Securities Auctions under Moral Hazard: An Experimental Study[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 debt and equity auctions in the presence of both private information and hidden effort. We show that the revenues to sellers in debt and equity auctions differ systematically depending on the returns to entrepreneurial effort. We then test these revenue rankings and other predictions of the theory using controlled laboratory experiments where we vary the returns to effort. While the bidding behavior, particularly in equity auctions, differs from the dominant strategy prediction of the theory, the predicted revenue rankings are borne out in the lab.

1 Introduction

In many settings, competition among a few firms for some scarce asset or resource differs 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. At various times, oil tracts have been auctioned using cash contracts with a fixed royalty component, pure royalty contracts, and even pure profit share 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, to pure equity offers. Another important area where the types of contracts are particularly rich and varied is in venture capital financing (see Kaplan and Stromberg (2003), Hellmann (2006)). 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 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), 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.[2] In a recent 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.

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

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

[2] See also Cremer (1985), Maskin and Riley (1984), Samuelson (1985), Laffont and Tirole (1987) and Hart (2001).

the project quality and incentives of the second-highest bidder, the revenues to the seller depends 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.

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 suggests otherwise. The element that is present in the Alaska case but abstracted from in much of 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. This effect would seem extremely severe in a venture capital setting, particularly at the angel financing level, where entrepreneurial effort is clearly a key component to the ultimate success of the venture. Thus, while an equity auction 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, a seller using an equity auction may end up with a larger slice of a much smaller pie compared to a debt auction, and this may not be preferred.[3]

To formally model this tradeoff, we offer a simple auction model where we compare competition in debt versus equity contracts in the presence of adverse selection and moral hazard. The goal of the model is to illustrate when the improved rent extraction characteristics of competition in equity contracts dominate and when the deleterious effect equity contracts have on effort incentives dominate. While the theory model is a simple conceptualization of this tradeoff, the payoff from constructing a formal model is that it provides a novel set of testable predictions about how variation in the returns to effort affects revenue ranking and bidding strategies in debt versus equity auctions.

It is important to note that we are certainly not the first to consider this set of tradeoffs. Abstracting away from particular auction forms, McAfee and McMillan (1987) use the revelation principal to characterize optimal contracts in a model with competition, adverse selection, and moral hazard. Their contracts have the property that the most efficient "agent" is selected and, under some conditions, the payment the agent receives is linear in output. In general, the payment structure in their optimal contract does not coincide with that produced either by an equity or a debt auction. Even within the context of debt and equity auctions, this tradeoff is somewhat anticipated by the working paper version of De Marzo, *et al.*

While the *theoretical* possibility of an extraction-incentives tradeoff depending on the form of competition (debt versus equity) is clear, determining whether the postu-

[3]Outside of auction theory, an early version of this same tradeoff 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 the undermining of effort incentives. However, this line of the literature uses a principal-agent framework rather than modeling competition as occurring among a small number of interested bidders.

lated effects indeed occur is a different matter entirely. First, field data are of limited use in examining these questions owing to the extreme difficulty of constructing a convincing counterfactual in what are, typically, unique situations. For instance, in the venture capital setting, it is difficult to imagine a convincing study answering the what-if question as to entrepreneurial performance both in securing financing and carrying off projects under an alternative contractual schemes and bidding competition.

Given these difficulties, controlled laboratory experiments offer a useful methodology for examining the extraction-incentives tradeoff. We design the experiment around two treatment variables: the structure of the financing terms of the auction (debt versus equity), and the returns to effort (high versus low). All other variables are held constant. Bidders compete by entering debt or equity amounts and effort choices in a computerized English auction using a soft (going, going, gone) ending rule. 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. Indeed, in our view, our experiments examining these questions form the main contribution of the paper.

Of course, one might argue that little new light is shed by simply subjecting theory to a direct test in the laboratory. After all, it might seem reasonable that, with sufficient experience, the competitive forces of the auction will ultimately lead subjects to equilibrium behavior and hence little is to be gained from this exercise. In fact, there is ample evidence in the extant literature that this is far from true even in the narrow realm of auction theory. For instance, many of the predictions of the revenue equivalence theorem, arguably the centerpiece of auction theory, do not hold in controlled laboratory settings (See Kagel (1995)). Furthermore, even weaker notions, such as strategic equivalence among auction forms, sometimes fail. For instance, Kagel, Harstad, and Levin (1987) have shown that second price sealed bid and English auctions—two strategically equivalent when bidders have private values—yield markedly different results. Thus, it is by no means a given that the theoretical predictions about the relative performance of auctions under moral hazard when bidding over debt versus equity contracts will obtain in the lab.

What is to be learned from the laboratory experiments is whether the theory leading to the extraction effect is *behaviorally* relevant for real auctions and furthermore, whether the countervailing effects of moral hazard associated with equity auctions are sufficient to offset the extraction effect in practice. Clearly, to the extent that businesses rely on the theoretical predictions about debt versus equity auctions in choosing both the form of the auction as well as the optimal bid, such a behavioral test is of considerable importance.

While the theoretical predictions and the empirical results are relevant to a broad set of economic situations discussed above, we cast the model in the form of entrepreneurs compete for venture financing. Clearly, the trade-off between surplus extraction and surplus creation is at the heart of the "negotiation dance" between entrepreneurs and financiers and therefore is an important application of the main ideas of the paper. To starkly capture the main forces of this trade-off we simplify matters by assuming that effort is contributed solely by the entrepreneur rather than as a sharing arrangement between the entrepreneur and the financier. Clearly, this abstraction is more appropriate to early round financing such as angel financing rather than at later rounds closer to IPO. Chammanur and Chen (2006) provide a useful discussion of the effort contributions at various rounds of financing as well as Kaplan and Strnoberg (2003) about the interaction of these incentives with the contractual terms of entrepreneurs and financiers.

Modeling this as an interaction in which entrepreneurs compete for financing is consistent with the documented average positive and persistent alpha (before fees) generated by venture funds (e.g., Cochrane (2005), Kaplan and Schoar (2005)). More broadly, we believe that an important independent contribution is to propose an empirically testable theory model for the interplay between *competing* entrepreneurs and venture financing agreements and to show that many of the predictions of the model are borne out in controlled laboratory experiments.

The main findings, both theoretical and empirical, 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). In short, while the theory predicts no difference in the efficiency of these two auction forms, actual behavior reveals that debt auctions are superior in this dimension.

2. **Incentives:** We show theoretically that equilibrium behavior in equity auctions can lead to under-provision of effort under an equity auction while the provision of 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 behaviorally the degree to which they are undermined is lower than theory predicts. Debt auctions lead to optimal effort provision in the overwhelming majority of cases (see Table 5). In short, the experiments reveal that behaviorally, revenue losses to sellers from moral hazard considerations in equity auctions are smaller than the theory predicts.

3. **Extraction-Incentives Tradeoff:** We show theoretically that the linkage effect dominates when the returns to entrepreneurial effort are extreme, while the incentive effect can dominate when the returns to entrepreneurial effort are intermediate (see Proposition 5). In other words, there is a non-monotonic relationship between the revenue ranking and the returns to effort. The main

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 returns to effort are intermediate (see Tables 3 and 5). In both cases, the laboratory experiments reveal that, in practice, the revenue *differences* between the two auctions forms are smaller than theory predicts.

What are the sources of the discrepancies highlighted above between observed behavior and the theoretical predictions? We investigate several possibilities and conclude that spiteful bidding plays an important role in auction results. In addition, the greater cognitive complexity of equity auctions relative to their debt cousins also appears responsible for some of the differences.

