur in the $(1, -1)$ cells of the table. That is, the highest losing bidder submits an unprofitable bid; however, the winning bidder's project is of sufficiently high quality that, despite this overbidding on the losing bidder's part, the winner still enjoys considerable surplus. One possible explanation for this is spiteful bidding—losing bidders with low project qualities realize that their overbidding is unlikely to result in their ultimately winning the auction while at the same time, their bids will reduce the surplus enjoyed by the winning bidder, i.e. the winning bidder will be spited by the losers. Other research (see Morgan and Stiglitz, 2002) suggests that spiteful bidding is a not infrequent occurrence in auctions.

A second implication of dominance for losing bidders implies that, conditional on not violating dominance in the form of overbidding, all observations should lie in the "0" columns of Table 8. As the table shows, this implication largely holds in the data. There is no profitable improved bid available to the highest losing bidder in at least 93% of the time in the both debt and equity auctions. This also rules out a further strategy that might have been employed successfully by winning bidders. It is possible that winning bidders might have attempted to "jump bid" in order to deter other bidders from competing. Jump bidding would imply realizations in the $(1,1)$ cells of the table. However, there is little evidence of successful jump bidding in the data.

5.3 Structural Estimation

While Tables 6 and 8 describe key qualitative features of individual bidding strategies with respect to the dominance and efficient sorting properties suggested by the theory, it is useful to consider the economic magnitudes of dominance violations, spiteful bidding, and inefficient sorting on revenues. To study these effects at an individual bidder level, we use the theory predictions to derive a structural model for revenues under the various treatments.

For debt auctions, we have

$$ER_{debt} = \begin{cases} v_2 & \text{if} \quad \text{low returns} \\ v_2(1+\delta) - 20 & \text{if} \quad \text{high returns} \end{cases}$$

where v_2 is the second highest project quality realization.

In the case of an equity auction under the low returns treatment, revenues are simply given by

$$ER^{low}_{equity} = \frac{v_1 + m}{v_2 + m} \times v_2 \tag{6}$$

However, we can nest this specification with those of debt auctions by linearizing equation 6 around $v_1 = v_2 = m$ using a first-order Taylor Series approximation. This yields

$$ER^{low}_{equity} \approx \frac{v_1+m}{v_2+m} \times v_2 + \frac{m}{m+m}(v_1-m) + m\frac{m+m}{(m+m)^2}(v_2-m) \tag{7}$$
$$= 0.5v_1 + 0.5v_2$$

The case of an equity auction under the high returns treatment is more complex. As noted above, it is sometimes optimal to undertake effort and sometimes not depending on the realizations of v_1 *and* v_2.[11] The relevant expected revenues in the two cases are

$$ER^{high}_{equity} = \begin{cases} \frac{v_1+m}{v_2+m} \times v_2 & \text{if} \quad v_1 < \frac{E(v_2+m)}{m\delta} \\ \frac{v_1(1+\delta)+m}{v_2+m} \times v_2 & \text{if} \quad otherwise \end{cases} \tag{8}$$

Linearizing equation (8) yields:

$$ER^{high}_{equity} \approx \begin{cases} 0.5v_1 + 0.5v_2 & \text{if} \quad v_1 < 1.54 \times (10+v_2) \\ 1.15v_1 + 0.825\,v_2 - 3.25 & \text{if} \quad otherwise \end{cases} \tag{9}$$

A difficulty with equation (9) is that the coefficients on v_1 and v_2 take on different values depending on the magnitude of v_1 relative to v_2. Thus, to pool all of the treatments together in a single estimating equation, we are required to restrict attention to realizations of v_1 and v_2 lying in one of the two cases. Since the predicted coefficients for the case where $v_1 < 1.54 \times (10+v_2)$ are identical to those in the equity auction under low returns, we opted to restrict attention to the opposite case.

