Deterring Entry with Debt and Capacity

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Abstract

In capital intensive industries, firms face complicated multi-stage financing, investment, and production decisions under the watchful eye of existing and potential industry competitors. We consider a two-stage simplification of this environment. In the first stage, a firm chooses its financing and investment in capacity. In the second stage, the firm chooses its production. Production in the second stage is the traditional transformation of input costs into revenues. Less traditionally, we treat first-stage financing and capacity as factors in the production of an important intermediate good: deterrence. The introduction of a two-factor deterrence production function permits an innovative analysis of the nature of the substitution and complementarity between financial and non-financial approaches to deterring potential competitors.

1 Introduction

Our interest in the use of debt and capacity as deterrence strategies comes from our empirical observation of the U.S. telecommunications industry. Although there have been continuous efforts to deregulate the industry over the past 20 years, the true milestone occurred with the 1996 Act
of Telecommunications which removed significant barriers to entry. Consequently, the number of telecommunication firms more than doubled: from 200 in 1995 to 426 in 2000 as reported in Compustat. In 2001, however, the number dropped to 324. Since then, many firms have not survived the harsher competition in the tight economy. It has also been argued that the regulatory freedom stimulated technological innovation, bringing unprecedented uncertainty to the market. For example, customers are switching from traditional telecom services to new technologies such as the internet, and potential customers are awaiting multimedia (voice, data, and video) services.

During that time, the telecommunications industry undertook an unusual amount of debt and capacity investment. The Wall Street Journal reported that “since 1996, telecoms have borrowed more than $1.5 trillion from banks and issued more than $630 billion of bonds, according to Thomson Financial, a data company - topping all other industries.” In the same article, the Wall Street Journal continues to state that “after the opening of the historically regulated industry to competition, firms went on a building binge.” “By the time the internet bubble burst, an estimated 39 million miles of fiber-optic cable stretched underneath the US.”¹ We investigate the extent to which the two phenomena are related to the increased competition. It is the primary motivation of our paper.

It is well-known that a firm’s capital structure affects its production choice. Brander and Lewis (1986) show that leverage commits the firm to produce more aggressively. When facing demand uncertainty, the leveraged firm can increase its returns in good states of the world and decrease its returns in bad states by producing more. Limited liability allows equityholders to ignore the lowest returns in bankrupt states. The agency problem, a variation of Jensen and Meckling’s (1976) asset

substitution problem, leads to a more aggressive production.\(^2\)

It is also well-known that a firm’s investment in capacity affects its production choice. Since the influential work of Spence (1977), capacity and other forms of investment are recognized as entry deterrents. Dixit (1980) shows that capacity commits the firm to an aggressive strategy. Capacity allows the firm to expand or produce at a lower cost.\(^3\)

We recognize that incumbents may deter potential entrants by increasing their leverage or by investing in capacity. In the next section, we examine the case where the two strategies are chosen simultaneously. We thus consolidate the two separate branches of the deterrence literature. We compare our model of debt and capacity deterrence with Brander and Lewis’s model of debt deterrence and with Dixit’s model of capacity deterrence. We show that debt deterrence is more effective when capacity is also available. And vice-versa: capacity deterrence is more effective when debt is also available. Debt and capacity magnify each other’s deterrence effect. Capacity deters not only through reducing the marginal cost of the incumbent, but also through its influence on the firm’s riskiness. Debt deters more effectively at the higher convexity of the equityholders’ payoff when the capacity investment necessary to produce already reduces the equityholders’ funds.

Also in the next section, we argue that debt and capacity should be considered as factors of production of the intermediate “deterrence” good. Section 3 presents the comparative statics results, where we show that debt and capacity are complements in the production of this intermediate good. When investments in capacity become cheaper, the firm can take on more debt to deter potential entrants without affecting its probability of default. We then present the supporting empirical

\(^2\)Other papers discussing the effect of a firm’s capital structure on its product market include Bolton and Scharfstein (1990); Chevalier (1995); Faure-Grimaud (1998); Fudenberg and Tirole (1986); Fulghieri and Nagarajan (1996); Khanna and Tice (2000); Kovenock and Philips (1997); Maksimovic (1988); Poitevin (1989); and Zingales (1998).

