

# On the Strategic Use of Debt and Capacity in Imperfectly Competitive Product Markets

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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 rivals. We consider a two-stage simplification of this environment. In the first stage, an incumbent firm benefits from two first-mover advantages by precommitting to a debt financing policy and a capacity investment policy. In the second stage, the incumbent and a single-stage rival simultaneously choose production levels and realize stochastic profits. We characterize the incumbent's first-stage debt and capacity choices as factors in the production of an intermediate good we call "output deterrence." In our two-factor deterrence model, we show that the incumbent chooses a *unique* capacity policy and a *threshold* debt policy to achieve the optimal level of deterrence coinciding with full Stackelberg leadership. When we remove the incumbent's first-mover advantage in capacity, the full Stackelberg level of deterrence is still achievable, albeit with a higher level of debt than the threshold. In contrast, when we remove the incumbent's first-mover advantage in debt, the Stackelberg level of deterrence may no longer be achievable and the incumbent may suffer a dead-weight loss. Evidence on the telecommunications industry shows that firms have increased their leverage in a manner consistent with deterring potential rivals following the 1996 deregulation.

# 1 Introduction

Our interest in the use of debt and capacity as factors in the deterrence of a rival's output is in part due to recent dramatic shifts in the U.S. telecommunications industry's competitive landscape. Although there has been ongoing effort to deregulate the industry over the past 20 years, the true breakthrough occurred when the 1996 Telecommunications Act removed significant barriers in providing telecommunications access to U.S. homes. Subsequent to the Act, the number of telecommunication firms has varied considerably. Figure 1 shows that the number of telecommunication firms increased from 369 in 1995 to 447 in 2000, and then decreased to 282 in 2002 in the aftermath of the "tech bubble."<sup>1</sup>

During that time, the telecommunications industry issued a great deal of debt and deployed extensive capacity in anticipation of future demand and competition. The Wall Street Journal reports 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 also states 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."<sup>2</sup>

The large number of new competitors suggests that the incumbents' use of debt and capacity

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<sup>1</sup>Based on COMPUSTAT's sample of firms with positive asset values (data item 6).

<sup>2</sup>The article "Domino Effect-Telecom's Troubles Spread From Upstarts To Sector's Leaders" appeared on the front page A1 on March 13, 2002.

may not have significantly diminished new entry in the telecommunications marketplace. Figure 2 shows that, although concentration decreased from an average Herfindahl index of 0.1877 in 1995 to 0.1282 in 1999, it then rebounded to 0.2247 in 2002.<sup>3</sup> Following the industry shake-out, many incumbent firms have been able to remain dominant players.

While a traditional notion of deterrence is keeping a potential entrant from actually entering, we are interested in how an incumbent attenuates a rival's production even when entry occurs. It is well-known that a firm's capacity investment can affect its own, and a rival's, production choices. Since the influential work of Spence (1977), capacity and other forms of investment have been recognized as deterrents to potential entrants. Dixit (1980) analyzes how capacity can commit an incumbent to a subsequent aggressive production strategy. As an incumbent's capacity costs become "sunk" by production time, they effectively lower the relevant marginal cost of incumbent production thereby inducing a traditional Cournot game where the incumbent has a cost advantage. It then follows from standard Cournot results for duopolists with differing production costs, that the incumbent produces at a level higher than the entrant who is deterred from the higher Nash production level.<sup>4</sup>

It is also a well-known theoretical notion that a firm's debt commitments can affect its production choice through convexity in the equity payoff. Brander and Lewis (1986) demonstrate that debt provides a future incentive to produce more aggressively. An increase in production enhances

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<sup>3</sup>Based on COMPUSTAT's sales (data item 12) using observations with the same four-digit SIC codes.

