The Effect of Leverage on Bidding Behavior: Theory and Evidence from the FCC Auctions

Matthew J. Clayton
Rutgers University

S. Abraham Ravid
Rutgers University

This is an exploration of how bidding behavior of firms in various auctions is affected by their capital structure. The theoretical model considers a first-price sealed bid and an English auction. We find that as debt levels increase, firms tend to reduce their bids. The lower bids give the competition incentives to reduce their bids as well. These results are investigated empirically using data from the 1994–1995 FCC spectrum auctions. Consistent with the theoretical model, higher debt levels of the bidding firm and of the competition tend to lead to lower bids. Additional determinants of bidding behavior in these auctions are also analyzed.

A growing body of literature examines the interactions of production and financial decisions. There have been two theoretical approaches to the issue. One approach seeks to find the link between production and financial decisions in the joint determination of bankruptcy and non-tax-paying states. The alternative approach is to view leverage as a strategic variable, affecting firm production choices.[1]

Our subject is a particular type of production interaction: the bidding behavior of firms in auctions. Auctions provide a unique environment for the examination of strategic interactions, because bidding is clearly a strategic decision with competing firms in mind.

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[1] Hite (1977), DeAngelo and Masulis (1980), Dotan and Ravid (1985), and Dammon and Senbet (1988) demonstrate that investment and financing decisions jointly determine the expected tax liability and the expected bankruptcy cost paid by firms. Jensen and Meckling (1976), Myers (1977), and later Brander and Lewis (1986), Maksimovic (1988), Showalter (1995), Dasgupta and Titman (1998), Chemmanur and Fulghieri (1999), Clayton (1999), and Safieddine and Titman (1999) suggest that debt can affect the quantity produced and the prices in oligopoly settings and that it can also impact decisions such as entry, takeovers, and investments. While the strategic approach seems to be supported by some empirical evidence [see Chevalier (1995a, b) and Phillips (1995)], there may be other explanations for these empirical findings [see Ravid (1999)].

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We first examine how leverage should affect optimal bidding behavior in two common types of auctions, a first-price sealed bid auction and an English auction, both with private values. We assume that firms submit bids to maximize equity value and show that in both cases, increasing leverage leads to, at least weakly, lower bids.[2] These two common auction designs broadly resemble the recent Federal Communication Commission (FCC) spectrum auctions, which we use to test our ideas.

Bids in one of the largest FCC spectrum auctions are collected and correlated with firm-specific and region-specific variables to determine which variables best explain the observed bidding behavior. We find that, as theory predicts, leverage tends to reduce firms' highest bids. We also identify several other important determinants of the bidding behavior.

The remainder of the article is organized as follows. Section 1 discusses auction theory and leverage. The equilibrium-bidding behavior in the first-price sealed bid auction is determined. In addition, the upper bound on the equilibrium bid in the English auction is determined. Section 2 presents the data and provides the empirical results from the FCC spectrum auction. Section 3 concludes.

1. Auction Theory

Auction design is important in determining the optimal strategies of bidders and the revenue to sellers. Different types of auctions may generate different strategies and yield different revenues. While real-life auctions usually do not conform precisely to any given model, a major focus of the literature has been a comparison of various auction structures in terms of strategies and revenues, and the derivation of "revenue-equivalence" theorems.

Vickrey (1961), under simplifying assumptions, shows that the open "English" and the first-price sealed bid auctions generate equal expected revenue. Two important assumptions in Vickrey's work are that each valuation is an independent draw from an identical uniform distribution, and that all players are risk neutral. Myerson (1981) and Riley and Samuelson (1981) extend Vickrey's results and demonstrate that, under less restrictive assumptions, several alternative auctions generate equivalent expected revenue.

The revenue equivalence theorem asserts that an open "English" auction, a first-price sealed bid auction, a second-price sealed bid auction, and a descending Dutch auction generate the same expected revenue. The assumption of risk neutrality is maintained. Valuations must be independent draws from an identical distribution, but the distribution need not be uniform. The importance of the theorem for sellers is that it asserts that the expected revenue is the same under various auction mechanisms.

[2] We abstract from agency costs caused by conflicts between the manager and shareholder.

Holt (1980), Riley and Samuelson (1981), Milgrom and Weber (1982), and Maskin and Riley (1984) demonstrate that under various assumptions revenue equivalence fails. This implies that, in realistic settings, auction design is likely to be relevant. Che and Gale (1998) show that when bidders face financial constraints, bidding strategies are different from strategies in the absence of constraints. In particular, revenue equivalence fails, and first-price auctions yield higher expected revenues and a more efficient allocation than second-price auctions. When there are financial constraints, willingness to pay and ability to pay are different. Financial constraints are modeled through an increasing marginal cost of expenditure. In our setting, firms are not financially constrained as in Che and Gale, but risky debt can also cause revenue equivalence to fail.

In a model of takeovers, Chowdhry and Nanda (1993) analyze the role of debt as a commitment device for high bids. They assume that shareholders may issue new debt with the same priority as outstanding debt to finance takeover bids, thereby expropriating current debt holders. This creates essentially a free pool of cash, which can finance a bid above intrinsic value. Such a bid may serve to deter competing bidders for a takeover target in a setting similar to that of Fishman (1988).

We assume that debt-holder value cannot be usurped through the issue of new debt with the same priority. In our model, companies can decide only whether they wish to bid: they do not have a two-stage decision process (should they acquire information, and then should they bid) as in Fishman (1988) and in Chowdhry and Nanda (1993). Therefore in our model there are no benefits to artificially high bids, which may become very costly.

The FCC auctions, which we discuss later on, were designed by game theorists, who took into consideration many of the elements we have just mentioned and much more. They developed an innovative auction form, called a *simultaneous ascending auction*. Several items are put up for sale simultaneously through a repeated sealed bid structure. In each round, participants submit sealed bids on one or more of the items. If any item receives a new high bid, the auction proceeds to the next round. When no new high bids are submitted, the auction ends, and the items are sold to the highest bidder at the price he bid. The FCC imposes a multitude of complex rules from dynamic eligibility requirements and the ability to withdraw bids to the possibility of a reserve price.

McMillan, Rothschild, and Wilson (1997:429) characterize the FCC auction process as "far more complicated than any model yet, or ever likely to be, written down." McAfee and McMillan (1996:171–172) concur:

> The spectrum sale is more complicated than anything in auction theory. No theorem exists—or can be expected to develop—that specifies the optimal auction form.
>
> A lesson from this experience of theorists in policymaking is that the real value of the theory is in developing intuition. The role of theory, in any

> policy application, is to show how people behave in various circumstances, and to identify the tradeoffs involved in altering those circumstances. What theorists found to be the most useful in designing the auction and advising the bidders was not complicated models that try to capture a lot of reality at the cost of relying on special functional forms. Such theorizing fails to develop intuition, as it confounds the effects of functional forms with the essential elements of the model. Instead, a focused model that isolates a particular effect and assumes few or no special functional forms is more helpful in building understanding.

In a similar vein, Milgrom (2000) proves several results regarding various aspects of simultaneous ascending auctions under some restrictive assumptions. His analysis demonstrates the effectiveness of game theory models in designing and studying proposed rules of complex auctions in simplified environments. However, he also concludes, that while "theoretical analyses have proved their worth in the practical business of auction design. . . . It is equally clear that designing real auctions raises important practical questions for which current theory offers no answers." [For some other aspects of these auctions see, for example, Ausubel et al. (1997) and Cramton and Schwartz (1999); for a general discussion of the applicability of modeling to real-life auctions see Rothkopf and Harstad (1994)].

While we do not model the FCC auctions in every detail, we consider two basic auction models that resemble the FCC auctions and discuss how leverage can affect bidding in these models. The FCC's *simultaneous ascending auction* includes design elements from both first-price sealed bid auctions and English auctions. In a first-price sealed bid auction, bidders are required to submit sealed bids. Upon completion of the auction, the firm with the highest bid wins and pays its bid. However, the structure of rounds is similar to an English auction. After every round bids are announced, and all firms are allowed to submit new bids.