\(^3\)Other papers discussing the effect of a firm’s capacity on its product market include Haruna (1996); Kirman and Masson (1986); Kulatilaka and Perotti (1998); Reynolds and Spulber (1981); Rosenbaum (1989); and Zhang (1993).
evidence in the U.S. telecommunications industry. The last section concludes.

2 Model

We consider two firms, an incumbent and an entrant, over two stages. Both firms are risk neutral and the riskless rate is zero. In the first stage, the incumbent maximizes the firm value by choosing how aggressively it want to deter entry via debt and capacity. In the second stage, the incumbent takes the debt value as given and maximizes the equity value by choosing how much to produce. In the second stage, the entrant chooses how much to produce. The following time line illustrates these choices:

<table>
<thead>
<tr>
<th>first stage</th>
<th>second stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incumbent chooses: debt and capacity</td>
<td>production</td>
</tr>
<tr>
<td>Entrant chooses:</td>
<td>production</td>
</tr>
</tbody>
</table>

We do not allow the incumbent to adjust its debt or capacity in the second stage. Debt and capacity are irreversible and credibly commit the firm to produce more aggressively. In reality, firms can retire debt and sell off assets. The model captures the fact that firms can only do so at a sizeable cost.

We do not consider debt as a means to finance the capacity investment. Following Brander and Lewis, we are strictly interested in its deterrence ability. Once the debt is raised, it is paid out to equityholders in the form of a dividend. If the debt proceeds were kept within the firm, the debt would be less risky. Without risky debt, the asset substitution effect of the production choice disappears. In reality, firms use debt to finance their operations. In the empirical analysis,
we account for the debt financing motive and show that debt is also used as a deterrent in the deregulated U.S. telecommunications industry.

The first stage deterrence choices and the second stage production choices are described below. Solving backwards, we begin by discussing the production choices.

2.1 Second Stage: Production

In the second stage, both the incumbent $I$ and the entrant $E$ choose how much to produce. Both observe and take as given the incumbent’s first stage deterrence choices of debt and capacity when choosing their production. The incumbent maximizes its equity value

$$\max_{q^I} \int_P \{ P(q^I + q^E, z)q^I - rk^I - \eta + \alpha - F^I \} d\Phi(z)$$

subject to the capacity constraint

$$q^I \leq k^I.$$  \hspace{1cm} (2)

The production level of the incumbent is denoted by $q^I$ and the production level of the entrant by $q^E$. The source of risk in the model is represented by a stochastic demand shock $\tilde{z}$. The market price schedule of the good produced $P(q^I + q^E, \tilde{z})$ depends on the aggregate quantity supplied and the stochastic shock. The debt face value and capacity level are represented by $F^I$ and $k^I$, where the cost of one unit of capacity is $r$. The entry cost, the main parameter affected by the deregulation, is represented by $\eta$. To insure that the incumbent has enough funds to pay its capacity and entry cost, the incumbent is endowed with initial funds $\alpha$. The initial funds insure that no debt is needed to finance the capacity. However, the initial funds should not be high enough that default never occurs. Default must occur at the lowest possible demand shock, otherwise the debt is riskless and cannot deter. The parameter value for $\alpha$ is thus chosen so that $-rk^I - \eta + \alpha > 0$ and $P(q^I + q^E, \tilde{z})q^I - rk^I - \eta + \alpha - F^I < 0$. 

5
The incumbent’s equity value accounts for the limited liability. The point at which equityholders default \( z \) is defined by

\[
P(q^I + q^E, \tilde{z})q^I - rk^I - \eta + \alpha - F^I = 0. \tag{3}
\]

When equityholders’ payoff is insufficient to repay the face value to debtholders, they trigger default. They walk away from their debt obligation and instead transfer the residual firm value to debtholders.

We simplify the analysis by specifying that the shock \( z \) follows a uniform cumulative probability distribution \( \Phi \) over the range \([\underline{z}, \overline{z}]\) where \(-\infty < \underline{z} < \overline{z} < \infty\). Because the distribution is uniform, the probability density function is \( \phi(z) = \frac{1}{\overline{z} - \underline{z}} \) and cumulative distribution function is \( \Phi(z) = \frac{z - \underline{z}}{\overline{z} - \underline{z}} \).

We further assume that \( \underline{z} = -\overline{z} \) so that the mean shock is zero.