<sup>4</sup>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 (1991); Rosenbaum (1989); and Zhang (1993).

the firm's equity payoff in good states with a less than offsetting decrease in payoff in bad states (due to the limited liability of equityholders). The agency problem, a variation of Jensen and Meckling's (1976) asset substitution problem, leads to more aggressive production.<sup>5</sup>

We examine the case where financial (debt) and real (capacity) strategies are chosen with the foresight that they may effectively precommit the incumbent to produce aggressively and thereby deter at least a portion of a rival's production. In dealing with the two factors of deterrence production, we integrate two separate branches of the deterrence literature allowing us to address the interactions and tradeoffs in deterring with debt versus deterring with capacity. For completeness, we compare our two-factor model to Brander and Lewis's single-factor model of debt deterrence, to Dixit's single-factor model of capacity deterrence, and to the traditional Nash and Stackelberg solutions. We show that debt and capacity can be, but will not always be, factor substitutes in the production of deterrence. We demonstrate that the two factors interact to produce deterrence through their joint production of convexity in the equity payoff. Importantly, however, the range in which the factors can jointly influence equity convexity is limited. Because production is constrained by the capacity in place, adding debt above a specific threshold level cannot increase production. Consequently, our deterrence production function exhibits regions where the factors have Leontief non-substitutability and zero marginal deterrence-product.

At the equilibrium, the incumbent produces at capacity and uses debt to achieve the optimal

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<sup>5</sup>Other papers discussing the effect of a firm's capital structure on its product market include Bolton and Scharfstein (1990), Chevalier (1995), Faure-Grimaud (1997), Fudenberg and Tirole (1986), Fulghieri and Nagarajan (1996), Khanna and Tice (2000), Kovenock and Philips (1997), Maksimovic (1988), Phillips (1995), Poitevin (1989), Rotemberg and Scharfstein (1990), Showalter (1999), and Zingales (1998).

level of deterrence. The optimal level of deterrence coincides with the Stackelberg leadership solution. Full Stackelberg leadership is also achieved when the firm deters with debt only. This may not be the case when the firm deters with capacity only. With capacity-only deterrence, the incumbent may suffer a deadweight loss. Our results suggest that examining debt deterrence on its own, as in Brander and Lewis, is likely to overstate the amount needed when incumbents also have first-mover advantages in paying sunk capacity costs. Examining capacity deterrence on its own can be similarly misleading. In fact, when the convexity induced by debt is sufficiently high, the incumbent may not perceive any advantage to paying capacity costs as a first-mover.

Admittedly, the empirical evidence supporting debt deterrence is not overwhelming. Chevalier (1995) on supermarkets, Khanna and Tice (2000) on discount department stores, Phillips (1995) on four manufacturing industries, and Kovenock and Phillips (1997) on firms within ten manufacturing industries show that large recapitalizations tend to lead to softer product market competition, inconsistent with the prediction of Brander and Lewis. Nonetheless, the rapidly growing telecommunication industry may behave differently from some of the mature industries considered in these studies, particularly when the mature industries are consolidating (e.g., the supermarket industry). Additionally, even in the existing studies, there is some evidence that increases in debt may precede tougher competition. For example, Khanna and Tice show that competition among discount department stores becomes tougher following leveraged buyouts and Phillips finds that debt makes the product market competition tougher in one of the four industries he considers (gypsum). Phillips attributes this different result to the fact that there are less barriers to entry in the gypsum

market.