Thus, all of the treatments may be structurally estimated using the following equation:

$$\begin{aligned} Revenues = {} & \alpha_1 + \alpha_2 D^{high} + \alpha_3 D^{equity} + \alpha_4 D^{equity} D^{high} \\ & + \beta_1 v_1 + \beta_2 v_1 D^{high} + \beta_3 v_1 D^{equity} + \beta_4 v_1 D^{high} D^{equity} \\ & + \gamma_1 v_2 + \gamma_2 v_2 D^{high} + \gamma_3 v_2 D^{equity} + \gamma_4 v_2 D^{high} D^{equity} \end{aligned} \tag{10}$$

This formulation allows us to clearly identify the driving forces behind revenues under all relevant conditions. In debt auctions, revenues are a function of the second highest value *only,* while in equity auction revenues dependent on the second *and* the first highest value. We also see that revenues become more sensitive to the second highest value when moving from low to high returns settings in both debt and equity auctions. At the same time, the sensitivity of equity revenues to the highest private

[11] For the parameters of the experiment, effort by the losing bidder will never be undertaken since the expression analogous to the condition $(m\delta - 1)\,v_i \geq m$ given in Lemma 2 is never satisfied. Specifically, the analogous expression is $(m\delta - E)\,v_i \geq mE$ where E denotes the cost of effort. Since $m = 10, \delta = 1.3$ and $E = 20$,this condition fails trivially—the left-hand side of the expression is always negative.

value goes down when in high returns to effort condition. Thus, the linkage principal weakens as result of the moral hazard problem.

The coefficient estimates arising when we estimate equation 10 are given in Table 9. To account for autocorrelation and heteroskedasticity, we use robust standard errors clustering by treatment. Columns two and three list the various sets of parameters for which the model makes predictions and their corresponding values. Columns four and five provide the coefficient estimates and associated standard errors. The stars on the coefficient estimates indicate significance levels against the null hypotheses implied by the level predictions of the theory.

Table 9: Structural Estimation Results: Revenues

Treatment	Parameter	Hypothesis	Estimate	*s.e.*
{Debt, Low}	α_1	0	4.1915*	1.8778
	β_1	0	.1186**	.04236
	γ_1	1	.8042**	.04122
{Debt, High}	$\alpha_1 + \alpha_2$	-20	-15.7865	5.8631
	$\beta_1 + \beta_2$	0	0.1597*	.07742
	$\gamma_1 + \gamma_2$	2.3	2.0138**	.07402
{Equity, Low}	$\alpha_1 + \alpha_3$	0	-4.5950*	1.8778
	$\beta_1 + \beta_3$	0.5	0.7942**	.02850
	$\gamma_1 + \gamma_3$	0.5	0.2880**	.03001
{Equity, High}	$\alpha_1 + \alpha_2 + \alpha_3 + a_4$	-3.25	-27.509	34.855
	$\beta_1 + \beta_2 + \beta_3 + \beta_4$	1.15	1.6432	.60266
	$\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4$	0.825	.15160	.91066
		$N = 720, R^2 = 0.8775$		

Statistical significance is denoted by * for 5% level and by ** for 1% level.

Debt Auctions

The coefficient estimates for the debt auctions indicate that, despite the theory prediction that revenue should be independent of the realization of the value of the highest quality project, under both high and low returns, this realization does appear to influence revenues. One might speculate that this is the result of overbidding on the part of bidders with the highest realizations; however, as was shown in Table 8, there were few instances of dominance violations among these bidders. Instead, the coefficient estimates appear to be driven by the combination of inefficient allocations where the bidder with the highest quality project is setting the price (which occurs

7% of the time in the low returns treatment) as well as by spiteful overbidding on the part of losing bidders with low realizations of project quality (which occurs 9% of the time in the low returns treatment). To get a sense of how spiteful bidding could lead to coefficient estimates qualitatively similar to those in Table 9, we estimated equation (10) using simulated auctions where the form of the spiteful bidding strategy was

$$bid_2 = \begin{cases} v_2 + f\left(E\left[v_1 | v_1 \geq v_2\right]\right) & \text{if} \quad v_2 < v_{\min} \\ v_2 & \text{if} \quad v_2 \geq v_{\min} \end{cases}$$

where v_i denotes ith highest project quality, $v_{\min}$ is a threshold for spiteful bidding, and $f(\cdot)$ is an increasing function. We find that such a bidding strategy leads to v_2 coefficients less than one and v_1 coefficients greater than zero.