We again simplify the analysis by specifying a linear demand schedule

\[
P(q^I + q^E, \tilde{z}) = a + \tilde{z} - b(q^I + q^E), \tag{4}
\]

where \( a \) is the price intercept and \( b \) is the unit price elasticity of output.

The entrant maximizes its firm value by choosing how much to produce

\[
\max_{q^E} \int_{\underline{z}}^{\overline{z}} \{ P(q^I + q^E, \tilde{z})q^E - wq^E - \eta + \alpha \} \, d\Phi(\tilde{z}). \tag{5}
\]

There are two features to note about the entrant’s problem. First, the entrant faces a higher cost \( w > r \) to build capacity when it also has to produce in that same stage. Second, it is irrelevant whether or not the entrant has access to the debt market because the Modigliani and Miller (1958) theorem holds. Without loss of generality, the entrant’s entry cost \( \eta \) and initial funds \( \alpha \) are assumed to be equal to those of the incumbent.
There are two possible solutions for the incumbent’s and entrant’s production choices, depending whether or not the capacity constraint of the incumbent is binding. The interior solution is

\[ q^I = \frac{a + w + z + \tilde{z}}{3b} \]  

(6)

\[ q^E = \frac{2a - 4w - z - \tilde{z}}{6b} \]  

(7)

and the corner solution is

\[ q^I = k^I \]  

(8)

\[ q^E = \frac{a - w - bk^I}{2b}. \]

(9)

In the case of the interior solution, it is possible to see the result of the incumbent’s deterrence: the incumbent’s production \( q^I \) is greater than entrant’s production \( q^E \). The entrant’s production choice \( q^E \) is negatively related to the incumbent’s default point \( \tilde{z} \). Whenever the incumbent finds a way to increase its probability of defaulting, it discourages the entrant from producing more. Equation (3) shows that more debt \( F^I \) or more capacity investment \( rk^I \) increases the default point \( \tilde{z} \). Both expenses decrease the funds available to equityholders and increase the probability of default. The incumbent can thus deter through debt or capacity. However, this capacity deterrence is different from Dixit: capacity deters not only through reducing the marginal cost to the incumbent, but also through its influence on the default point \( \tilde{z} \). The debt deterrence is similar to Brander and Lewis: debt only influences the default point. However, because capacity is necessary for production and the capacity investment already decreases the default point, debt deters more effectively at the higher convexity of the equityholders’ payoff.

In the case of the corner solution, the entrant’s production choice \( q^E \) is negatively related to the incumbent’s capacity choice \( k^I \) but unaffected by the incumbent’s debt choice \( F^I \) (or \( \tilde{z} \)). The
incumbent’s own production choice \( q^I \) is determined only by the capacity not by its debt. Debt does not deter.

### 2.2 First Stage: Debt and Capacity Deterrence

In the first stage, the incumbent maximizes its equity value by choosing how much debt to issue and how much to invest in capacity

\[
\max_{F^I, B^I, D^I, k^I} \int_{\mathbb{P}} \left\{ P(q^I + q^E, \bar{z})q^I - rk^I - \eta + \alpha - F^I + B^I - D^I \right\} d\Phi(\bar{z})
\]

(10)

subject to fairly pricing its debt

\[
B^I = \int_{\mathbb{P}} F^I d\Phi(\bar{z}) + \int_{\bar{z}} \left\{ P(q^I + q^E)q^I - rk^I - \eta + \alpha + B^I - D^I \right\} d\Phi(\bar{z})
\]

(11)

and given that the debt issue is immediately paid out to equityholders

\[
D^I = B^I.
\]

(12)

The fair-pricing equation states that the market value of the debt \( B^I \) is equal to the expected debt face value \( F^I \) when no default occurs (i.e., when \( \bar{z} > \bar{z} \)) and the expected residual firm value when default does occur (i.e., when \( \bar{z} \leq \bar{z} \)).