We examine how debt affects bidding behavior in both the standard first-price sealed bid setting and the standard English auction setting. We find that the effects of leverage in the two types of auctions are similar, providing qualitatively similar empirical predictions.

1.1 The general setting

For simplicity, we assume one seller, and n bidding firms. We also assume that all players are risk neutral and that firms bid to maximize their equity value. The value of the object sold may be different for each bidder, but each bidder knows its own valuation. This is the *private value* assumption, which is one of two standard auction settings.

The alternative assumption is *common value*. In the common value framework, the value of the object is assumed to be the same for all bidders, but this value is unknown. Bidders may receive signals regarding this unknown value. Several sources indicate that common value elements were less important for the FCC auctions [see Salant (1997)], so we present only a private value analysis.[3]

The value to firm i of acquiring the good, v_i, is distributed with a known probability distribution F_i. The value realization of each firm is assumed to be an independent draw from the distribution. Prior to bidding, each firm knows its own value, but only the distributions of the competing firms' values are known. Firm i has debt outstanding with face value B_i that must be paid before shareholders receive a payoff. The debt level of each firm is common knowledge. Each firm is assumed to have cash on hand, c_i that it cannot pay as a dividend prior to repayment of the outstanding debt. If a firm cannot pay debt holders in full, the shareholders' payoff is zero.

We assume throughout that the debt of each firm is risky. For simplicity, this risk is created through the assumption that $B_i > c_i$. This means that if a firm does not win the auction it will default. As we will show, the degree of the debt overhang is a key determinant of bidding behavior. We define the net debt overhang of firm i as $D_i = B_i - c_i$, and we refer to D_i as "debt" or "leverage" throughout.

Alternatively we could assume that the underlying assets have a random value, and with some positive probability the total value of these assets will be less than the amount of debt outstanding. This assumption would produce the same basic result (more risky debt leads to lower bids), but the effects would be mitigated. That is, if the firm knows it will not be bankrupt, it will bid as if D_i is zero. If the firm knows it will be bankrupt (if it loses the auction), it will behave according to the predictions of our model (lower bids if leverage is higher). If there exists a probability distribution over possible asset values, so that the firm may or may not be bankrupt as a result of the auction, the optimal bid would take into account both eventualities. The observed bid should be between the two bids, and thus we would expect it to be decreasing in D_i as well.[4]

This more complicated model does not alter the basic insight: firms that bid to maximize equity value consider profits only conditional on remaining solvent. Thus we proceed under the simpler assumption that a firm that loses the auction will default.

In each auction, firms compete by following a bidding procedure. The strategy of firm i will be a bid, $b_i(.)$, which is a function of the firm's own value, v_i, the firm's own debt D_i, the competing firms' debt D_j $(j \neq i)$, and

[3] We thank a referee for bringing this to our attention. An analysis of common value auction with leverage is available from the authors.

[4] This assumes the firm knows the value of the object, v_i, with certainty. For a discussion of random object value, see Section 1.4.

the distribution of the competing firms' values, $F_j(v_j)$ $(j \neq i)$. The winner receives the good for a payment equal to its bid.[5]

We assume throughout that firm i wins the auction. We also assume that the winner does not default on the auction payment. To ensure no default, the value of the object or good along with the cash on hand must be sufficient to make the payment, that is, $b_i < v_i + c_i$. In essence, this means that a firm will not default on its payment, although it can finance some of the payment or have a forward agreement to sell the proceeds if $b_i > c_i$.[6] Firm i receives profits of $v_i - b_i$, and all other firms receive zero profits from the auction. Firm i must pay its debt, D_i, and its shareholders receive any residual profits. Firm i's shareholders receive $\max\{v_i - b_i - D_i, 0\}$. Since $D_j > 0$, the shareholders of any other firm j $(j \neq i)$ receive nothing.[7]

1.2 First-price sealed bid auction

In a first-price sealed bid auction, firms submit their bids to the seller simultaneously. If multiple firms submit equal bids, the winner is determined randomly, and each of the high-bidding firms has an equal chance of winning. The winning firm receives the value v_i, and is left with $\max\{v_i - b_i - D_i, 0\}$ to distribute to its shareholders. All other firms lose the auction and receive no additional payoffs.

A strategy for firm i is a bid function $b_i(.)$ based on its own realized value, v_i, the debt levels of all the firms, D_i, and its belief of the distribution of the competing firms' values and bid functions. A Nash equilibrium is a bid function for each bidder, in which each firm maximizes the expected payoff to shareholders, given the bid functions of the competing firms. The bid functions $b_i(.)$ are equilibrium bid functions if, for all i,

$$b_i \in \arg\max_{b} [\max(v_i - b_i - D_i, 0)] \Pr\{b_i > b_{-i}(.)\}.$$

The intuition of this expression is straightforward: A bid function is optimal if the expected payoff from winning is maximized (when the firm loses, the payoff is zero).

A firm will not bid above its valuation because if it does and wins, it will generate negative profits. If a firm bids above its valuation in a first-price auction, the shareholders are guaranteed a zero payoff. Moreover, if

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[5] In general, the payment in an auction can be a function of all bids submitted. For example, in a second-price sealed bid auction, the highest bidder wins the auction, but makes a payment equal to the second-highest bid. We consider only auctions in which the high bid wins and pays that bid, as in the FCC auctions.

[6] For example, if the object value is 100, the bid is 60, and cash on hand is 50, the firm can have a credit line for the extra 10 to pay for the good. Alternatively, it can have a forward contract to resell the object, should it win, with a guarantee of payment.

[7] It is important that the object auctioned is valuable enough to pull the firm out of default. This arises from the simplifying assumption that the firm is in default unless it takes the project. More generally, the model applies to settings where there is only a probability that a failed bidder will default.

the firm submits a bid greater than or equal to its valuation of the good minus its debt ($b_i \geq v_i - D_i$), and if it wins the auction, there will be no residual profit left for shareholders. In fact, if $b_i > v_i - D_i$, then upon winning the auction the firm will not have enough money to completely pay off the outstanding debt. For this reason, a firm that chooses a bid to maximize the expected payoff to shareholders will bid $b_i < v_i - D_i$. As the firm reduces its bid from $b_i = v_i - D_i$, the probability of winning the auction decreases, but the payoff that shareholders receive conditional on winning increases. The firm will decrease its bid below $v_i - D_i$, trading off the two effects until the expected payoff to shareholders is maximized, given its value realization and the competitors' bidding strategies.

For each firm, define a random variable $w_i = v_i - D_i$, and the relation

$$\arg\max_b[(w_i - b_i)\Pr\{b_i > b_{-i}(.)\}] \subset \arg\max_b[\max(w_i - b_i, 0)\Pr\{b_i > b_{-i}(.)\}]$$

The relation indicates that any bid that maximizes the shareholders' expected payoff if the firm wins and the shareholders do not have limited liability also maximizes the shareholders' expected payoff under limited liability.[8]

If we assume the values, w_i, are independent draws from an identical distribution, bids as follows represent an equilibrium [see Milgrom (1989)]:

$$b_i^* = w_i - \frac{\int_{\underline{w}}^{w_i} [F(\xi)]^{n-1}\, d\xi}{[F(w_i)]^{n-1}}, \tag{1}$$

where F is the cumulative distribution function of w. This will be true for symmetric bidders, that is, if all values are independent draws from the same distribution, and all firms have the same amount of debt, that is, for all i, $D_i = D$. From the relation and Equation (1), bids as follows represent an equilibrium:

$$b_i^* = v_i - D - \frac{\int_{\underline{v}}^{v_i} [G(\zeta)]^{n-1}\, d\zeta}{[G(v_i)]^{n-1}}, \tag{2}$$

where G is the cumulative distribution function of v.

Proposition 1. *The Nash equilibrium bids, b_i, are decreasing in D.*

Proof. Follows immediately from the first derivative of Equation (2).

Proposition 2. *The expected high bid, and thus the expected payment to the seller, is decreasing in D.*

Proof. Result follows from Proposition 1.

Proposition 3. *Each firm's expected profits increase in D.*

Proof. Result follows from Proposition 1.

[8] We thank a referee for pointing out this result. This relation allows us to simplify the exposition of the symmetric private value case.