These results suggest 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 a 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: We conclude this section by reviewing the related VC and experimental literature. In section 2 we sketch the model and characterize equilibrium bidding behavior in debt and equity auctions with both adverse selection and moral hazard. Section 3 outlines the design of the experiment. Section 4 reports on the results of the experiments. We conclude in section 5. The proofs of all the theory results as well as a description of the structural model used in some of the estimations is contained in an appendix.

Related Literature

Most closely related to our paper is the VC literature that focuses on a two-sided moral hazard problem of financisers and entrepreneurs. Here, contracts are designed to solve the problem that both parties need to give effort and each party has an incentive to free-ride. Typically this is done in a principal-agent setting (see, for instance, Cassamatta (2003) and Schmidt (2003)). Repullo and Suarez (2004) add a dynamic element to the contracting process. Inderst and Muller (2004) grapple with the two-sided moral hazard problem in a competitive setting. Of particular interest of this paper is how the relative scarcity of talent on each side of the market affects surplus splitting in equilibrium. Relative to this literature, we add adverse selection but remove the moral hazard by the financier from the analysis. Like Inderst and Muller (2004), we focus on how imperfect competition, which we model as an auction, affects the form of equilibrium contracts.

Our paper contributes to the growing body of work examining contractual performance using controlled experiments. Perhaps most closely related to our paper is

Asparouhova (2006) who examines competition in a screening model. Along these same lines, Goswami, Grace, and Rebello (2008) study equilibrium contracting in a signaling model. Despite the considerable complexity of both settings, equilibrium predictions perform surprisingly well.

While most of the theoretical literature on optimal contracting focuses on pecuniary incentives and contractual enforceability, laboratory experiments provide evidence that non-pecuniary incentives and non-credible threats do matter. For instance, Fehr and Falk (2002) provide an excellent survey illustrating how social preferences such as reciprocity and inequity aversion impact contractual performance. Fehr and Gaechter (2002) show that the introduction of punishment threats that are not credibly from a purely pecuniary perspective do in fact positively influence performance. Our paper adds to this literature by highlighting how the competition, moral hazard, and adverse selection affect contracts in a VC context. From a behavioral context, our results highlight the role of dominance violations in the form of spiteful bidding.

2 Theory

Consider a setting in which two entrepreneurs compete for resources from a venture capital firm to fund a risky project.[4] 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.[5] 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; however, it is commonly known that for all i, v_i is drawn from the atomless distribution F on $[\underline{v}, \overline{v}]$ with positive density over its support. In addition, an entrepreneur privately

[4] The analysis is done for the case of two entrepreneurs and a single VC. However, since the theory model amounts to a single unit independent private values auction, it may be straightforwardly extended to allow for n entrepreneurs and k VCs to compete simultaneously. In that extension, each VC would offer a package of resources for a single entrepreneur, each entrepreneur would have unit demand, and the analogous auction would be a uniform price auction.

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

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.

The contribution of the package of resources by the VC to the winning bidder has the effect of unlocking v_i and making effort on the part of the entrepreneur valuable. The effort of the VC itself, has no synergistic effect on the returns to the winning entrepreneur. This representation is more suited to early rounds of VC financing, such as angel financing, where the VC is less likely to play an active role in management. See Chemmanur and Chen (2006) for a detailed discussion of this distinction.

Notice that there is a trade-off between undertaking the project and risking a failure (even on the most favorable possible terms) versus retaining the "safe" outside option, m. 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 the project 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 even absent any entrepreneurial effort. Formally, this amounts to the condition:

$$m \leq p\left(\underline{v} + m\right)$$

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

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

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.

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. The objective of the manager of the VC is to maximize the expected return of the investors subject to the 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 model the competition as an English auction which, in the case of our model, is (strategically) equivalent to a second-price sealed-bid auction.

We shall consider the following schemes:

1. **Equity auction:** In an equity auction, entrepreneurs compete by offering the VC fractional ownership of the company in exchange for the VC's resources. The entrepreneur offering the larger ownership share is the "winner" of the auction at the bid amount.

2. **Debt auction:** In a debt auction, entrepreneurs compete by offering the VC debt contracts in exchange for VC's resources. Again, we model this process as an English 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 establish the conditions under which dilution reduces effort incentives to the point where the entrepreneur will no longer find it optimal to exert effort. This amounts to a condition stating that the residual returns to the entrepreneur from exerting effort equal or exceed the cost of effort. Formally,

Lemma 1 *Winning entrepreneur i should undertake effort if and only if he retains a share of at least $\frac{1}{v_i \delta p}$*

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. So how should an entrepreneur bid? Clearly, the entrepreneur can do no better than to remain in the auction if, at the current price, it is more profitable to receive funding from the VC and exert effort optimally than to bow out of the competition. On the other hand, for a sufficiently high price, bowing out is optimal. Thus, the equilibrium is in weakly dominant strategies which entail "cutoff" price levels at which the entrepreneur should exit. Formally,

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

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

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

The relationship between the drop out price and the quality of the entrepreneur's project differs depending on whether the entrepreneur expects to exert high effort or not at the drop out price. This gives rise to continuous, increasing bidding functions that are *kinked* at the project quality where it first becomes optimal to exert effort at the drop out price. Notice that, since the bidding strategies are symmetric and strictly increasing, the entrepreneur with the higher quality project is willing to drop out at a strictly higher price regardless of whether that price leads to effort being undertaken or not. Thus, it follows directly that the auction always succeeds in choosing the higher quality project. Formally,

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

Analysis of Equilibrium in Debt Auctions

Next, we turn to debt auctions. Unlike equity auctions, where dilution of the entrepreneur's position can undermine effort incentives, in a debt auction effort is determined purely by whether there are positive social returns to effort. This amounts to the condition that the expected (private and social) return to effort, $v\delta p$ exceeds the cost of effort. Entrepreneurs whose project quality falls below this threshold will anticipate undertaking low effort and bid accordingly while those above the threshold will anticipate undertaking high effort. As in the equity auction, an entrepreneur can do no better than to remain in the auction so long as undertaking optimal effort at the current price yields a payoff as least as high as the entrepreneur's outside option. This yields the following characterization of a bidding equilibrium in weakly dominant strategies:

Proposition 3 *In a debt auction, an equilibrium in weakly dominant strategies is for bidder i to drop out at price*

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

and exert effort if and only if $v_i \geq \frac{1}{\delta p}$.

Again, the bidding strategy displays a kink for project quality where the expected return to effort just equals the cost of effort. For higher quality projects, the slope of the bidding function is steeper than for projects whose quality falls below this threshold. As with equity auctions, since bidding consists of symmetric and strictly increasing drop out bids, it then follows that the higher quality project is always chosen by the VC. Formally,

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

To summarize, thus far we have shown that both debt and equity auctions have equilibria in weakly dominant strategies and both of these auctions succeed in choosing the higher quality project. Interestingly, equilibrium bidding functions are kinked at the point where the project quality becomes sufficiently high such that the entrepreneur is willing to exert high effort, and this occurs at a lower quality threshold for debt than for equity. This reflects the dilution effects of auction competition in ownership shares.

2.1 Revenue Comparisons

Notice that the "price" to the VC is set at the drop out level of the entrepreneur with the lower quality project. In the case of debt auctions, this drop out price alone determines expected revenues. In the equity auction, however, revenues are in part determined by the winning entrepreneur's project quality, and in part by the winning entrepreneur's effort. These latter two effects give rise to systematic revenue differences across the auction forms. The key tradeoff is whether the additional value captured by the VC through tying the revenues to the project quality of the winner is sufficient to overcome the deleterious effect on entrepreneurial effort caused by the dilution of effort incentives. In thinking about this tradeoff, it is useful to keep in mind the following three equilibrium possibilities arising under the equity auction:[6]

(i) *The dilution effect is absent*: The losing entrepreneur drops out at a price where he would have undertaken high effort had he won at that price. In this case, the winning entrepreneur will also exert high effort in equilibrium.