The incumbent’s problem reduces to maximizing the firm value

\[
\max_{F^I, k^I} \int_{\bar{z}} \left\{ P(q^I + q^E, \bar{z})q^I - rk^I - \eta + \alpha \right\} d\Phi(\bar{z}).
\]

(13)

#### 2.2.1 Interior Solution in Production

Substituting for the interior solution in production, the incumbent’s problem is written as

\[
\Pi^I_{\text{interior}} = \max_{F^I, k^I} \int_{\bar{z}} \left\{ \left( \frac{2a + 2w - \bar{z} - \bar{z}}{6} \right) \left( \frac{a + w + \bar{z} + \bar{z}}{3b} \right) - rk^I - \eta + \alpha \right\} d\Phi(\bar{z}).
\]

(14)
The first-order conditions with respect to debt $F^I$ and capacity $k^I$ are

$$\left(\frac{a + w - 2z - 2\hat{z}}{18b}\right) \frac{\partial \hat{z}}{\partial F^I} = 0$$  \hspace{1cm} (15)

and

$$\left(\frac{a + w - 2z - 2\hat{z}}{18b}\right) \frac{\partial \hat{z}}{\partial k^I} - r = 0.$$  \hspace{1cm} (16)

We first consider that debt and capacity are not interior solutions as described in equations (15) and (16) but determined at a corner. Recall that the constraints for debt $F^I$ and capacity $k^I$ are $F^I > P(q^I + q^E, \hat{z})q^I - rk_I - \eta + \alpha$ and $k^I \geq q^I$. Both constraints are lower boundaries so that no upper limit is placed on debt and capacity. However, we rule out the possibility of infinite debt and infinite capacity. We also rule out the possibility of riskless debt $F^I = \epsilon + P(q^I + q^E, \hat{z})q^I - rk_I - \eta + \alpha$. The only interesting possible corner solution occurs when the incumbent produces at capacity $k^I = q^I$.

Because we are interested in an interior solution for the debt $F^I$, we begin by discussing its first-order equation. Equation (15) implies

$$\frac{a + w - 2z - 2\hat{z}}{18b} = 0$$  \hspace{1cm} (17)

or

$$\frac{\partial \hat{z}}{\partial F^I} = 0.$$  \hspace{1cm} (18)

It cannot be the case that the debt face value has no effect on the default point. Substituting for the incumbent’s and entrant’s production choices of equations (6) and (7) in the default definition (3) and totally differentiating the default definition yields

$$\frac{\partial \hat{z}}{\partial F^I} = \frac{18b}{7a + 4x + 10\hat{z} + 7w - 18br \frac{\partial \hat{z}}{\partial x}}.$$  \hspace{1cm} (19)
Equation (18) can only hold if $\tilde{z} = \pm \infty$ or $\frac{\partial k^I}{\partial F} = \pm \infty$. The default point at infinity $\tilde{z} = \pm \infty$ is impossible because $\tilde{z}$ is bounded between $[\underline{z}, \overline{z}]$. In any case, it would not be interesting that debt be riskless ($\tilde{z} = -\infty$) or always in default ($\tilde{z} = +\infty$). An infinite effect of the default point on the capacity $\frac{\partial k^I}{\partial F} = \pm \infty$ is also impossible. Alternatively stated, it cannot be the case that capacity has no effect on the default point $\frac{\partial \hat{z}}{\partial k^I} = 0$. If it were the case, substituting for $\frac{\partial \hat{z}}{\partial k^I} = 0$ in the first-order condition (16) indicates a corner solution where the capacity is equal to the incumbent’s production $k^I = q^I = \frac{a + w + \overline{z} + \underline{z}}{3b}$. Differentiating the capacity with respect to the default point yields $\frac{\partial k^I}{\partial F} = \frac{1}{3b}$ which contradicts $\frac{\partial k^I}{\partial F} = \pm \infty$.

Hence the first order condition for the debt $F^I$ determines the default point

$$\tilde{z}^* = \frac{a + w}{2} - \overline{z}. \quad (20)$$

Substituting for this in the first-order condition of the capacity (16) indicates a corner solution in capacity

$$k^I^* = q^I^*. \quad (21)$$

Finally, substituting for the default point $\tilde{z}^*$ in the production choices (6) and (7) and in the default definition (3) yields

$$q^I^* = \frac{a + w}{2b}, \quad (22)$$

$$q^E^* = \frac{a - 3w}{4b}, \quad (23)$$

and

$$F^I^* = \frac{(a + w)(3a + 3w - 4\overline{z} - 4\underline{z})}{8b} - \eta + \alpha. \quad (24)$$
2.2.2 Corner Solution in Production

Substituting for the corner solution in production, the incumbent’s problem is written as

$$
\Pi_{\text{corner}}^I = \max_{F^I, k^I} \int_{\bar{z}} \left\{ \left( \frac{a + w - bk^I}{2} \right) k^I - rk^I \eta + \alpha \right\} d\Phi(\bar{z}). \tag{25}
$$

Debt does not appear in the incumbent’s problem. Debt has no deterrence effect on production. There are infinite solutions of debt face value $F^I^*$ and the default point $\bar{z}^*$ that satisfy the default definition (3).