Risky debt affects bidding strategies. As the amount of debt, D, increases, the bids of all firms decrease. This reduces the expected revenue to the seller. It also increases the expected profits and the total value of the bidding firms.

We have thus demonstrated that as all bidders increase their debt levels they will bid less aggressively in a first-price sealed bid auction. In other words, higher leverage, on the part of a firm and its competitors, should be associated with lower bids.

1.3 English auction

In the standard English auction, bidders are allowed to increase their bids continually. Bidding remains open until no bidder is willing to submit a higher bid. The high bid wins, and pays the amount bid. There are elements of this structure in the FCC auctions. We maintain all the assumptions we have established about bidders in the previous subsection, except that the rules of the auction change. The classic solution in such a setting, when capital structure is not a consideration, is that each bidder will continue to increase its bid by the minimum increment until bidding reaches their valuation. That is, each bidder i sets $b_i^* = v_i$, where b_i^* is the maximum bid that firm i is willing to submit.

How does leverage affect bidding strategies in an English auction? Our first observation is that each firm will clearly be willing to bid up to the point at which $v_i - b_i = D_i$. That is, $b_i = v_i - D_i$. To see this, note that, if the firm wins the auction with a bid of b_i, the profits from the auction are $v_i - b_i$. If b_i is such that $v_i - b_i > D_i$, the profits are sufficient to pay off the debt holders, and the shareholders receive $v_i - b_i - D_i$. If the firm loses the auction, shareholders receive zero. Thus it is always beneficial for the firm to choose a stopping rule $b_i^* \geq v_i - D_i$.

Proposition 4. *A stopping rule $b_i^* \in \{v_i - D_i, \infty]$ for all participants constitutes a Nash equilibrium in the English auction.*

We show above why $v_i - D_i$ is the minimum stopping point a firm would choose. Note that equity receives a payoff of zero if the firm bids above $v_i - D_i$, and wins the auction. Equity also receives a payoff of zero if the firm loses the auction, so the firm is indifferent between any stopping rule $b_i^* \geq v_i - D_i$.

Proposition 5. *The lower bound of the set of sustainable Nash equilibrium bids is decreasing in leverage.*

This follows immediately from examining the equilibrium bid interval in proposition 4. If a firm has larger debt, D_i, then the minimum equilibrium stopping point is at a lower bid, $v_i - D_i$.

We have thus established that bidding will decrease in leverage for first-price sealed bid auctions, and that the lower bound of the set of equilibria for English auctions will also decline in leverage. We can prove more specific results if we allow for some realistic modifications of our abstract setting. The most straightforward modification is allowing for a cost of submitting bids. If there is a cost to submit each bid, bidders have incentives to end an auction as quickly as possible. Daniel and Hirshleifer (1996) show that bidding costs can lead to jump bids that serve to signal valuations, thereby reducing the number of steps in the auction.

We have also assumed that a manager can submit bids without incurring any personal cost, such as expending effort. If the bidding cost includes a direct cost to the manager, no bids above $v_i - D_i$—(the cost to submit a bid) will ever be submitted, since the bidder-manager incurs a cost but all benefits go to debt holders. If we fully model the effects of an effort cost to the manager, we would have to explicitly model the benefits the manager receives from winning the auction. The benefit is likely to come through either (1) promotion and increased salary based on the profitability of winning the auction for the firm (i.e., based on $v_i - D_i - b_i$), or (2) an increase in the value of stock or stock options that the manager holds.

If we abstract from direct modeling of benefits, but allow for some personal bidding costs, our model effectively reduces to the Daniel and Hirshleifer (1996) model, except that the values are debt adjusted. In the case of two bidders, they show that bidder A will begin with a bid identical to the optimal bid in a first-price sealed bid auction, and then bidder B will either quit or jump to a bid equal to the signaled valuation of bidder A. It follows immediately (since in our case bids are net of debt levels) that bids will drop as debt levels increase. The actual minimum stopping bid would be slightly lower, and it would be based on the manager's cost to submit the bid compared to the benefit the manager receives when $v_i - D_i - b_i > 0$.

More importantly, submitting a bid above $v_i - D_i$ can no longer be an equilibrium strategy. Any bid above $v_i - D_i$ provides no benefit if the firm wins, but entails a personal bidding cost. Thus we have:

Proposition 6. *If managers incur a personal cost in bidding, the highest bid they will be willing to submit in an English auction will decline with leverage.*

The English auction ends when there are no further bids. Suppose that there are two bidders, and the first has a fixed amount of debt, while the second has increased its leverage. Suppose further that the competitor with the fixed amount of debt had the higher (debt-adjusted) valuation before the second bidder added debt. Then, since the competitor will stop bidding at a lower value after the increase, an increase in the second firm's debt, assuming that Proposition 6 holds, will produce a lower equilibrium outcome, and a lower bid by the first bidder.

Suppose instead that, prior to the debt increase, the second firm had the higher (debt-adjusted) valuation. If the second firm still has the higher (debt-adjusted) valuation after the increase, it will win the auction with the same outcome as before (the highest bid by the first bidder). In this case, the highest bid by the first bidder will not change. If, after the debt increase, the first bidder has the higher valuation, then the equilibrium outcome will be at the valuation of the second bidder. Thus we have shown:

Proposition 7. *An increase in a competitor's leverage, everything else being equal, will weakly reduce the firm's bid and thus the winning bid in an English auction.*

So far we can conclude that in simplified settings in the two auction types that are closest to the FCC auctions, leverage will reduce bids.

1.4 Uncertain object value

There are two classic effects of leverage on firm behavior, dating back to Jensen and Meckling (1976) and Myers (1977). The first is underinvestment. Shareholders choose not to invest if all revenues accrue to debt holders. Thus they may turn down a project even if it has a positive net present value. The second effect is risk shifting, that is, shareholders will tend to select riskier projects, since they reap a disproportionate share of the benefits if the project succeeds, while bondholders bear most of the costs if the project fails.

When a firm reduces its bid in our setting, it is underinvesting, and at the same time increasing the risk of the auction. The risk is increased because with a lower bid the firm has a lower probability of winning the auction, but if it wins it will realize a higher payoff. This assumes that the auction is a private value auction, that is, the firm knows what value it places on the object.

If, on the other hand, we assume that the true value of the object is unknown to the bidder, there are two actions the bidder can take in an attempt to increase the risk of the auction. The first would be to lower the bid as above. The second would be to raise the bid, thus increasing the probability of winning and reaping a large benefit should the value of the object turn out to be high. Yet if the object turns out to be of low value, the firm will lose more. Thus if the value of the object is uncertain, higher bidding may result in taking more risk.

Our predictions are most applicable when the main source of uncertainty is whether a bidder wins at a given price rather than how much an object or a good is worth (after conditioning on all the information available to bidders). It is extremely difficult to model the value uncertainty in the private value case. In fact, we know of no such model. Uncertainty of object value is typically modeled in a common value framework.

The consultants who designed the FCC auctions suggested that common value and affiliated value effects are not important in those auctions [see Salant (1997)]. If object value uncertainty exists, however, leverage may lead to either higher or lower bids and the issue becomes an empirical question.

A second point is more general. Risk shifting is often made difficult by various bond covenants, especially for riskier companies (some of the firms in our sample are rated BBB and below). On the other hand, underinvestment essentially cannot be prevented; there are no covenants that force companies to invest. It would thus seem that it is easier to respond to underinvestment incentives than to risk-shifting incentives. Further, since in real life future investment opportunities may not be known at the time debt is issued, pricing them would be impossible. For these two reasons, one would expect our theoretical analysis to be applicable to the FCC auctions. However, again, what actually happens is of course an empirical issue.

We have assumed throughout that the firm makes decisions to maximize shareholder value. We thus ignore any agency costs created by managers making decisions on behalf of shareholders (except when bidding is costly). If managers are averse to financial distress, however, they may choose to avoid risk (instead of seeking risk) when the firm has more leverage [see Grossman and Hart (1982)]. They may thus raise or reduce bids depending on the source of uncertainty, and these decisions may not necessarily be in the best interest of the shareholders.