(ii) *The dilution effect is strongest*: The losing entrepreneur drops out at a price where the winning entrepreneur optimally exerts low effort. Because the losing entrepreneur's project quality is below that of the winner, then it would have been optimal for the loser to undertake low effort as well and the drop out price is set accordingly.

(iii) *The dilution effect is intermediate*: The losing entrepreneur drops out at a price where he would have undertaken low effort had he won at that price; however, the winning entrepreneur's project is of sufficiently high quality that high effort is optimal at this price. In this case, the dilution incentives depress the drop-out price but not the winning entrepreneur's effort.

With these cases in mind, we are now in a position to rank the revenues arising under the two auction forms. While revenue rankings are typically expressed in terms of expected revenues, for a range of parameters in our model, it is possible to obtain a stronger result–a revenue ordering for every possible realization of valuations. The advantage of this *ex post* revenue ranking is that it is distribution free. The disadvantage is that, since it is a stronger requirement than an ordering on expected revenues, the ex post ordering depends on the realized values under certain parameter configurations.

Without loss of generality, we assume that v_1 denotes the highest quality project and v_2 denotes the quality of the second highest project. First, suppose that the quality of the worse project is sufficiently high that the dilution effect is absent (i.e. $v_2 \geq \frac{m}{m\delta-1}$). In that case, high effort will be undertaken in both the debt and equity auctions and the linkage between the payment of the winning bidder and his project quality will dominate. Second, suppose that the quality of the worse project is sufficiently low that even a self-financing entrepreneur would find it undesirable to undertake effort (i.e. $v_2 < \frac{1}{\delta p}$). In that case, the price under both auctions is determined by a drop out conditions assuming low effort, winning entrepreneurs in both cases exert low effort, and the linkage effect again dominates. To summarize,

[6] There is a fourth possibility, a price set as though high effort will be undertaken followed by a low effort choice from the winning entrepreneur in the equity auction. However, this case can be ruled out since it is inconsistent with equilibrium.

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

Finally, we consider the intermediate cases. Here, the trade-off is more complicated and depends on the share of the company, α^*, retained by the winning entrepreneur. The dilution effect is most pronounced when the project quality of the better project is sufficiently low that no effort is undertaken under equity (i.e. $\alpha^* < \frac{1}{\delta p v_1}$) but where the worse project is of sufficiently high quality that in a debt auction the drop-out price reflects the anticipation of high effort (i.e. $v_2 > \frac{1}{\delta p}$). Even in this case, however, the linkage effect in the equity auction can dominate provided that there is a sufficiently large gap between the quality of the best and second-best projects.

A similar case occurs when (1) the price in the debt auction is set in anticipation of high effort (i.e. $v_2 > \frac{1}{\delta p}$); (2) the price in the equity auction is set in anticipation of low effort $\left(\text{i.e., } v_2 < \frac{m}{m\delta-1}\right)$; and (3) the dilution effect is small enough that high effort is still undertaken by the winning entrepreneur in the equity auction (i.e. $\alpha^* \geq \frac{1}{v_1 \delta p}$). Here, the gap in quality between the best and second-best projects can be smaller and still be sufficient for the equity auction to revenue dominate.

Why is the gap condition needed? The reason is that, if the gap between the two project qualities is small, then the additional surplus extracted through the linkage effect is also small since the value of funding the project to the losing entrepreneur is almost the same as the value to the winner. In contrast, once the gap is large, then the linkage effect becomes relevant and, as we show in the proposition below, its effects are sufficiently strong to overcome the adverse effects on price and effort of dilution. Formally,

Proposition 6 *Suppose that $v_2 \geq \frac{1}{\delta p}$:*

1. Suppose $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p \delta}$. If $v_1 - v_2 \geq \Delta$, the equity auction yields greater revenues to the VC than does the debt auction while the reverse is true if $v_1 - v_2 < \Delta$.

2. Suppose $1 - \frac{m}{p(v_2+m)} \leq \frac{v_1 p\delta - 1}{v_1 p \delta}$. If $v_1(1+\delta) - v_2 \geq \Delta$, the equity auction yields greater revenues to the VC than does the debt auction while the reverse is true if $v_1(1+\delta) - v_2 < \Delta$,

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

Taken together, the propositions comparing revenues under the two auction forms reveal a surprising non-monotonicity in the revenue ranking of debt versus equity auctions. When returns to effort are either low or high, equity dominates while for intermediate cases, debt can dominate. Thus, a simple threshold rule for which auction form to choose will never be optimal.

One might worry that the non-monotonicity of revenue rankings depends on binary effort choice. This is not the case. The result that when returns to effort are low, equity auctions dominate while raising returns to effort improves the performance of debt auctions occurs in continuous effort models as well. The result that, for sufficiently high returns to effort, equity auctions once again dominate, depends on whether there is a finite upper bound on the amount of effort that can be exerted. When there is no finite upper bound, the relationship is monotonic—equity is best for low returns, debt for high returns. When there is a finite upper bound, equity auctions again outperform debt auctions since dilution ceases to be an issue once returns are high enough to induce maximal effort.

While the analysis of equilibrium bidding and effort choice above is conducted in the context of two entrepreneurs and a single VC, it may be straightforwardly extended to the case where there are n entrepreneurs and $k < n$ VCs. In that extension, each VC would offer a package of resources sufficient to fund a single entrepreneur and each entrepreneur would demand a single package of resources. Thus, the framework would amount to a unit demand independent private values setting.[7] In such a setting, the uniform price auction is analogous to the English auction. We eschew the detailed analysis here since it adds substantial complications while still producing the same basic trade-off as the case we analyze.

Since the revenue ranking depends on the returns to effort, the underlying gap in project quality, and the form of the auction, it is difficult to test its behavioral validity using field data. Hence, we turn to controlled laboratory experiments where we can both observe and vary project quality and returns to effort and assess whether the entrepreneurs adjust their efforts and bids to account for these differences.

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.

All sessions started with subjects being seated in front of computer terminals 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.

Each session consisted of three 12-round "phases". In each round subjects participated as "entrepreneurs" and bid for a single unit of "financing". During the first and last phase, subject bid with debt while in the second phase they bid with equity. Thus, the sequence of auctions within a session is debt, equity, debt.

[7] See Krishna (2002) for how the basic single unit independent private values auction model may be straightforwardly extended. Inderst and Muller (2004) show how changes in the relative scarcity of VCs compared with entrepreneurs affects surplus allocation between parties.

At the beginning of each round, 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 number from a uniform distribution with a support of 0 to 100, which corresponded to the quality (value) of a project, in points. Each entrepreneur then submitted bids in a computerized process subject to an improvement rule (this mechanism mirrors the one used by large art auction houses as Christie's and Sotheby's). The round 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 choice. While the former is standard, the latter 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.[8] Subjects received a real time report of the current high bid (but not the effort selection) for the auction in which they were participating. Each subject was informed that she was bidding against three other randomly drawn subjects in each round. Since subjects were anonymously rematched with others after each round, concerns about repeated game strategies and signaling were minimized.

The terminal provided a calculator which allowed subjects to compute their earnings given different inputs of winning bids and effort decisions. Finally, at the start of each round subjects were endowed with ten points each, corresponding to the parameter m in the model.

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.[9] Losing bid earned ten points. At the end of each round, subjects' earnings were calculated and displayed on their interface.