The first-order condition with respect to capacity $k^I$ gives

$$
k^I^* = \frac{a + w - 2r}{2b}. \tag{26}
$$

Substituting for this in the production choices (8) and (9) yields

$$
q^I^* = k^I^* \tag{27}
$$

and

$$
q^E^* = \frac{a - 3w + 2r}{4b}. \tag{28}
$$

As in the case of the interior solution, it is possible to see the result of the incumbent’s deterrence: the incumbent’s production $q^I$ is greater than the entrant’s production $q^E$. The incumbent’s production $q^I^*$ is smaller here than with an interior solution and, conversely, the entrant’s production $q^E^*$ is greater here than with an interior solution. This suggests that deterrence with capacity only is less effective than deterrence using debt and capacity. We indeed find that the incumbent’s first stage firm value is higher when debt also deters

$$
\Pi_{\text{interior}}^I = \frac{a + w}{2b} \left( \frac{a + w}{4} - r \right) - \eta + \alpha > \Pi_{\text{corner}}^I = \frac{a + w}{2b} \left( \frac{a + w}{4} - \frac{r}{2} \right) - \eta + \alpha. \tag{29}
$$
The optimal debt, default point, capacity, and production choices corresponding to the interior solution in production of equations (21) to (24).

Next, we compare our model with a model of debt deterrence as in Brander and Lewis and with a model of capacity deterrence as in Dixit.

2.3 Deterring with Debt Only

The incumbent’s problem is very similar as before, except that there is no capacity investment \( r_k^I \) necessary to produce and no corresponding constraint \( q^I < k^I \). In the second stage, the incumbent maximizes its equity value

\[
\max_{q^I} \int_{\Phi} \left\{ P(q^I + q^E, \bar{z})q^I - \eta + \alpha - F^I \right\} d\Phi(\bar{z}),
\]  

(30)

where the default point is defined by

\[
P(q^I + q^E, \bar{z})q^I - \eta + \alpha - F^I = 0.
\]  

(31)

The entrant’s problem is also very similar, except that there is no capacity investment \( wq^E \) necessary to produce. The entrant maximizes its firm value

\[
\max_{q^E} \int_{\Phi} \left\{ P(q^I + q^E, \bar{z})q^E - \eta + \alpha \right\} d\Phi(\bar{z}).
\]  

(32)

The incumbent’s and entrant’s production choices are

\[
q^I = \frac{a + \bar{z} + \bar{z}}{3b}
\]  

(33)

and

\[
q^E = \frac{2a - \bar{z} - \bar{z}}{6b}.
\]  

(34)
We again see the result of the incumbent’s deterrence: the incumbent’s production \( q^I \) is greater than entrant’s production \( q^E \).

In the first stage, the incumbent maximizes its equity value by choosing how much debt to issue

\[
\max_{F^I,B^I,D^I} \int_{\bar{z}} \{ P(q^I + q^E, \bar{z})q^I - \eta + \alpha - F^I + B^I - D^I \} \, d\Phi(\bar{z})
\]  

subject to fairly pricing its debt

\[
B^I = \int_{\bar{z}} F^I d\Phi(\bar{z}) + \int_{\bar{z}} \{ P(q^I + q^E)q^I - \eta + \alpha + B^I - D^I \} \, d\Phi(\bar{z})
\]

and given that the debt issue is immediately paid out to equityholders

\[
D^I = B^I.
\]

The incumbent’s problem again reduces to maximizing the firm value

\[
\max_{F^I} \int_{\bar{z}} \{ P(q^I + q^E, \bar{z})q^I - \eta + \alpha \} \, d\Phi(\bar{z}).
\]

Substituting for the second-stage production choices (33) and (34), the incumbent’s problem is written as

\[
\max_{F^I} \int_{\bar{z}} \left\{ \left( \frac{2a - \bar{z} - \hat{z}}{6} \right) \left( \frac{a + \bar{z} + \hat{z}}{3b} \right) - \eta + \alpha \right\} \, d\Phi(\bar{z}).
\]

The first-order condition with respect to debt \( F^I \) is

\[
\left( \frac{a - 2\bar{z} - 2\hat{z}}{18b} \right) \frac{\partial \hat{z}}{\partial F^I} = 0.
\]

As before, it cannot be the case that the debt face value has no effect on the default point.