2. Evidence from FCC Spectrum Auctions

Researchers examining the interaction of capital structure with decisions generally model a single firm or a small number of competitors [see, e.g., Dotan and Ravid (1985), Brander and Lewis (1986), Dammon and Senbet (1988), Maksimovic (1988), and Clayton (1999)]. Each "firm" is modeled essentially as a single project. Empirical testing of these models is generally performed in a more complex setting. Maksimovic and Kim (1990), Chevalier (1995a, b), and Phillips (1995) all use data from industries with many competitors and a great number of projects.[9] Naturally we face the same constraints. More specifically, our theory assumes that firms go bankrupt if they lose the auction. The important issue, however, is that when the firm is not bankrupt, and it wins, it must pay the outstanding debt before shareholders receive any profits. Thus the more debt the firm has, the lower its expected bid. Debt will have this effect even if a firm could obtain the following contract: if it wins, it has to pay the debt, but when it loses the auction, all debt will be paid by someone else, leaving a predetermined amount (can be nothing) to shareholders, in effect eliminating (in a particular way) the possibility of bankruptcy. Therefore the primary variable of interest is a proxy for the amount of debt overhang, for which we use debt-equity ratio.

In reality, however, there are no contracts as suggested above, and thus, if the firm has enough money to pay the debt in all states of nature, it will

[9] See Porter (1995) for an example of empirical auction literature.

essentially act as an all-equity firm. This is true, of course, for all debt overhang papers, including Jensen and Meckling (1976), Myers (1977), Brander and Lewis (1986), and Maksimovic (1988), and others. Thus, empirically, if debt is to play a role, there should be a state where bankruptcy or financial distress is possible. Therefore we also test for financial strength using the usual proxies—Altman's Z-score, bond ratings, and interest coverage. We would expect proxies for debt and financial strength to be significant—firms will lower their bid if they are highly leveraged and if they have a significant probability of bankruptcy.

Finally, our model contains a prediction about the directional relationship between bids and debt level (where higher debt levels should be associated with lower bids). However, due to the complexity of the FCC auctions relative to our model, we cannot predict a precise functional relation. Thus we examine the basic relation through simple OLS regressions.

We selected the FCC auctions to test our conjectures, because we needed detailed information regarding bids, and we also needed competitors that are publicly traded firms so that we can estimate their leverage. The FCC auctions provided both.[10]

With the expansion of communications and broadcast media in recent years, the government has begun auctioning off the airwaves. Access to airwaves had previously been given away, essentially free of charge, to radio and television stations, telephone companies, and others complying with certain regulatory restrictions. There have been several spectrum auctions in recent years, employing reasonably complex rules. This multiround FCC auction is essentially an open outcry auction. However, since sealed bids are submitted, there are elements of a first-price sealed bid auction as well.

The auction we investigate offered for sale the important "broadband" spectrum. Two blocks (A and B) of 30 MHz each in 51 metropolitan areas were open for bids (except for New York, Los Angeles, and Washington, D.C., where only block B was auctioned). This produced a total of 99 blocks. These blocks cover the entire continental United States. Each geographic area had two incumbents, winners of previous auctions, holding title to a 25 MHz band each. A and B licenses thus allowed a third and a fourth competitor to enter, each receiving title to a 30 MHz band. This spectrum was intended for "personal communication," which has a broad legal meaning, but is well suited for digital cellular communication, including facsimile and data transmission. The auction began on December 5, 1994, and ended on March 13, 1995, after 112 rounds. It raised $7.7 billion for the government.

In round 1, each firm submitted a sealed bid on any block (or blocks) it chose. These bids were then revealed, and the high bid for each block was

[10] Appendix A describes the FCC auctions. For a more detailed analysis, see Cramton (1997). An auction with costly bidding, such as in Daniel and Hirshleifer (1996), would produce bids closer to the empirical bids observed in the FCC auctions, but that model is still a simplified version of a more complex reality. The Daniel and Hirshleifer model in our setting requires more cumbersome theoretical analysis.

determined. The auction then proceeded to round 2, when each firm could again submit a sealed bid for any block (or blocks) it wished. The bids were announced, and it was determined if any blocks had new high bids. If at least one block had a new high bid, the auction continued to round 3, when again firms could submit sealed bids for any block (or blocks). The auction continued until no block received an increased bid.[11]

The FCC established this mechanism because it believed there would be synergies between the blocks, which is consistent with our empirical results. The winning bidders essentially had to pay the amount they bid in cash. Specifically, there was an up-front payment that established eligibility; 20% of the bid was due five business days after the auction closed, and the remainder of the bid was due when the license was formally awarded.[12]

We use the A and B block auction to test the theory that the highest bid submitted by a company (not necessarily the winning bid) is affected by a firm's own capital structure and the capital structure of the competing firms. According to the theoretical models developed, we should expect the highest submitted bid of a firm to decrease both with its own debt level, as well as with the debt level of rival firms.

We also examine whether the FCC is correct in the hypothesis that the blocks have synergies. That is, we investigate whether the value of a block is higher if the firm owns a block in an adjacent area [although there may be other issues that may determine the value of an area to a bidder; see Appendix A and Cramton (1997)]. If synergies exist, we would expect to see a firm raise the highest bid for an area if it owns the rights in an adjacent area. We also use additional control variables.

2.1 Data

The main source of data is the FCC Web site (FCC.gov), which lists all bids in all auctions. For each block for which a firm submitted a bid, we collect the final (highest) bid submitted by the company. Because the two

[11] Each time the auction moved to a new round, firms could submit higher bids for any block, not just blocks that had received a new high bid in the last round.

[12] Licenses were typically awarded one to three months after the auction was concluded. In a later auction of C blocks (intended mainly for relatively small firms, and offering a different spectrum band), the winning bidders were required to post a down payment of only 10% of the amount bid. In that auction, bidding reached stratospheric heights, and in 1997 several important bidders were on the verge of bankruptcy. The FCC had to come up with a plan, adopted with a narrow majority, to save the auction (see *New York Times*, September 26, 1997, p. D1). Auctions of later blocks (after block C) were investigated in 1997 for collusion and fraud. In late 2000, the FCC tried again to sell licenses to "small businesses." Some of the licenses won by the previous failed competitors were resold in addition to new offerings. Subsidies were offered. However, large companies managed to enter into "bidding partnerships" with the small firms that were allowed to bid. The *New York Times* (February 12, 2001) reported that two companies, Salmon and Alaska Native Wireless, made up-front auction down payments of $240 million each, "staggering sums," considering that qualified companies could not exceed $125 million in annual revenues. Their secret—partnership with large wireless companies, SBC and ATT, respectively. In early 2001, losing bidders were preparing to sue over that auction. In 2000 there were also quite a few wireless license sales around the world, with mixed results. The auctions of blocks A and B, which we are discussing, are thus some of the "cleanest" auctions to work with and the closest to our theoretical model.

blocks, A and B, are essentially identical, we consider only the highest bid between the two blocks for each company (some companies quickly dropped out of the bidding for block A, but continued bidding for block B in the same metropolitan area; no firm was allowed to win both block A and B in the same metropolitan area).

Thirty companies participated in bidding for the various metropolitan areas. Some companies were limited partnerships; others were privately held. For other companies we could find no additional identifying information. For 14 companies we could assemble a complete dataset, leading to 150 company-bid pairs. This is a relatively high number of company-bid pairs, because we have information about the largest and generally most active companies.[13]

Company information comes from Compustat for year-end 1994, which is approximately when the auction took place. Appendix B lists all companies in the auction. The most active bidder, Wireless Co., is a partnership of Sprint, Tele-Communications, Cox Cable, and Comcast. For that bidder we form a weighted average for all company data according to the weights in the partnership.

For leverage, we use book and market value debt-equity ratios. It is important to note that while the companies in our sample are indeed large and publicly traded, they fit our characterization (i.e., they have risky debt). One company was rated AAA; all others were rated lower, down to BBB-. At BBB, the cumulative default probability over 10 years is over 4%; at BB, it is close to 17% [see Altman and Arman (2002)].