At the conclusion of each session participants received a show-up fee of $3 plus a payment that depended on their cumulative point earnings over the course of a session. Points were compensated at an exchange rate of 5 cents per point. On average subjects earned $25.3 for participation in a session lasting around 2 hours.

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 examine whether subjects adjust bid and effort decisions to reflect differences in project quality, the returns to investment, and, most importantly, the auction environment.

[8]Note that this effort cost is only incurred if the bidder wins the auction.

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

When returns to effort are low, the moral hazard problem is immaterial and equity auctions are predicted to 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 are predicted to yield higher expected revenues to the seller. The returns treatment was implemented across subjects so that some sessions were parameterized with low returns to effort while other sessions were parameterized with high returns to effort. The security type treatment was implemented within subjects so that each subject participated in both debt and equity auctions. This within-subjects design provides improved power for detecting revenue and effort differences across auction forms for a given level of returns to effort (see Table 4, below).

One may worry that requiring bidders to simultaneously choose both a bid and an effort conditional on winning is at odds with the theory model, which assumed that effort choices occur *after* the conclusion of the auction. It is easy to show, however, the two mechanisms are *strategically equivalent.* In the theory model, bidders can perfectly anticipate their effort choice at each point in the bidding. Moreover, since values are private, a bidder obtains no new information about the returns to effort from that fact that he or she has won the auction. Thus, the experimental design does not alter the predicted equilibrium effort choices.

One contribution of the study is to model the auction in the lab as a computerized English 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 implementations of the English auction (see, for 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, including competition for venture capital financing, the outcry form of the English auction appears more natural. This mechanism also 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 under sealed bid auctions (see Kagel (1995) for a review of this literature).

We parameterized the experiment such that in the "low returns" sessions the effort value was low enough to make it unprofitable in either the debt or equity auctions to exert effort. "High returns" sessions were parameterized such that the effort value was high enough to make it profitable to exert effort in all debt auctions 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.

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.[10] 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 experimental points). While the revenues are derived for the actual private values drawn by the subjects in the experiment, the revenues predicted in the table can be closely matched using order statistics of a uniform distribution. Given the experiment parameters, the highest private value is expected to be 80 and the second highest private value is expected to be 60. In a debt auction with low returns to effort, the winning bidder would not exert effort and would pay the second highest bid, which is simply 60. When returns to effort are high, the winning bidder would bid up to the reservation value of the second highest bidder which would equal to 118.0 $(= 60 * 2.3 - 20)$. In equity auction, in both the high and low returns, it is not optimal for the winning bidder with a private value of 80 to exert effort if the second highest private value is 60. In that case, the second highest bidder would bid up to $\frac{6}{7}$ $(= 1 - \frac{10}{10+60})$ and the revenue to the seller would be $\frac{6}{7}(80 + 10) = 77$.

- **Normalized Revenues:** Since the valuations of each of the bidders are drawn randomly, there are variations in a seller's revenues that are purely driven by the 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

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

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 is a dummy indicating whether the winning bidder chose to exert effort (coded as "1") or not (coded as "0").

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%

The values represent averages across all auction instances in all sessions and rounds. 'Revenues' measures the average experimental points earned by the auctioneer, 'Normalized Revenues' measures the fraction of theoretical surplus captured by the auctioneer, and 'Effort choices' measures the percentage of instances in which the winning bidder chose to exert effort.

4 Results

4.1 Overview

We start by presenting descriptive statistics from the experiment. These 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.[11] The next two columns correspond to the high return cases under both security types.

[11] Our first four sessions focused on varying the auction form without varying the returns treatment. Subsequently, we added the returns dimension to the experimental design and ran five sessions under each treatment. Since our experimental procedures for low returns were identical to those used in the intial set of sessions, we added these sessions to the analysis as well. This provides more data but produces an unbalanced design.

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

Low (High) returns correspond to sessions in which returns to effort were low (high). Each session consisted of 12 debt auction rounds, followed by 12 equity auctions rounds, followed by 12 debt auction rounds. In each round two separate market instances took place. There were four subjects per market.

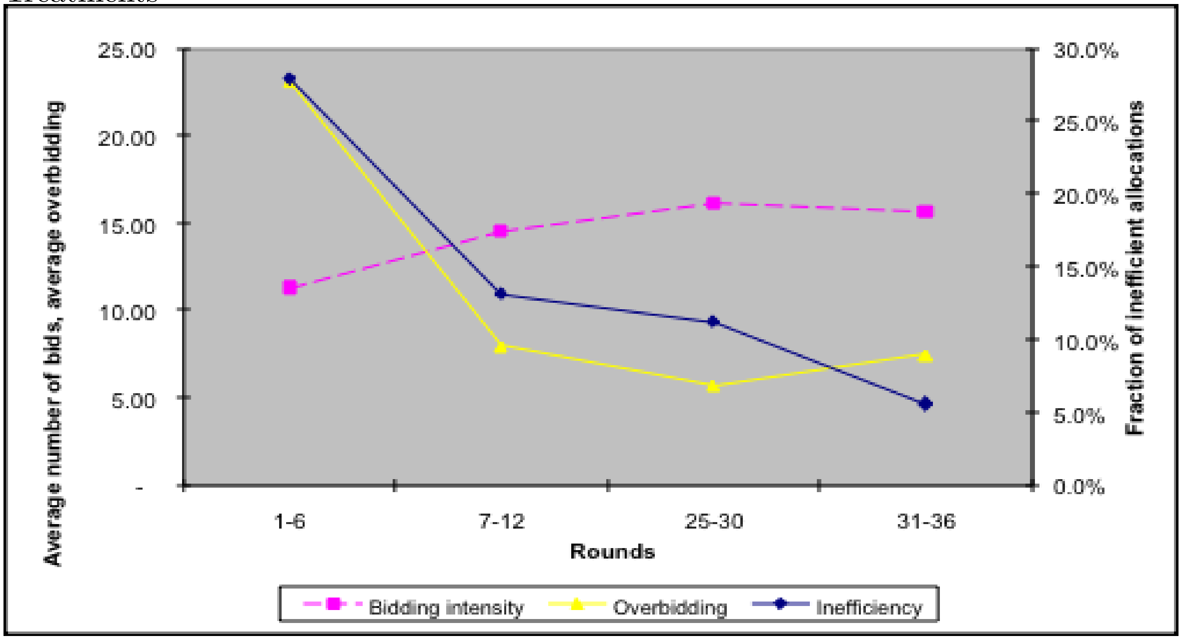
There are roughly twice as many rounds under the Debt columns as there are under the Equity columns.[12] This is because of our ABA design where debt auctions occur both at the beginning and at the end of each experimental session.

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. Since we are interested in equilibrium behavior, we decided to start the sessions with rounds of debt auctions that serve to familiarize 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 (recall that in rounds 13 through 24 we use share auctions). We constructed a number of measures that capture the dynamics of the 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 bidder with the highest 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 treatments, there is a dramatic decrease in inefficiency and overbidding, from the initial rounds (1-6) to the subsequent rounds. Following round 6, there is little change in either inefficiency or overbidding during the course of the experiment. Further, the intensity of bidding seems to be fairly stable across rounds in the both treatments, while there is a downward (upward) trend in the high (low) returns treatment. These results suggest that presentation effects are absent 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 about half way through phase one.

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

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



'Bidding intensity' measures the average number of bids (per market instance) submitted, 'Overbidding' measures the average difference between winning bid and theoretical bid, in experimental points, if the former exceeded the latter, and 'Inefficiency' measures the percentage of market instances in which the winning bidder did not posses the highest project value.