Substituting for the incumbent’s and entrant’s production choices of equations (33) and (34) in the default definition (31) and totally differentiating the default definition yields

\[
\frac{\partial \hat{z}}{\partial F^I} = \frac{18b}{7a + 10\hat{z} + 4\bar{z}}.
\]
The debt face value has no effect on the default point only if $\tilde{z} = \pm \infty$. The default point at infinity $\tilde{z} = \pm \infty$ is impossible because $\tilde{z}$ is bounded between $[\underline{z}, \bar{z}]$. As before, it would not be interesting to consider riskless debt ($\tilde{z} = -\infty$) or debt always in default ($\tilde{z} = +\infty$). Hence the first-order condition (40) determines the default point

$$\tilde{z}^* = \frac{a}{2} - \frac{\bar{z}}{2}.$$ (42)

Substituting the production choices (33) and (34) and in the default definition (31) yields

$$q^I^* = \frac{a}{2b},$$ (43)

$$q^E^* = \frac{a}{4b},$$ (44)

and

$$F^I^* = \frac{a(3a - 4\bar{z})}{8b} - \eta + \alpha.$$ (45)

Table I summarizes the differences between debt deterrence when capacity is also used to deter and debt deterrence when capacity is not used. When capacity is not necessary to produce, the capacity investment no longer draws on the equityholders’ funds, leading to a lower probability of defaulting (lower $\tilde{z}^*$). Because the debt is less risky, it does not deter as much (higher $q^E^*$ and lower $q^I^*$).

### 2.4 Deterring with Capacity Only

The incumbent’s problem is very similar as before, except that there is no debt. In the second stage, the incumbent maximizes its firm value

$$\max_{q^I} \int_{\bar{z}}^{\tilde{z}} \left\{ P(q^I + q^E, \tilde{z}) q^I - r k^I - \eta + \alpha \right\} d\Phi(\tilde{z})$$ (46)
subject to the capacity constraint

\[ q^I \leq k^I. \]  

(47)

The entrant’s problem is the same as before. The entrant maximizes its firm value

\[
\max_{q^E} \int_{\mathbb{Z}} \{ P(q^I + q^E, \bar{z})q^E - wq^E - \eta + \alpha \} \, d\Phi(\bar{z}).
\]  

(48)

As before, there are two possible solutions for the incumbent’s and entrant’s production choices, depending whether or not the capacity constraint of the incumbent is binding. The interior solution is

\[
q^I^* = \frac{a + w}{3b},
\]

(49)
\[
q^E^* = \frac{a - 2w}{3b},
\]

(50)
while the corner solution is the same as before

\[
q^I = k^I
\]

(51)
\[
q^E = \frac{a - w - bk^I}{2b}.
\]

(52)

For the case of the interior solution, it is possible to see the result of the incumbent’s deterrence: the incumbent’s production \( q^I \) is greater than entrant’s production \( q^E \).

In the first stage, the incumbent maximizes its firm value

\[
\max_{k^I} \int_{\mathbb{Z}} \{ P(q^I + q^E, \bar{z})q^I - rk^I - \eta + \alpha \} \, d\Phi(\bar{z}).
\]  

(53)

Substituting for the interior solution in production, the incumbent’s problem is written as

\[
\Pi_{\text{interior}}^I = \max_{k^I} \int_{\mathbb{Z}} \left\{ \left( \frac{(a + w)^2}{9b} \right) - rk^I - \eta + \alpha \right\} \, d\Phi(\bar{z}).
\]  

(54)
Clearly, the smallest capacity $k^I$ feasible maximizes the incumbent’s problem

$$k^I^* = q^I^*. \quad (55)$$

Substituting for the corner solution in production, the incumbent’s problem is written as

$$\Pi_{corner}^I = \max_{k^I} \int_\mathbb{Z} \left\{ \frac{(a + w - bk^I)}{2} - rk^I - \eta + \alpha \right\} d\Phi(z). \quad (56)$$

The first-order condition with respect to capacity $k^I$ gives the same solution as before

$$k^I^* = \frac{a + w - 2r}{2b}. \quad (57)$$

Substituting for this in the production choices (51) and (52) yields

$$q^I^* = k^I^* \quad (58)$$

and

$$q^E^* = \frac{a - 3w + 2r}{4b}. \quad (59)$$

As in the case of the interior solution, it is now possible to see the result of the incumbent’s deterrence: the incumbent’s production $q^I$ is greater than entrant’s production $q^E$.