The market value ratios are computed using stock prices as of December 31, 1994. We adjust bond prices as follows. From the Warga Lehman Brothers' fixed income database we obtain market values for all bonds available for each company. We adjust the book value of the bonds for which we have information to reflect market values. We then adjust the rest of the debt listed for the company by the same average percentage. For example, if a company has two bonds, of equal book value, and only one bond is listed at a price of 102, we increase the price of both bonds by 2% over the book values.

We also use interest coverage, bond ratings, and Altman's Z-score as alternative measures of default risk. For the bond ratings, we use both a variable that transforms each rating into a numerical count, as well as several variations of dummy variables that divide the companies into more or less risky subsets.[14] Altman's Z-score is frequently used to study the default risk of firms, and we use it as a proxy for the risk of bankruptcy.

We develop several variables to directly test our theory on the effect of competing firms' leverage on bids. We construct a weighted average of the capital structures of all competitors in a specific market using market values

[13] Note, however, that our theory relates to bidding behavior and therefore is applicable to each bid by each company rather than to total bidding behavior.

[14] We report results using only one bond rating dummy. Results were similar with the alternative specifications.

as weights. We calculate weighted averages of the market value measure, book value measure, interest coverage, and bond rating variable of the competitors. We should note that since we do not have information on all participants in all auctions, the competitors' variables might be representative but are not inclusive. However, since we have most of the large players and use market value weights, the problem is mitigated.

Additional Compustat data collected include sales and total assets. Since bidding strategies varied by firm, we also include dummy variables for some firms [see Cramton (1997)].

We construct several additional variables to control for possible synergies that one may obtain in holding licenses for adjacent areas. We create a dummy variable with a value of one if the company in question had won a license in an adjacent market in a previous round of the current (A and B block) auction and zero otherwise. Another variable measures whether or not the company had won licenses in the same area in previous auctions. The FCC did not allow companies with a strong presence in a market (in terms of market share) to bid for that same market during this auction. Specifically, no company was allowed to hold more than 45 MHz in any metropolitan area. Incumbent companies held 25 MHz already, and hence were ineligible to bid for an additional 30 MHz in the same metropolitan area. Firms with less of a market share were not prohibited from bidding for a market. We also determined if companies had won earlier auctions for different wavelengths in adjacent areas.

Bids are strongly influenced by the population of each area and its economic circumstances. Our dependent variable is thus stated as the high bid in terms of dollars per capita.[15] Population information for each market is listed on the FCC Web site. We use additional data from Demographics USA (1997) on population and total disposable income in each metropolitan area. This information is used to calculate income per capita for the largest metropolitan area in each region.

2.2 Results

Table 1 provides summary statistics that describe the data. Note that there is great variability in the bids per capita and in firm characteristics, which should provide a fertile ground for investigation.

The dependent variable in all regressions that follow is the highest bid per capita that each firm submitted for a region.[16] An OLS regression is used to ascertain whether leverage plays a role in determining the highest bid each firm is willing to submit for a particular metropolitan region. According to

[15] This is the common way bids are described by professionals and by participants. In fact, the up-front payments and some auction rules are defined in terms of MHz pop, which is similar to our definition.

[16] This bid is not necessarily the winning bid. If a firm did not win a market, we use the highest bid the firm submitted in that market.

Table 1
Summary statistics

Variable	Mean	Std. dev.	Maximum	Minimum
Per capita income	15.596	2.292	20.079	5.124
High bid per capita	12.584	7.599	31.902	0.600
Adjacent market dummy	0.307	0.463	1.000	0.000
Current market dummy	0.073	0.262	1.000	0.000
Natural log of sales	9.104	1.472	11.227	6.032
Natural log of assets	9.778	1.120	11.281	7.536
Book debt-asset ratio	0.712	0.130	1.175	0.457
Competitors book debt-equity ratio	0.749	0.044	0.818	0.457
Market debt-equity ratio	0.787	0.412	3.111	0.102
Competitors market debt-equity ratio	0.833	0.247	2.001	0.102
Interest coverage	3.965	1.465	6.308	0.221
Competitors' interest coverage	4.584	1.067	6.003	2.230
Z-score	3.816	2.884	8.796	0.305
Bond rating dummy	0.320	0.468	1.000	0.000
Competitors bond dummy	0.320	0.302	1.000	0.000
PrimeCo. dummy	0.120	0.326	1.000	0.000

Per capita income is the income per capita of each region. High bid per capita is the highest bid each firm submitted in each region per population of that region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Current market dummy takes a value of one if the firm has a presence in the market (as defined by the FCC) and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Natural log of assets is the natural log of the bidding firm's assets as of December 31, 1994. Book debt-asset ratio is the debt-asset ratio of the bidding firm in book values. Competitors' book debt-asset ratio is a weighted average of the competing firms' debt-asset ratio in book values. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. Z-score is a five-factor multiple discriminate analysis, using weights from Altman. Bond rating dummy takes a value one if the firm's bonds are rated AA or higher and zero otherwise. Competitors' bond rating dummy is a weighted average of the competing firms' bond rating dummy variable. PrimeCo. dummy takes a value of one if the bidding firm is PrimeCo. and zero otherwise.

our theory, an increase in leverage should reduce the highest bid a firm is willing to submit in each region in which the firm actively participates. In the case of an English auction, we have shown a direct impact of competitors' debt on bids. In the case of first-price auctions, such a direct proof is unattainable (due to technical limitations) but we have shown that an increase in all bidders' debt will cause bids to drop. Hence, lower bids in response to higher competitors' debt will be consistent with our story.

2.2.1 Basic regressions with market leverage ratios. In our baseline regressions, we use the market debt-equity ratio to represent leverage. We expect a negative coefficient on this variable, since the theory predicts lower bids for more highly levered firms. We also use the weighted average debt-equity ratio of the competitors in each market as an independent variable. If the competition reduces bids with higher debt, we would expect the optimal response to entail a lower bid. For each metropolitan area, we also include per capita income. We expect areas with higher income to be more valuable, and thus elicit higher bids. We control for firm size by including either the log of firm sales or the log of its assets.

Table 2
Market value regressions

Variable	Estimate	Estimate	Estimate	Estimate
Constant	2.337	2.432	2.131	2.234
	(0.37)	(0.39)	(0.29)	(0.30)
Per capita income	0.858	0.848	0.858	0.848
	(3.34)***	(3.28)***	(3.34)***	(3.28)***
Natural log of sales	0.039	0.034		
	(0.09)	(0.08)		
Natural log of assets			0.058	0.053
			(0.10)	(0.09)
Market debt-equity ratio	−1.717	−1.847	−1.725	−1.856
	(−1.09)	(−1.15)	(−1.09)	(−1.15)
Competitors market debt-equity ratio	−4.404	−4.289	−4.406	−4.290
	(−1.78)*	(−1.72)*	(−1.79)*	(−1.73)*
Adjacent market dummy	4.986	5.064	4.991	5.069
	(3.77)***	(3.79)***	(3.80)***	(3.83)***
Current market dummy		1.273		1.273
		(0.55)		(0.55)
R^2	0.1529	0.1547	0.1529	0.1547
Adjusted R^2	0.1235	0.1192	0.1235	0.1192

Results of OLS regressions in which the dependent variable is the highest bid each firm submitted in each region per population of that region. Per capita income is the income per capita of each region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Current market dummy takes a value of one if the firm has a presence in the market (as defined by the FCC) and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Natural log of assets is the natural log of the bidding firm's assets as of December 31, 1994. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. T-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

As discussed earlier, we include a dummy variable that equals one if the bidding firm has won an adjacent market in the current auction. We expect the sign of this coefficient to be positive. In addition, we include a dummy variable that equals one if the bidding firm already owns a license in the metropolitan area in question. Table 2 presents the results of the basic regressions. As expected, income per capita and the adjacent dummy both have positive and significant coefficients in all regressions. This implies that firms bid more for a region in which there is higher per capita income, and also bid more in regions that are adjacent to regions in which they hold a franchise from this auction. Of interest is the fact that although the coefficient on the dummy variable for presence in the area is positive, it is not significant. This may be due either to the very small presence allowed under FCC rules or to the fact that different portions of the spectrum are used for very different purposes.