Pooled Results

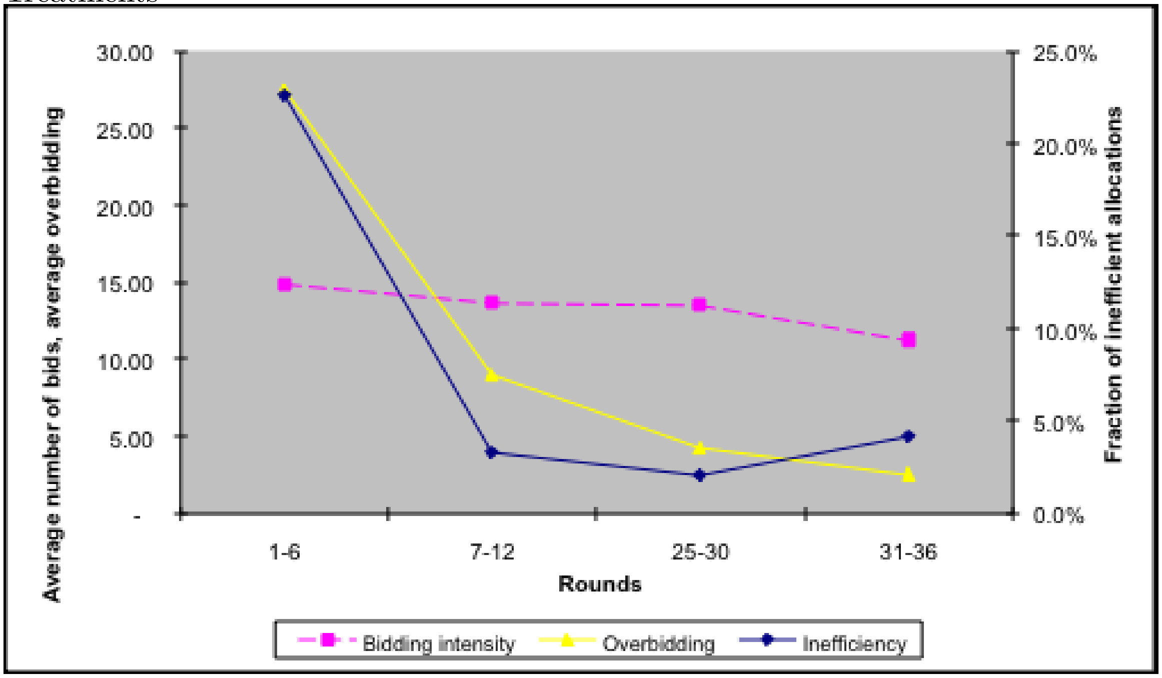
As a first cut, the table below pools all of the sessions under each treatment (excluding rounds 1-12) thus allowing a direct comparison with the theory predictions of Table 1.

As Table 3 shows, the revenue rankings predicted by the theory are 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 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 Revenues and Effort

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

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



'Bidding intensity' measures the average number of bids (per market instance) submitted, 'Overbidding' measures the average difference between winning bid and theoretical bid, in experimental points, if the former exceeded the latter, and 'Inefficiency' measures the percentage of market instances in which the winning bidder did not posses the highest project value.

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 an 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 handling of the data or the particular specification employed.

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,

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%

The values represent averages across all auction instances in all sessions and rounds 13-36. 'Revenues' measures the average experimental points earned by the auctioneer, 'Normalized Revenues' measures the fraction of theoretical surplus captured by the auctioneer, and 'Effort choices' measures the percentage of instances in which the winning bidder chose to "upgrade" the asset.

an extremely conservative view of the data is that each session constitutes a single 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).[13]

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 across auction forms against the one-sided alternative implied by 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% level.

Hypothesis 2 predicts that the revenue ranking should 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

[13] 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 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)

difference in average effort undertaken across auction forms. Formally, we fail to reject the null hypothesis of a zero treatment effect at the 68% level.

Hypothesis 4, however, predicts that in high returns treatments, equity auctions should 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.

4.3 Revenue Ranking - Regression Analysis

In the session level analysis contained in Section 4.2, 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 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.

Specifically, we run the following regression:

$$measure_{st} = \beta\left(auction\ form_t \times agency\ effects_s\right) + \gamma_t X_{st} + \varepsilon_{st} \tag{1}$$

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 round t and zero if a debt auction occurred in that round. 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 include a linear and squared time trends, as well as a measure of within-security-learning, $learning_{st}$, which is equal to the number of previous rounds conducted within the same security type, in round t, session s. For instance, if round t were the kth round 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, one may be concerned that past market interactions 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. Using equation (1), we obtain the following coefficient estimates summarized in Table 5.[14]

To see how the regression coefficients bear on the hypotheses listed above, it is helpful to write out the interaction terms explicitly (setting aside the vector of controls). 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

[14]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.

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.

of zero when returns to effort are low, we obtain that the measures in the four cases are:

- Debt auction, low returns: β_0
- Equity auction, low returns: $\beta_0 + \beta_1$
- Debt auction, high returns: $\beta_0 + \beta_2$
- Equity auction, high returns: $\beta_0 + \beta_1 + \beta_2 + \beta_3$

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

According to Hypothesis 1, when returns to effort are low, equity auctions 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 (10.794 for revenues and .1267 for normalized revenues) and statistically different from zero (at the 5% level). Hypothesis 2 suggests that in the high returns case, debt auctions should yield higher revenues and normalized revenues than do equity auctions, implying that $\beta_1 + \beta_3 < 0$. We find that this sum is negative for both revenues (−23.1) and normalized revenues (−0.119) 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

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	2%	84%	7%	4%	87%	5%
		2	6%	0%	2%	3%	0%	0%
		3-4	1%	0%	0%	0%	0%	0%
	Equity	1	0%	55%	18%	0%	59%	18%
		2	11%	0%	8%	17%	0%	4%
		3-4	6%	1%	0%	0%	2%	0%

Percentages in each cell are expressed as a fraction of total realizations under the given treatment, across sessions, for rounds 13-36.

regression should not be significantly different from zero. Indeed, the results suggest that the value of this coefficient (0.0126) is indistinguishable from zero at conventional significance levels. According to hypothesis 4, effort choices should be significantly different across the auction forms when returns to effort are high. The results strongly support the hypothesis. Our estimates indicate that $\beta_1 + \beta_3$ is negative (-23.1) and significant at 1% confidence level.

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

4.4 Efficiency

Recall that Propositions 2 and 4 suggest that, theoretically, the adverse selection problem is perfectly solved by using either debt or equity auctions, irrespective of the returns to effort. We first examine differences in efficiency at the market level. In Table 6, 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 the theory 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 93% of the time under low returns and 96% of the time under high returns. In contrast, equity auctions are less efficient—the highest quality project is funded only 73% of the time under low returns and 77% of the time under high returns.

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 (1). 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: 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.

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 explanatory power. We performed this analysis and observed that the coefficient on gap was -0.0005; it is 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

Since bidding strategies are monotone, it follows 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 discuss later and discount), 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 a debt auction, conditional on awarding funding to the highest quality project, the highest losing bid comes from the bidder with the second-highest quality project 86% of the time under low returns and 91% 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 53% of the time under low returns and 55% 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

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%	1%	0%	0%	1%	1%
		0	1%	18%	1%	0%	9%	0%
		1	9%	69%	2%	9%	74%	6%
	Equity	-1	0%	14%	0%	2%	8%	0%
		0	1%	40%	1%	8%	36%	2%
		1	4%	38%	2%	7%	34%	3%

Percentages in each cell expressed as a fraction of total realizations under the given treatment, across sessions, for rounds 13-36. The indicators "-1," "0," "1" denote negative, zero, and positive surplus bids, respectively.

compared with the theory prediction can mainly be explained by inefficient sorting.