Equity Auctions

Similarly, the coefficient estimates for the equity auctions also indicate greater weight being placed on the realization of v_1 and lower weight on v_2 than that predicted by the theory. In this case, however, spiteful bidding seems less likely as an explanation. In particular, as Table 8 showed, the percentage of final allocations influenced by overbidding on the part of the losing bidder is relatively small while dominance violations on the part of the winning bidder occurred with much greater frequency compared to debt auctions. Moreover, these dominance violations also manifest themselves in the form of inefficient allocations, as showed in Table 6. Thus, it would appear that the greater cognitive complexity leads to dominance violations and ultimately a greater weight placed on the realization of v_1 than is predicted by the theory. That being said, this does not immediately imply revenue gains for the VC. As we saw in Table 3, revenues fell short of the theory predictions for the low returns treatment while exceeding the theory predictions in the high returns treatment. This difference reflects a combination of dominance violations, inefficiency, and incorrect effort choices on the part of the winning bidder.

Comparing Debt and Equity Auctions

Recall that the a key prediction generated by the theory (for a fixed effort level) is that equity auctions generate higher revenues than debt auction by creating a linkage between the returns to the VC and the realized project quality of the winning bidder. In terms of the structural estimation, this linkage manifests itself in the form of a higher coefficient on v_1. In the low returns treatments, the formal test of linkage amounts to a test of the joint hypothesis that $\beta_3 > 0$ and $\gamma_3 < 0$ compared to the null hypothesis of no treatment effect. We can reject the null at the 1% significance level in favor of the one-sided alternative implied by linkage. The high returns case is more complicated in general owing to differences in predicted equilibrium effort choices. However, for the case considered in the structural estimation, where equilibrium effort is high in both debt and equity auctions, linkage amounts to a test of the joint hypothesis that $\beta_3 + \beta_4 > 0$ and $\gamma_3 + \gamma_4 < 0$ against the null hypothesis of no treatment effect. Again, we can reject the null at the 1% significance level.

Thus, the structural estimation offers support for the transmission path leading to the revenue ranking predicted by the theory.

6 Conclusions

We have shown that in imperfectly competitive settings where both hidden information and hidden action affect the returns to the seller of some scarce resource, the form of the contracts over which competition occurs can has a significant effect on seller profits. Specifically, we have compared auctions under two archetypal contractual forms—debt and equity—and identified a key tradeoff faced by a seller in determining which form to use. We showed that equity auctions have the advantage of reducing the information rent paid by the seller to obtain an efficient "sort" of the quality of the bidders projects. This reduction occurs owing to the *linkage* in the contract between the revenues to the seller and the underlying value of the resource to the winning bidder. At the same time, equity auctions have the disadvantage that, by diluting the upside from effort investment on the part of the winning bidder, the moral hazard problem is exacerbated. This, in turn, reduces the revenues to the seller. We have shown that when returns to effort are either very low or very high, the linkage effect dominates and equity auctions produce greater revenue than do debt auctions. For cases where returns to effort are intermediate, we have identified conditions where the dilution effect dominates and debt auctions outperform equity auctions.

Finally, we have tested the main predictions of the theory model in a controlled laboratory experiment in which we varied the form of the contract (debt vs. equity) and the returns to effort (low and moderate). Our findings support the theory predictions: Revenues to sellers between debt and equity auctions differ depending on the returns to entrepreneurial effort in the direction predicted by the theory. Furthermore, other aspects of the theory model, such as efficiency, effort choice, and bid levels are also closely tied to the theory predictions.

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7 Appendix

7.1 Structural model

In developing the structural model, we claim that

$$ER_{equity}^{high}(effort) \approx 1.15v_1 + 0.825\,v_2 - 3.25$$

To see that, use first order approximation around $v_1 = v_2 = m$.

$$ER_{equity}^{high}(effort) = \frac{v_1(1+\delta)+m}{v_2+m}v_2 \approx$$

$$\frac{v_1(1+\delta)+m}{v_2+m}v_2 + \frac{\partial}{\partial v_1}\left(\frac{v_1(1+\delta)+m}{v_2+m}v_2\right)(v_1-m) + \frac{\partial}{\partial v_2}\left(\frac{v_1(1+\delta)+m}{v_2+m}v_2\right)(v_2-m) =$$

$$\frac{v_1(1+\delta)+m}{v_2+m}v_2 + v_2\frac{\delta+1}{m+v_2}(v_1-m) + \frac{m}{(m+v_2)^2}(m+v_1+\delta v_1)(v_2-m) =$$

$$\frac{m(1+\delta)+m}{m+m}m + m\frac{\delta+1}{m+m}(v_1-m) + \frac{m}{(m+m)^2}(m+m+\delta m)(v_2-m) =$$

$$1.15v_1 + 0.825\,v_2 - 3.25$$