The market debt-equity ratio has a negative coefficient in all four regressions, as expected, but it is insignificant. The coefficient on competitors' debt-equity ratio is negative, as expected, and significant at the 10% level.

2.2.2 Alternative measures of risk. The choice of leverage is endogenous. All else being equal, higher debt should be associated with lower bids, as shown earlier. Yet a firm may have very low distress costs or an exogenously low probability of financial distress and thus optimally choose to have high leverage. As stated earlier, the overall level of debt is also important, so we continue to include the debt-equity ratio in all regressions. However, we now add independent proxies for bankruptcy risk. In general, we would expect bids to be less affected by leverage if bankruptcy is not an issue.

The regressions in Table 3 include three additional measures of bankruptcy risk: interest coverage, Altman's Z-score, and bond rating. Lower interest coverage may indicate financial difficulties. Thus we would expect the coefficient on the interest coverage variable and the weighted average of the competitors' interest coverage to be positive. The Z-score is a weighted average of several firm characteristics. A higher Z-score implies a lower risk of bankruptcy. Thus we would expect the coefficient on Z-score to be positive as well. The bond rating proxy is a dummy variable that takes the value one if the firm is rated AA or better and zero otherwise. A higher bond rating suggests a lower probability of financial distress, so we would expect the

Table 3
Market value regressions with alternative measures of risk

Variable	Estimate	Estimate	Estimate	Estimate
Constant	2.982	6.982	0.646	2.963
	(0.38)	(0.98)	(0.10)	(0.37)
Per capita income	0.834	0.851	0.863	0.833
	(3.28)***	(3.22)***	(3.36)***	(3.26)***
Natural log of sales	1.624	−0.482	0.174	1.639
	(1.71)*	(−0.81)	(0.38)	(1.51)
Market debt-equity ratio	−4.751	−1.166	−2.273	−4.759
	(−2.21)**	(−0.74)	(−1.47)	(−2.19)*
Competitors market	−5.587	−4.770	−4.120	−5.594
debt-equity ratio	(−2.16)**	(−1.86)*	(−1.65)	(−2.14)**
Interest coverage	−1.781			−1.802
	(−2.00)**			(−1.57)
Competitors interest	−0.878			−0.874
coverage	(−1.49)			(−1.44)
Bond rating dummy		2.098		
		(1.19)		
Competitors bond		−1.620		
rating dummy		(−0.79)		
Z-score			0.213	−0.010
			(0.87)	(−0.03)
Adjacent market dummy	4.224	4.902	4.509	4.241
	(3.14)***	(3.70)***	(3.11)***	(2.88)***
R^2	0.1851	0.1672	0.1594	.1851
Adjusted R^2	0.1449	0.1262	0.1242	.1389

Results of OLS regressions in which the dependent variable is the highest bid each firm submitted in each region per population of that region. Per capita income is the income per capita of each region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. Z-score is a five-factor multiple discriminate analysis, using weights from Altman. Bond rating dummy takes a value one if the firm's bonds are rated AA or higher and zero otherwise. Competitors' bond rating dummy is a weighted average of the competing firms' bond rating dummy variable. T-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

coefficient on the bond rating dummy and the competitors' weighted average bond rating dummy to be positive.[17]

The coefficient on own debt-equity ratio is negative in all regressions and significant at the 5% level in one and at the 10% level in another. This result is consistent with the theory that as leverage increases, bids decline. The competitors' debt-equity ratio coefficient is also negative in all regressions and significant in three of the four equations as the theory predicts. This suggests that as the competition increases its debt levels, the firm will reduce its bid. The Z-score variable and the bond rating variables are all insignificant. This suggests that while increases in debt lead to lower bids, adding Z-score or bond rating as risk measures does not help in predicting bid levels.

Own interest coverage is negative and significant. This is the opposite of what we would expect, since an increase in debt should lead to a decrease in interest coverage (all else being equal). However, interest coverage may be a noisier signal than debt-equity ratio regarding the actual probability of financial distress, because operating income can vary dramatically from period to period. If the firm experiences a period of low (or negative) operating income, interest coverage can fall to less than 1.0 or even become negative. If the firm has a large amount of cash on hand, liquid assets, or if assets exceed the value of debt, there may be little danger of bankruptcy. A high debt-equity ratio may thus be a better indicator.[18] The competitors' interest coverage variable is insignificant.

The size variable, the natural log of sales, is positive and significant at the 10% level in one of the models. This is a common result, and also broadly consistent with Che and Gale (1998), who suggest that financial constraints, which are more likely to affect smaller firms, will lead to less aggressive bidding in a first-price auction. The coefficients on per capita income and the adjacent dummy are positive and significant.

Next, we added a fixed-effects dummy for each bidding firm to control for possible firm-specific strategy components, which our regressions have not captured. The coefficients of the fixed-effects model are generally not significant, except for Prime Co., which is included in the regressions in Table 4. The results are similar to those in Table 3, with analogous interpretations.

[17] We first run each of these proxies individually. Our last regression includes several of these proxies. This can be done without significant econometric problems since the proxies are not generally highly correlated, so they may pick up different important dimensions of the risk of bankruptcy. The exception is the correlation between interest coverage and bond ratings, which is more than 70%. Thus our last regression includes interest coverage, competitors' interest coverage, and Z-score, but not the bond rating dummies. We use interest coverage instead of the bond rating dummies because it is significant in the individual regression, while the bond rating dummies are not.

[18] For examples of use of interest coverage as an indicator of financial distress, see Whited (1992), Rajan and Zingales (1995), and Gilson (1997). The latter study also discusses the pros and cons of using interest coverage as a proxy. While not all these authors support our view of the relative merit of interest coverage versus other debt ratios, they can help the reader put our work in perspective.

Table 4
Market value regressions with fixed effect for PrimeCo.

Variable	Estimate	Estimate	Estimate	Estimate
Constant	−0.018	2.321	−0.810	−0.361
	(−0.00)	(0.30)	(−0.12)	(0.05)
Per capita income	0.910	0.894	0.934	0.905
	(3.61)***	(3.39)***	(3.64)***	(3.57)***
Natural log of sale	1.852	−0.015	0.093	2.064
	(1.97)*	(−0.02)	(0.20)	(1.91)*
Market debt-equity ratio	−4.999	−1.802	−2.123	−5.118
	(−2.36)**	(−1.11)	(−1.38)	(−2.39)**
Competitors market debt-equity ratio	−4.805	−4.295	−3.527	−4.879
	(−1.87)*	(−1.68)*	(−1.42)	(−1.89)*
Interest coverage	−2.124			−2.425
	(−2.39)**			(−2.09)**
Competitors interest coverage	−0.845			−0.790
	(−1.46)			(−1.32)
Bond rating dummy		−0.232		
		(−0.10)		
Competitors' bond rating dummy		−1.233		
		(−0.60)		
Z-score			0.218	−0.133
			(0.90)	(−0.40)
Adjacent market dummy	4.134	5.013	4.517	4.369
	(3.12)***	(3.80)***	(3.15)**	(3.01)***
PrimeCo. dummy	4.321	3.782	3.759	4.435
	(2.40)**	(1.59)	(2.08)**	(2.43)**
R^2	0.2170	0.1819	0.1844	0.2179
Adjusted R^2	0.1726	0.1355	0.1441	0.1676

Results of OLS regressions in which the dependent variable is the highest bid each firm submitted in each region per population of that region. Per capita income is the income per capita of each region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. *Z*-score is a five-factor multiple discriminate analysis, using weights from Altman. Bond rating dummy takes a value one if the firm's bonds are rated AA or higher and zero otherwise. Competitors' bond rating dummy is a weighted average of the competing firms' bond rating dummy variable. PrimeCo. dummy takes a value of one if the bidding firm is PrimeCo. and zero otherwise. *T*-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Prime Co. entered the bidding with a very specific strategy. According to some assessments of the auctions, it is one of the few companies that had a national vision. Cramton (1997) observes that Prime Co. is the only company that "reduced competition" (p. 454) because it had deep pockets. Because of its partner composition, however, Prime Co. was allowed to bid on only 36% of the population in question. The reduced competition in specific markets may account for the occasional significance of this firm-specific dummy. When we include the additional firm dummies, the equations are qualitatively similar, but no other firm dummy is significant.