4.5 Bidding Behavior

An important implication of the theory is 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 final bids yielding payoffs strictly below the outside option for the winning and highest losing bidder respectively. Rows or columns marked "1" correspond to final 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 final 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 is 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 2% of outcomes in a given treatment involve dominance violations by winning bidders. In contrast, there are considerably 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 is consistent with the view that such auctions are 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 80% of the time for debt auctions with low returns and 89% of the time for debt auctions with high returns. This contrasts sharply with equity auctions where winning bidders obtained positive net surplus only 44% of the time under low or 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 9% 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.

Spiteful Bidding

One rationale for the observed departures from weak dominance on the part of losing bidders stem from spiteful bidding (see Morgan and Stieglitz (2002) for an theoretical model of spiteful bidding in debt auctions). Spiteful bidding occurs when losing bidders derive (non-pecuniary) benefits from reducing the payoffs to winning bidders. It seems likely that, with experience, bidders with low valuations soon realize that they have little chance of winning the auction. Furthermore, overbidding on the part of these bidders is also 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. The effects of spiteful incentives on the part of bidders lead to differences across the two auction forms. In an equity auction, a given degree of overbidding produces a more pronounced effect on reducing the surplus of the winner owing to the linkage between the winner's payment and his or her valuation, compared with a debt auction. Thus, a spiteful bidder choosing to overbid by (say) two percentage points in an equity auction will have relatively little effect on his or her own payoff in the event her bluff is "called" (since 2 percent multiplies a relatively low valuation) while having a much larger effect on the payoffs of a bidder with a higher valuation. In contrast, there is no such "magnification effect" in a debt auction. By overbidding by 2 experimental points, a bidder with a low valuation exposes him or herself to exactly as much of a downside (two points) as the loss he or she inflicts on the winning bidder (again two points).

Jump Bidding

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: jump bidding. 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.

4.6 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

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

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

$$ER^{low}_{equity} = \frac{v_1 + m}{v_2 + m} \times v_2 \tag{2}$$

However, we can nest this specification with those of debt auctions by linearizing equation 2 around $v_1 = v_2 = m$ using a first-order Taylor Series approximation. This yields

$$\begin{aligned} ER^{low}_{equity} &\approx \frac{v_1 + m}{v_2 + m} \times v_2 + \frac{m}{m+m}(v_1 - m) + m\frac{m+m}{(m+m)^2}(v_2 - m) \\ &= 0.5v_1 + 0.5v_2 \end{aligned} \tag{3}$$

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.[15] The relevant expected revenues in the two cases are

$$ER^{high}_{equity} = \begin{cases} \frac{v_1+m}{v_2+m} \times v_2 & \text{if} \quad v_1 < \frac{E(v_2+m)}{m\delta} \\ \frac{v_1(1+\delta)+m}{v_2+m} \times v_2 & \text{if} \quad otherwise \end{cases} \tag{4}$$

Linearizing equation (4) yields:

$$ER^{high}_{equity} \approx \begin{cases} 0.5v_1 + 0.5v_2 & \text{if} \quad v_1 < 1.54 \times (10 + v_2) \\ 1.15v_1 + 0.825\, v_2 - 3.25 & \text{if} \quad otherwise \end{cases} \tag{5}$$

A difficulty with equation (5) 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 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:

$$\begin{aligned} Revenues &= \alpha_1 + \alpha_2 D^{high} + \alpha_3 D^{equity} + \alpha_4 D^{equity} D^{high} \\ &+ \beta_1 v_1 + \beta_2 v_1 D^{high} + \beta_3 v_1 D^{equity} + \beta_4 v_1 D^{high} D^{equity} \\ &+ \gamma_1 v_2 + \gamma_2 v_2 D^{high} + \gamma_3 v_2 D^{equity} + \gamma_4 v_2 D^{high} D^{equity} \end{aligned} \tag{6}$$

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

Where D's denote dummy variables taking on the value of 1 in the case denoted by superscript, and 0 otherwise. 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 value goes down when in high returns to effort condition. Thus, the linkage principal is predicted to weaken as result of the moral hazard problem.

The coefficient estimates arising when we estimate equation 6 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

(1) Treatment	(2) Parameter	(3) Hypothesis	(4) Estimate	(5) *s.e.*
{Debt, Low}	α_1	0	-1.7408	1.5695
	β_1	0	.1972**	.05579
	γ_1	1	.7790**	.05866
{Debt, High}	$\alpha_1 + \alpha_2$	-20	-19.8032	10.7583
	$\beta_1 + \beta_2$	0	.1933	.11256
	$\gamma_1 + \gamma_2$	2.3	2.0150*	.13771
{Equity, Low}	$\alpha_1 + \alpha_3$	0	-1.7408	1.5695
	$\beta_1 + \beta_3$	0.5	.8059**	.03777
	$\gamma_1 + \gamma_3$	0.5	.2630**	.03804
{Equity, High}	$\alpha_1 + \alpha_2 + \alpha_3 + a_4$	-3.25	-27.6170	33.0955
	$\beta_1 + \beta_2 + \beta_3 + \beta_4$	1.15	1.5790	.58311
	$\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4$	0.825	.3335	.93058
$N = 448, R^2 = 0.8530$				

Statistical significance resulting from testing the equality between column (3) and column (4) is denoted by * for 5% level and by ** for 1% level. Only rounds 13-36 were included in the estimation.

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. In short, behaviorally, there appears to be a *linkage effect* in debt auctions—even though there is no theoretical reason to expect linkage.

What could be responsible for this result? 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 (6) 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 where $f(\cdot)$ 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. Taken together with the results of the structural estimated from the debt auctions, this suggests that linkage in practice for both types of auctions is greater than theory predicts.

In the equity auctions 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 but highlights that spiteful overbidding (in the case of debt auctions) and cognitive complexity (in the case of equity auctions) lead to level predictions at odds with the theory. One may, however, worry that the coefficient estimates are driven by the linearization specification. An alternative (but non-nested) specification is to perform log linearization to obtain an estimating equation. In the appendix, we perform this alternative procedure and obtain qualitatively similar results.

5 Conclusions

We have shown that in imperfectly competitive settings where both hidden information and hidden actions affect the returns to the seller of some scarce resource, the form of the contracts over which competition occurs can have 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. The net effect is 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.

While the model describes the linkage-dilution tradeoff in an intuitive fashion, of much greater importance is whether the tradeoff is behaviorally relevant. Do bidders adjust their effort and bid choices to account for differences across debt versus equity auctions? To answer these questions, we 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 broadly 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. At the same time, we found other elements, such as spiteful bidding and inefficient sorting, that arose in the experiments but were not predicted by the theory.

While capturing a basic trade-off between the linkage and dilution effects, the simple model used to derive the theory and motivate the experiments abstracts away from many important features present in the field. For instance, the VC is often an active participant in the management of the firm and hence effort on the VC side is also important. Specifying payoff and performance is also considerably more complex than the simple model where the financial outcome of the project is publicly revealed at the conclusion of the auction. For all of these reasons, actual contracts between VCs and entrepreneurs are considerably more complex than mere debt or equity contracts. Indeed, most real-world contracts are hybrid securities—they blend the beneficial incentives of debt contracts for projects whose returns are modest with the superior linkage components of equity contracts for projects whose returns are more substantial.