For the case of the interior solution, capacity does not directly affect the production. The capacity commitment deters only through a lower cost $r < w$ to the incumbent. For the case of the corner solution however, capacity deters by reducing the cost to the incumbent as well as by directly reducing the entrant’s production. Equation (52) indeed shows that the entrant’s production $q^E$ is negatively related to capacity $k^I$. We find that the incumbent’s first stage firm value is higher at
the corner solution in production

\[
\Pi_{\text{interior}}^I = \left(\frac{a+w}{2b}\right) \left(\frac{a+w}{4} - r\right) - \eta + \alpha < \Pi_{\text{corner}}^I = \left(\frac{a+w-2r}{2b}\right) \left(\frac{a+w}{4} - \frac{r}{\mathcal{E}}\right) - \eta + \alpha
\]

\[
0 < \frac{(a+w)^2}{72b} - r \left(\frac{a+w}{6b}\right) + \frac{r^2}{2b}
\]

\[
0 < \frac{1}{72b} \left( (a+w)^2 - 12r + 36r^2 \right)
\]

\[
0 < \frac{1}{72b} (a + w - 6r)^2 \tag{60}
\]

The optimal capacity and production choices correspond to the corner solution in production of equations (57) to (59).

Table II summarizes the differences between capacity deterrence when debt is also used to deter and capacity deterrence when debt is not used. When debt deterrence is not used, the incumbent invests less in capacity (lower \(k^I^*\)). Capacity does not deter as much (higher \(q^E^*\) and lower \(q^I^*\)). It only deters through the lower cost to the incumbent \(r < w\). It no longer influences the default point.

Tables I and II show that the incumbent reduces the entrant’s production \(q^I^* > q^E^*\) with the use of debt and/or capacity. Table I shows that debt deters more effectively (i.e., leads to a lower \(q^E^*\)) when capacity is also available and Table II shows that capacity deters more effectively when debt is also available. Debt and capacity magnify each other’s deterrence effect. Capacity deters not only through the lower cost to the incumbent, but also through its influence on the default point \(\bar{z}\). Debt deters more effectively at the higher convexity of the equityholders’ payoff. Because capacity is necessary for production, the capacity investment reduces the equityholders’ funds and increases the default point.
2.5 Deterrence Production Function

[to be written.]

3 Empirical Evidence

3.1 Comparative Static Results

The comparative static results generate possible hypotheses to be tested in the data. We differentiate the debt $F^I^*$ and capacity $k^I^*$ solutions of equations (21) and (24) as well as the debt-to-capacity ratio $F^I^*/k^I^*$ with respect to all model parameters: the price intercept $a$, the unit price elasticity of output $b$, the dispersion of the distribution $\bar{z} = -z$, the incumbent’s capacity investment cost $r$, the entrant’s cost $w$, the entry cost $\eta$, and initial funds $\alpha$. The signs of the derivatives are displayed in table III.

We first discuss the effect of market parameters. A higher price intercept $a$ represents a strong demand, which leads to a higher production. Both debt $F^I^*$ and capacity $k^I^*$ increase, but the effect on the debt-to-capacity ratio is indeterminate.

A higher price elasticity of output $b$ means that the aggregate production has a larger effect on the market price. The incumbent does not find it profitable to deter as aggressively as before. Both debt $F^I^*$ and capacity $k^I^*$ decrease. The effect on capacity is more important than the effect on debt due to the direct link between capacity and production, leading to a higher debt-to-capacity ratio.

A wider dispersion of the demand shock distribution, i.e., a higher $\bar{z}$, does not affect capacity $k^I^*$. Debt however becomes more risky and the firm does not need to issue as much debt to deter entry. Both the debt $F^I^*$ and the debt-to-capacity ratio are lower.