2.2.3 Interaction variables. Although, in theory leverage should affect bidding behavior as long as there is some probability of bankruptcy, and, as noted, all firms but one in our sample are not AAA rated, it may be that the effects we consider are accentuated for firms for which financial distress looms large, or alternatively, are less significant if bankruptcy is only a remote possibility. To test this idea, and also to shed more light on the impact of some of the variables, we run regressions with interactive variables. The variables are market debt-equity level multiplied by a measure of risk (interest coverage, Z-score, and bond rating).

The results are reported in Table 5. First note that the debt-equity ratio and weighted average of the competitors' debt-equity ratio are negative and significant in all three-interaction regressions. This adds to our evidence that higher debt levels lead to lower bids. Only the interaction between debt-equity ratio and bond rating is significant at the 10% level. Bond rating is one if the firm is rated AA or better. The positive coefficient means that if a firm is not likely to go bankrupt (bond rating = 1), a high debt level would not necessarily cause the firm to lower its bid. This is broadly consistent with our story.

Table 5
Regressions with interactions between risk measures and debt levels

Variable	Estimate	Estimate	Estimate
Constant	6.606	5.483	2.860
	(0.71)	(0.69)	(0.35)
Per capita income	0.829	0.880	0.832
	(3.25)***	(3.46)***	(3.26)***
Natural log of sales	1.194	1.188	1.669
	(1.11)	(1.21)	(1.50)
Market debt-equity ratio	−6.163	−3.852	−4.747
	(−2.15)**	(−1.75)*	(−2.20)**
Competitors market debt-equity ratio	−5.449	−5.146	−5.603
	(−2.09)**	(−2.33)**	(−2.15)**
Interest coverage	−2.203	−2.102	−1.841
	(−2.09)**	(−2.33)**	(−1.55)
Competitors interest coverage	−0.866	−0.876	−0.868
	(−1.47)	(−1.50)	(−1.43)
Adjacent market dummy	4.296	3.985	4.269
	(3.18)***	(2.96)***	(2.90)***
(Market debt-equity)* interest coverage	0.974		
	(0.75)		
(Market debt-equity)* bond rating dummy		4.318	
		(1.73)*	
(Market debt-equity)*Z-score			−0.023
			(−0.08)
R^2	0.1883	0.2021	0.1851
Adjusted R^2	0.1423	0.1568	0.1389

Results of OLS regressions is which the dependent variable is the highest bid each firm submitted in each region per population of that region. Per capita income is the income per capita of each region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. Z-score is a five-factor multiple discriminate analysis, using weights from Altman. Bond rating dummy takes a value one if the firm's bonds are rated AA or higher and zero otherwise. T-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

Table 6
Regressions using book value of debt and equity

Variable	Estimate	Estimate	Estimate	Estimate
Constant	−10.248	−10.534	−14.963	−20.317
	(−0.85)	(−0.84)	(−1.22)	(−1.50)
Per capita income	0.920	0.921	0.882	0.890
	(3.53)***	(3.53)***	(3.44)***	(3.46)***
Natural log of sales	0.277		2.668	
	(0.54)		(2.52)**	
Natural log of assets		0.289		2.909
		(0.44)		(2.19)**
Book debt-asset ratio	−5.133	−4.731	−17.676	−14.883
	(−0.87)	(−0.82)	(−2.33)**	(−2.04)**
Competitors book	10.135	9.702	14.986	11.497
debt-asset ratio	(0.73)	(0.70)	(1.09)	(0.84)
Interest coverage			−2.217	−1.931
			(−2.62)***	(−2.32)**
Competitors' interest			−0.496	−0.401
coverage			(−0.90)	(0.73)
Adjacent market dummy	5.037	5.077	4.308	4.755
	(3.81)***	(3.84)***	(3.24)***	(3.60)***
Prime dummy	4.014	4.032	5.119	5.050
	(2.20)**	(2.21)**	(2.78)***	(2.72)***
R^2	0.1695	0.1690	0.2101	0.2017
Adjusted R^2	0.1347	0.1341	0.1653	0.1564

Results of OLS regressions in which the dependent variable is the highest bid each firm submitted in each region per population of that region. Per capita income is the income per capita of each region. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Natural log of sales is the natural log of the bidding firm's sales over the 12 months prior to the auction. Natural log of assets is the natural log of the bidding firm's assets as of December 31, 1994. Book debt-asset ratio is the debt-asset ratio of the bidding firm in book values. Competitors' book debt-asset ratio is a weighted average of the competing firms' debt-asset ratio in book values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. PrimeCo. dummy takes a value of one if the bidding firm is PrimeCo. and zero otherwise. T-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

2.2.4 Book value regressions. Market values are of course more relevant than book values. However, no adjustment is perfect. To test robustness, Table 6 uses book values instead of market values.[19] The own debt-to-assets ratio has a negative coefficient (as expected) and is significant for some models. Competitors' debt-equity ratios are insignificant in all regressions. We can expect a less significant result for the book ratios because they are clearly less representative of the actual state of affairs, especially in the bull market of the 1990s. Table 1 shows that there is much more variability in the market debt-equity ratios than in the book debt-equity numbers. The coefficients of the other variables in Table 6 are similar, with similar significance levels and similar interpretations to those reported earlier.

We tried several additional adjustments and combinations of control variables. The negative sign for own debt and usually for competitors' debt prevails. The results in our empirical analysis are thus generally consistent with the hypothesis that as leverage increases, a firm's bid is reduced. In addition, there is evidence that as the leverage of the competition increases, a firm's

[19] For the reasons we suggest, many studies use book values as well as market values. See, for example, Titman and Wessels (1988) or Rajan and Zingales (1995).

bid is reduced, which is broadly consistent with the theory. We also identify two other factors that are significant in the FCC auctions. First, income per capita is important to the value of a metropolitan area, and thus has an important impact on the bid a firm submits for a region.

Second, if a firm has won in one region, this has a significant positive effect on its future bids for an adjacent area. This result implies that there are synergies from owning rights in adjacent metropolitan regions. Prior presence in the same area does not seem to be a determining factor in bidding behavior. This may be because different wavelengths can be used for much different purposes, with no necessary synergies.

2.2.5 Probability of winning. The final set of tests investigates whether leverage is related to the probability of winning a market.[20] A probit analysis is used in which the dependent variable is one if a firm wins the market and zero otherwise. The natural log of assets, market debt-equity ratio, and the adjacent dummy variable are used as independent variables. If winning an adjacent market increases the value of a market to the firm (and thus the highest bid it is willing to submit), we would expect the adjacent market dummy to be positive. Debt-equity ratio and a proxy for financial distress are used as independent variables to directly test the hypothesis that leverage affects the probability of winning. In general, since leverage reduces bids, we expect that it would lower the probability of winning. For the same reason, we also look at the debt-equity ratios of competitors, which may affect this probability as well.

We run three regressions, which include interest coverage, Z-score, and a bond-rating dummy as alternative additional financial indicators. As noted, we would expect a negative coefficient on the market debt-equity ratio if higher debt levels lead to a lower probability of winning. For the other proxies, we expect a higher probability of distress to lead to a lower probability of winning. Lower interest coverage, lower Z-score, and lower bond rating all imply a higher probability of financial distress. Thus we would expect a positive coefficient on interest coverage, Z-score, and the bond rating dummy. For the variables of the competition, we expect higher debt by the competition to enhance the probability of winning. This implies a positive coefficient on the competitors' weighted average debt-equity ratio.

The results are reported in Table 7. The first column shows that interest coverage is not significantly related to the probability of winning (this is related to our earlier interpretation). In the next two columns, the coefficients of Z-score and of the bond rating dummy are both positive and significant. Thus two of the three proxies for financial distress show that firms with a higher probability of financial distress are less likely to win. The coefficient for the market debt-equity ratio is negative, and it is significant in one of the

[20] We thank a referee for suggesting this analysis.