Nonetheless, many of the basic features of our model are consistent with aspects of contracts in practice. Specifically, Kaplan and Stromberg (2003) report coefficient estimates associated with the characteristics of funded projects as they relate to the entrepreneurs' share of residual cash flows (see Table 4 of their paper). First, serial entrepreneur's enjoy greater residual cash flows than first-time entrepreneurs. In terms of our model, one might imagine that serial entrepreneurs are likely to enjoy superior returns to effort; thus, debt contracts are preferred. Second, higher volatility industries tend to have more equity-like contracts. To the extent that one believes that returns to individual effort are likely to be lower in high volatility industries (perhaps they are overwhelmed by industry level demand and capacity fluctuations), this again is consistent with the model. Finally, more debt-like contracts are associated with industries whose R&D to sales ratio is higher. If one imagines that the creativity of the entrepreneur is more important in these industries then avoiding the dilution effect becomes more important, which is again consistent with the model. In short, while the model does a poor job of explaining the full structure of observed contracts, it proves useful at predicting the "tilt" (debt versus equity) of contracts observed in the field.

References

[1] Asparouhova, E. N. (2006): "Competition in Lending: Theory and Experiments," Review of Finance, 10:189-219.

[2] Bulow, J. and Klemperer, P. (1996): "Auctions versus Negotiations," American Economic Review, Vol. 86(1), pp. 180-194.

[3] Bulow, J., Huang, M., and Klemperer, P. (1998): "Toeholds and Takeovers," Journal of Political Economy, Vol. 107, pp. 427–454.

[4] Casamatta, C. (2003): "Financing and Advising: Optimal Financial Contracts with Venture Capitalists," Journal of Finance, vol. 58, pp. 2059-2085.

[5] Chemmanur, T. J. and Z. Chen (2006): "Venture Capitalists versus Angels: The Dynamics of Private Firm Financing Contracts," unpublished working paper.

[6] Cochrane, J. (2005): "The Risk and Return of Venture Capital," Journal of Financial Economics, Vol. 75, pp. 3-52.

[7] Coppinger, V., Smith, V., and Titus, J. (1980): "Incentives and Behavior in English, Dutch and Sealed-Bid Auctions," Economic Inquiry, Vol. 18(1), pp. 1-22.

[8] Cremer, J. (1985): "Auctions with Contingent Payments: Comment," The American Economic Review, Vol. 75(4), p. 746.

[9] DeMarzo P., Kremer, I., and A. Skrzypacz (2005): "Bidding with Securities: Auctions and Security Design," American Economic Review, Vol. 95, pp. 936-959.

[10] Fehr, E., and A. Falk (2002): "Psychological Foundations of Incentives," European Economic Review, Vol. 46, pp. 687-724.

[11] Fehr, E., and S. Gachter (2002): "Altruistic punishment in humans," Nature, Vol. 415, pp. 137-140.

[12] Goswami, G., M. F. Grace, and M. J. Rebello (2008): "Experimental Evidence on Coverage Choices and Contract Prices in the Market for Corporate Insurance," Experimental Economics, Vol. 11, pp. 67-95.

[13] Hansen, R. (1985): "Auctions with Contingent Payments," American Economic Review, Vol. 75(4), pp. 862-865.

[14] Hart, O. (2001): "Financial Contracting," Journal of Economic Literature, Vol. 39(4), pp. 1079-1100.

[15] Hellmann, T. (2006): "IPOs, Acquisitions and the Use of Convertible Securities in Venture Capital," Journal of Financial Economics, 81(3), pp. 649-679.

[16] Inderst, R., and H. M. Muller (2004): "The Effect of Capital Market Characteristics on the Value of Start-Up Firms," Journal of Financial Economics, Vol. 72, pp. 319-356.

[17] Krishna, V. (2002): "Auction Theory," Academic Press.

[18] Jensen, M. and Meckling, W. (1976): "Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure," Journal of Financial Economics, Vol. 3(4), pp. 305-360.

[19] Kagel, J. (1995): "Auctions: A Survey of Experimental Research," in Handbook of Experimental Economics (J. Kagel and A. Roth, eds.), Princeton University Press.

[20] Kagel, J., Harstad, R., and Levin, D. (1987): "Information Impact and Allocation Rules in Auctions with Affiliated Private Values: A Laboratory Study," Econometrica, Vol. 55(6), pp. 1275-1304.

[21] Kaplan, S. and Schoar, A. (2005): "Private Equity Performance: Returns, Persistence and Capital Flows," Journal of Finance, Vol. 60(4), 1791–1823.

[22] Kaplan, S. and Stromberg, P. (2003): "Financial Contracting Theory Meets the Real World: An Empirical Analysis of Venture Capital Contracts," Review of Economic Studies, Vol. 70(2), pp. 281-315.

[23] Laffont, J. and Tirole, J. (1987): "Auctioning Incentive Contracts," Journal of Political Economy, Vol. 95(5), pp. 921-937.

[24] Leland, H. and Pyle, D. (1977): "Informational Asymmetrics, Financial Structure, and Financial Intermediation," The Journal of Finance, Vol. XXXII(2), pp. 371-387.

[25] McCabe K., Rassenti, S., and Smith, V. (1990): "Auction Institutional Design: Theory and Behavior of Simultaneous Multiple-Unit Generalizations of the Dutch and English Auctions," The American Economic Review, Vol. 80(5), pp. 1276-1283.

[26] Maskin, E. and Riley, J. (1984): "Optimal Auctions with Risk Averse Buyers," Econometrica, Vol. 52(6), pp. 1473-1518.

[27] McAfee, R.P. and J. McMillan (1987): "Competition for Agency Contracts," RAND Journal of Economics, Vol. 18, No. 2, pp. 296-307.

[28] Morgan, J., K. Steiglitz, and G. Reis (2003): "The Spite Motive and Equilibrium Behavior in Auctions," Contributions to Economic Analysis & Policy: 2003, Vol. 2(1), Article 5.

[29] Myers, S. and Majluf, N. (1984): "Corporate Financing and Investment Decisions When Firms Have Information That Investors Do Not Have," Journal of Financial Economics, Vol. 13(2), pp. 187-221.

[30] Repullo R., and J. Suarez (2004): "Venture Capital Finance: A Security Design Approach," Review of Finance, Vol. 8, pp. 75-108.

[31] Riley, J. and Samuelson, W. (1981): "Optimal Auctions," American Economic Review, Vol. 71(3), pp. 381-392.

[32] Rothkopf , M. and Engelbrecht-Wiggans, R. (1992): "Innovative Approaches to Competitive Mineral Leasing," Resources and Energy, Vol. 14(3), pp. 233-248.

[33] Samuelson W. (1985): "Auctions with Contingent Payments: Comment," American Economic Review, Vol. 75(4), pp. 740-745.

[34] Schmidt, K. M. (2003): "Convertible Securities and Venture Capital Fnance," Journal of Finance, Vol. 58, pp. 1139–1166.