We now discuss the effect of firm-specific parameters. A higher capacity cost $r$ to the incumbent
does not affect capacity $k^I\ast$. This counter-intuitive result arises because the optimal capacity is a corner solution at its minimum feasible value. With a higher capacity cost, the incumbent cannot afford to raise as much debt. Both the debt $F^I\ast$ and the debt-to-capacity ratio are lower. This negative relation between the capacity cost and the debt face value confirms that debt and capacity are complements in the deterrence production function.

A higher capacity cost $w$ to the entrant increases the capacity advantage of the incumbent. Facing higher cost, the entrant decreases its production while the incumbent increases its production. Because capacity deterrence is more effective, the incumbent increases capacity $k^I\ast$. The incumbent benefits from the higher production and can afford to increase its debt $F^I\ast$. However, the effect on the debt-to-capacity ratio is indeterminate.

A higher entry cost $\eta$ does not affect capacity $k^I\ast$. The higher cost however increases the default point $\hat{z}$. To deter with debt, the incumbent increases its debt $F^I\ast$. The debt-to-capacity ratio is consequently higher. Higher initial funds $\alpha$ lead to the converse effect: no effect on capacity $k^I\ast$ but decreases in debt $F^I\ast$ and in the debt-to-capacity ratio.

We examine the U.S. telecommunications industry around the 1996 deregulation. Controlling for non-deterrence factors influencing capacity and debt, we find that incumbent firms (those that exist before 1996) increase their debt-to-capacity ratio after 1996.

[Preliminary results done, but not incorporated in the text yet.]

These results are consistent with the anecdotal evidence reported in the Wall Street Journal and Johnson’s (1989) discussion of an anticompetitive use of excess capacity in telecommunications industry.
4 Conclusion

[To be written.]
REFERENCES


Table I: Debt Deterrence With and Without Capacity Deterrence

<table>
<thead>
<tr>
<th></th>
<th>Debt and Capacity</th>
<th>Debt Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q^*_I$</td>
<td>$(a + w)/2b$</td>
<td>&gt; $a/2b$</td>
</tr>
<tr>
<td>$q^*_E$</td>
<td>$(a - 3w)/4b$</td>
<td>&lt; $a/4b$</td>
</tr>
<tr>
<td>$F^*_I$</td>
<td>$(a + w)(3a + 3w - 4\bar{z} - 4r)/8b - \eta + \alpha$</td>
<td>$(3a - 4\bar{z})a/8b - \eta + \alpha &gt; a/2 - \bar{z}$</td>
</tr>
<tr>
<td>$\bar{z}$</td>
<td>$(a + w)/2 - \bar{z}$</td>
<td></td>
</tr>
</tbody>
</table>

Note: The production level of the incumbent is denoted by $q^I$, the production level of the entrant by $q^E$, the debt face value of the incumbent by $F^I$, and the default point of the incumbent by $\bar{z}$.  


Table II: Capacity Deterrence With and Without Debt Deterrence

<table>
<thead>
<tr>
<th></th>
<th>Debt and Capacity</th>
<th>Capacity Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q^I^*$</td>
<td>$(a + w)/2b$</td>
<td>$(a + w - 2r)/2b$</td>
</tr>
<tr>
<td>$q^E^*$</td>
<td>$(a - 3w)/4b$</td>
<td>$(a - 3w + 2r)/4b$</td>
</tr>
<tr>
<td>$k^I^*$</td>
<td>$(a + w)/2b$</td>
<td>$(a + w - 2r)/2b$</td>
</tr>
</tbody>
</table>

Note: The production level of the incumbent is denoted by $q^I$, the production level of the entrant by $q^E$, and the capacity of the incumbent by $k^I$. 
Table III: Comparative Static Results

<table>
<thead>
<tr>
<th>Parameters</th>
<th>$F^I$</th>
<th>$k^I$</th>
<th>$F^I$/$k^I$</th>
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</thead>
<tbody>
<tr>
<td>$a$</td>
<td>+</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>$b$</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>$\bar{z}$</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>$r$</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>$w$</td>
<td>+</td>
<td>+</td>
<td>?</td>
</tr>
<tr>
<td>$\eta$</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>

Note: The price intercept is denoted by $a$, the unit price elasticity of output by $b$, the dispersion of the demand shock distribution by $\bar{z} = -\Delta$, the capacity cost to the incumbent by $r$, the capacity cost to the entrant by $w$, the entry cost by $\eta$, and initial funds by $\alpha$. 