Table 7
Determinant of the probability of winning

Variable	Estimate	Estimate	Estimate
Constant	−1.988	−6.439	0.394
	(−1.06)	(−3.89)***	(0.29)
Natural log of assets	0.337	0.662	−0.073
	(1.32)	(3.78)***	(−0.52)
Market debt-equity ratio	−0.320	−1.850	0.276
	(−0.69)	(−2.95)***	(0.88)
Competitors market debt-equity ratio	−0.301	0.142	−0.194
	(−0.87)	(0.30)	(−0.40)
Interest coverage	−0.154		
	(−0.87)		
Competitors interest coverage	−0.080		
	(−0.75)		
Z-score		0.322	
		(4.56)***	
Bond rating dummy			0.739
			(2.34)**
Competitors bond rating dummy			−0.415
			(−1.11)
Adjacent market dummy	0.820	0.331	0.786
	(3.30)***	(1.18)	(3.17)***
McFadden R^2	0.0933	0.2061	0.1192

Results of ordered probit regressions in which the dependent variable is one if the firm wins a market it bid upon and zero otherwise. Adjacent market dummy takes a value of one if the firm has won an adjacent region during this auction and zero otherwise. Natural log of assets is the natural log of the bidding firm's assets as of December 31, 1994. Market debt-equity ratio is the debt-equity ratio of the bidding firm in market values. Competitors' market debt-equity ratio is a weighted average of the competing firms' debt-equity ratio in market values. Interest coverage is the firm's interest coverage. Competitors' interest coverage is a weighted average of the competing firms' interest coverage. Z-score is a five-factor multiple discriminate analysis, using weights from Altman. Bond rating dummy takes a value one if the firm's bonds are rated AA or higher and zero otherwise. Competitors' bond rating dummy is a weighted average of the competing firms' bond rating dummy variable. T-statistics are in parentheses and *,**, and *** indicate significance at the 10%, 5%, and 1% level, respectively.

three regressions. This is also the regression with the highest R^2. As for the competitors' variables, interest coverage and bond rating are both negative (as expected) but insignificant.

Overall the evidence is consistent with the theory—that is, firms with higher leverage and a risk of bankruptcy tend to bid lower, reducing the probability of winning. This is also consistent with the idea that when risky debt is present, lower bids will increase risk. There is no support for the idea that in the presence of uncertainty about the value of the object, risk-seeking shareholders will tend to increase their bids.

3. Conclusion

We have presented a theoretical framework predicting how leverage should affect bidding behavior in private value auctions. It is shown that both the degree of leverage of the bidding firm and the debt-equity ratio of the competition are important factors in the bid a firm is willing to submit. In particular, as a firm increases its debt level, the highest bid it is willing to submit drops. Higher debt levels on the part of the competition also seem to induce lower bids.

An FCC auction serves as a testing ground to determine whether the effect of debt on bidding behavior is economically significant. We find that, as a firm's own debt level increases, and as the competition's debt level increases, firms tend to submit lower bids. This supports our theoretical model. We also find that income per capita and winning adjacent markets strongly affect the bids submitted by different companies.

Appendix A: Description of the FCC Auction[21]

In the mid-1990s, the FCC adopted a new way of assigning licenses for personal communication services (PCS), namely, a simultaneous multiple-round auction. The format and the rules were developed with the help of auction experts Paul Milgrom, Robert Wilson, and Preston McAfee.

To test and refine the auction design, the FCC first auctioned 10 narrowband (50 kHz) licenses, which are used to provide paging services. This auction took place in July 1994. Next, 30 regional narrowband licenses were sold. The former auction raised $617 million, and the latter, in November 1994, raised $395 million. In some sense, these two auctions were but a dress rehearsal for the auction analyzed in this article, which was a broadband auction, that is, 30 MHz licenses, for personal communication.

This auction (A and B blocks) took place between December 1994 and March 1995 and raised $7.7 billion. It was followed by another broadband auction that raised $10.2 billion. This auction, C block, was open only to small companies (annual revenues less than $125 million) and featured generous payment schedules. The bids were very high, and many winning bidders defaulted on the bid payment (see note 12).

While the narrowband auctions included relatively small firms, the A and B block broadband auctions analyzed here elicited bids from some medium-size firms as well as the largest communication firms in the world. Furthermore, several alliances were formed. The variety of firms and the fact that many of them are publicly traded make this auction especially suitable for this study, which requires financial information at the firm level.

The designers of the A and B block auction faced several important questions, and in general opted for a design that was as transparent and accessible as possible, while preventing the formation of monopolies. First, they had to decide between a sealed bid and an open auction. Although sealed bids tend to discourage collusion, they have the disadvantage of concealing information, thus causing the designers to favor the open bid multiple-round design. For similar reasons, a simultaneous auction (auctioning all licenses at the same time) was preferred to a sequential design. Also, the FCC decided against package bids, that is, submitting one bid for several regions or areas.

Several specific rules and regulations constrained the bidders. First, the FCC required that no bidder end up with too much power. For the narrowband spectrum, a firm could not hold more than three licenses in any market. For broadband auctions, the spectrum was limited, so a firm could not hold more than 45 MHz in each market. This effectively meant that an incumbent (holding a 25 MHz band) could not compete in the A and B block auction, and also that each bidder could obtain, at most, one license per market.

Payments were required in three stages. The first stage was an up-front payment that ensured eligibility. The payment was 2 cents for each MHz $\times$ population (MHzpop). For example, for a million people and 30 MHz, a firm had to pay $600,000 up front. The winner was expected to provide a down payment of 20% five business days after the close of the auction, and pay the balance five business days after the license had been formally awarded. Licenses were typically awarded one to three months after the auction.

[21] This appendix is based largely on Cramton (1997).

Bidding was in discrete increments, initially set at the greater of 5% or 2 cents/MHzpop. There were three activity stages set by the FCC, as proposed by Paul Milgrom and Robert Wilson. In the initial stage, each bidder had to be active (submit bids) for at least one-third of its current eligibility (in terms of MHzpop). If activity fell below the one-third level, eligibility was reset to three times the actual level of bidding activity. For example, if a bidder were eligible to bid on 180 million MHzpop, which would buy six 30 MHz licenses in areas with one million people each, then if valid bids for at least two such licenses were not placed, eligibility was reduced. If a bid for only one license were placed, eligibility was reduced to 90 million. In stage 2, the activity level was raised to two-thirds of the eligibility, and in the third stage to 100%. There were up to five waivers available per bidder.

The FCC was also able to control the pace of bidding activity through the number of rounds per day. In the narrowband auction, there were several rounds per day. In the broadband auction, initially only one round per day was conducted, increasing to two rounds as the auction progressed. Clearly all these rules and regulations had an impact on bidding behavior, but proxies for differential effects on different bidders are difficult to conceptualize.

The auction ended if a single round passed with no bids in any market. Each bidder was fully informed about the identity, the eligibility, and the bids of all competitors. The narrowband auctions ended after 47 and 105 rounds. The broadband auction we discuss ended after 112 rounds.

Bid withdrawal was possible, but it entailed a penalty. Bidders in the broadband auctions formed alliances, even though the alliances limited the number of markets in which each alliance could bid.

The bidders in the broadband auction were very cautious. Bids were rarely increased by more than the minimum increment. Most firms kept activity level near the minimum necessary to maintain eligibility. This contrasts sharply with the narrowband experience. There were 21 bid withdrawals in the broadband auctions, mostly in round three, but only 6 qualified for a penalty. In the end, all licenses were sold and all monies paid, unlike the C block auction, which resulted in higher prices but many bankruptcies and protracted legal settlements (see note 12).

Appendix B: Public Company Participants in FCC Auction for Blocks A and B

American Portable Telecommunication
Ameritech Wireless Communication
AT&T Wireless PCS, Inc.
Bell Atlantic
Bell South Personal Communication
Century Communication Corp.
Comcast Telephony Services
Continental Cablevision, Inc.
Cox Cable Communications, Inc.
GTE Macro Communications Corp.
Pacific Telesis Mobile Service
PhillieCo, L.P.
PrimeCo.
Southwestern Bell Mobile Systems
WirelessCo, L.P.

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