A Appendix

A.1 Proofs of Propositions

Proof of Lemma 1:

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

$$\alpha\geq\frac{1}{v_i p\delta}. \blacksquare$$

Proof of Proposition 1:

Let α_i^0 denote the share level at which the entrepreneur is indifferent between remaining in the auction and dropping out conditional on exerting no effort. That is,

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

Likewise, let α_i^1 denote the share level at which the entrepreneur is indifferent between remaining in the auction and dropping out conditional on exerting effort. That is,

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

From Lemma 1, it is optimal to exert effort if and only if $\alpha\geq\frac{1}{\delta p v_i}$. Substituting for α_i^1,this becomes

$$\frac{m+1}{p\left(v_i\left(1+\delta\right)+m\right)}\geq\frac{1}{\delta p v_i}$$

Simplifying yields the condition

$$v_i\geq\frac{m}{m\delta-1}$$

Weak dominance follows from standard arguments—the entrepreneur can do no better than to remain in the auction when her payoff (relative to the outside option) is positive and to exit when her payoff turns negative. Hence, it is a weakly dominant strategy to drop out at price $1-\alpha_i^0$ if $\left(m\delta-1\right)v_i-m<0$ and drop out at price $1-\alpha_i^1$ if $\left(m\delta-1\right)v_i-m\geq 0$. $\blacksquare$

Proof of Proposition 2:

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. ■

Proof of Proposition 3

If $v_i \geq \frac{1}{\delta p}$,an entrepreneur should undertake effort if she wins. Furthermore, from arguments identical to Proposition 1, it is a weakly dominant strategy for the entrepreneur to remain in the auction so long as her payoffs exceed those of her outside option and to drop out thereafter. The point at which the inside option and outside option are equal is the value of D_i solving

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

which yields the expression in the proposition. An identical argument yields the drop out bid when $v_i < \frac{1}{\delta p}$. ■

Proof of Proposition 4:

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 increasing 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 increasing 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, $D_1 > D_2$. Hence entrepreneur 1's project is funded. ■

Proof of Proposition 5:

When $\delta p v_2 < 1$, then revenues in the debt auction are

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

whilst revenues in the equity auction are

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

where the inequality follows from the fact that the revenues in the equity auction are at least as large as those obtained when the winning entrepreneur exerts no effort.

Differencing these expressions one obtains

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

When $(m\delta - 1)\,v_2 - m \geq 0$, revenues in the equity auction are

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

whilst revenues in the debt auction are

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

Differencing these expressions yields

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

since $v_1 > v_2$. ■

Proof of Proposition 6:

Suppose that $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p\delta}$.This is equivalent to $\frac{m}{p(v_2+m)} < \frac{1}{v_1 p\delta}$. Since $\delta p v_2 \geq 1$,the expected revenues in the debt auction are

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

When $1 - \frac{m}{p(v_2+m)} > \frac{v_1 p\delta - 1}{v_1 p\delta}$,then $\alpha^* p\delta v_1 < 1$ and hence the revenues in the equity auction are

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

Differencing these expressions yields

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

First, consider the pair of values, $v_1$and v_2 where the revenue expressions are equal. That is,

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

Letting $\Delta = v_1 - v_2$,we can rewrite this expression as

$$\frac{\Delta}{v_2 + m}\,(pv_2 - (1-p)\,m) = pv_2\,(1+\delta) - (1-p)\,m - 1 - pv_2 + (1-p)\,m \tag{7}$$

Simplifying and solving for Δ yields

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

Finally, since the left-hand side of the equation (7) is increasing in Δ,it then follows that if $v_1 - v_2 \geq \Delta$, the equity auction produces higher expected revenues than the debt auction.

Next when $1 - \frac{m}{p(v_2+m)} \leq \frac{v_1 p\delta - 1}{v_1 p\delta}$,then $\alpha^* p\delta v_1 \geq 1$ and

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

Differencing these two expressions

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

And using a virtually identical argument it can be shown that $ER_{equity} \geq ER_{debt}$ if and only if $v_1\,(1+\delta) - v_2 \geq \Delta$. ■

A.2 Structural Estimation

A.2.1 Linearization

In developing the structural model, we claim that

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

To see this, we use a first-order Taylor series approximation around $v_1 = v_2 = m$.This yields:

$$ER^{high}_{equity}(effort) = \frac{v_1(1+\delta)+m}{v_2+m}v_2 \approx$$
$$\frac{v_1(1+\delta)+m}{v_2+m}v_2 + \frac{\partial}{\partial v_1}\left(\frac{v_1(1+\delta)+m}{v_2+m}v_2\right)(v_1-m) + \frac{\partial}{\partial v_2}\left(\frac{v_1(1+\delta)+m}{v_2+m}v_2\right)(v_2-m) =$$
$$\frac{v_1(1+\delta)+m}{v_2+m}v_2 + v_2\frac{\delta+1}{m+v_2}(v_1-m) + \frac{m}{(m+v_2)^2}(m+v_1+\delta v_1)(v_2-m) =$$
$$\frac{m(1+\delta)+m}{m+m}m + m\frac{\delta+1}{m+m}(v_1-m) + \frac{m}{(m+m)^2}(m+m+\delta m)(v_2-m) =$$
$$1.15v_1 + 0.825\,v_2 - 3.25$$

A.2.2 Log linearization

Next, we consider an alternative formulation of the structural approximation that uses log-linearization, instead of Taylor series approximation.

In the case of debt auctions, no linearization is needed and we obtain

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

where v_2 is the second highest project quality realization.

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

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

Taking logs of both sides we obtain

$$\ln\left(ER^{low}_{equity}\right) = \ln(v_1+m) - \ln(v_2+m) + \ln(v_2)$$

In the case of an equity auction under the high returns treatment, we need to divide the analysis into two sub-cases

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

Once again taking logs of both sides we obtain

$$\ln\left(ER^{high}_{equity}\right) \approx \begin{cases} \ln(v_1+m) - \ln(v_2+m) + \ln(v_2) & \text{if } v_1 < 1.54 \times (10+v_2) \\ \ln(v_1(1+\delta)+m) - \ln(v_2+m) + \ln(v_2) & \text{if } otherwise \end{cases}$$

Since the resulting behavior in the equity auction under high returns to effort is identical to low returns to effort when the difference between the highest and the second highest quality project is sufficiently small (i.e., $v_1 < 1.54 \times (10 + v_2)$), we focus on this case.

Even with the restriction that $v_1 < 1.54 \times (10 + v_2)$,it is apparent that we cannot nest the four treatments in a single regression specification using log-linearization. Therefore, we run four separate regressions and examine the restrictions imposed by the theory:

- Debt auction under low returns to effort: $ER = a + b_1 v_1 + b_2 v_2$. We test whether $a = 0$, $b_1 = 0$, $b_2 = 1$.
- Debt auction under high returns to effort: $ER = a + b_1 v_1 + b_2 v_2$. We test whether $a = -20$, $b_1 = 0$, $b_2 = 2.3$.
- Equity auction under low returns to effort: $\ln(ER) = a + b_1 \ln(v_1 + 10) + b_2 \ln\left(\frac{v_2}{v_2+10}\right)$. We test whether $a = 0$, $b_1 = 1$, $b_2 = 1$.
- Equity auction under high returns to effort: $\ln(ER) = a + b_1 \ln(v_1(1+\delta) + 10) + b_2 \ln\left(\frac{v_2}{v_2+10}\right)$. We test whether $a = 0$, $b_1 = 1$, $b_2 = 1$.

The results contained in Table 10 under log-linearization are qualitatively similar to those reported in Table 9 using a Taylor-series approximation. Thus, the results of the structural estimation are not strongly influenced by the approximation procedure.

Table 10: Structural Estimation Results of Revenues Using Log-Linearization

Treatment	Parameter	Hypothesis	Estimate	*s.e.*	R^2	N
{Debt, Low}	a	0	$-.01882$	1.690	0.820	197
	b_1	0	.2029**	.05179		
	b_2	1	.7629**	.05685		
{Debt, High}	a	-20	-18.9079	11.0457	0.818	90
	b_1	0	.1993	.1167		
	b_2	2.3	2.010	.1448		
{Equity, Low}	a	0	$-.3313$	.1948	0.896	157
	b_1	1	1.0670	.0424		
	b_2	1	.8579*	.0673		
{Equity, High}	a	0	-3.668*	1.7249	0.440	19
	b_1	1	1.5619	.3156		
	b_2	1	$-.1639$*	.5325		

Statistical significance resulting from testing the equility between column (3) and column (4) is denoted by * for 5% level and by ** for 1% level. Only rounds 13-36 were included in the estimation.