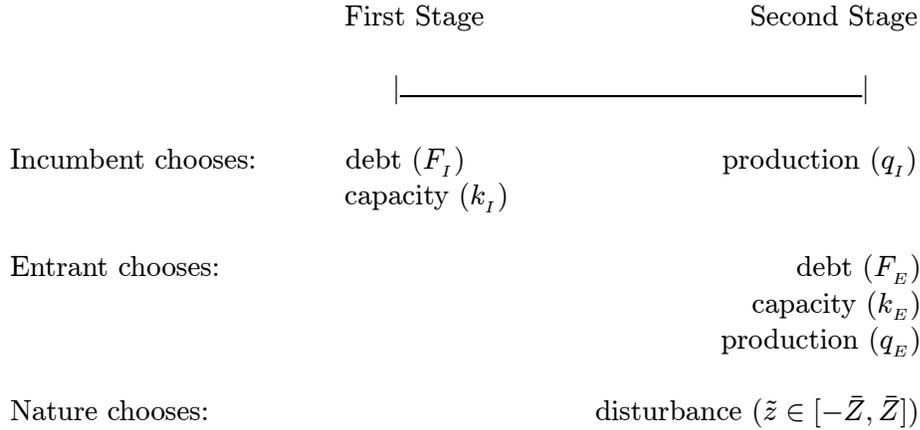
This empirical literature takes considerable effort to account for the firms' endogenous decision to increase leverage. Instead of dealing with the endogeneity problem, however, our approach lies with the exogenous deregulation event in the telecommunications industry. Zingales (1998) also relies on a natural experiment: the rate deregulation and entry in the trucking industry. He documents that incumbent firms were negatively affected by the rate competition and that those with the highest existing leverage were least likely to survive. In contrast, our natural experiment does not deal with a rate deregulation. We find that firms increased their leverage in a manner consistent with deterring potential rivals.

This paper proceeds as follows. Section 2 introduces our two-factor model of deterrence. Section 3 analyzes the production subgame. Section 4 characterizes the incumbent's first-stage optimal choices of debt and capacity. Section 5 presents supporting empirical evidence using a sample of telecommunications firms around the period of the 1996 deregulation. Section 6 concludes.

## **2 A Two-Factor Model of Deterrence**

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 firm value by choosing how aggressively it wants to deter a rival's production through the incumbent's choice of debt and capacity. In the second stage, the incumbent and the entrant take the incumbent's debt and capacity choices as given and maximize their equity payoffs by choosing how much to produce. The

following timeline illustrates these choices:



where, for simplicity, we assume a linear inverse demand function  $p(q_I, q_E) = (a + \tilde{z} - b(q_I + q_E))$  with stochastic intercept  $(a + \tilde{z})$  and slope  $b$ .<sup>6</sup> The sequencing introduces the ability for the incumbent to use debt and capacity (both assumed to be common knowledge prior to production) to influence the production subgame equilibrium. The critical feature here, and in Dixit, is that the incumbent's debt and capacity choices are observable prior to production, whereas the entrant's are not. We assume the incumbent's choices are irreversible prior to production. The incumbent and the entrant deploy debt and capacity only once in this model. As we demonstrate below, and Dixit argues, the incumbent would not deploy additional capacity in the second stage even if allowed.

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<sup>6</sup>As we hope will become obvious, our basic insights are not confined to the case of linear demand although it provides a very useful tractability.

### 3 The Production Subgame

We analyze a Cournot production subgame and its Nash equilibria. In this subgame, the incumbent is constrained to choose only feasible quantities,  $q_I \leq k_I$ ; the incumbent's capacity costs of  $r_I k_I$  are sunk; its debt financing is fixed; and both debt and capacity are common knowledge. Consequently, the entrant's production choice can be adapted to the incumbent's debt and capacity, raising explicitly the possibility of strategic deterrence. In contrast, we assume that the incumbent does not observe the entrant's debt and capacity choices prior to production and therefore cannot adapt its production to the entrant's debt and capacity choices. We assume that  $\tilde{z}$  is drawn after production, that the only marginal production cost is the capacity cost, and that existing equity bases, if any, are denoted by  $\alpha_I$  and  $\alpha_E$ .

#### 3.1 The Entrant's Best Reply

The entrant chooses debt, capacity, and production simultaneously during the production subgame. None of these quantities are observed by the incumbent prior to production. In keeping with our emphasis on the deterrence effect of debt, we structure the debt financing as a recapitalization to avoid having the debt offering interact directly with the risk of the firm. We thus assume that any debt proceeds  $B_E$  are paid as a pre-production dividend. As a result, we can write the entrant's second-stage equity flow as:

$$B_E + \int_{\hat{Z}_E}^{\tilde{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_E - r_E k_E + \alpha_E - F_E] d\Phi(\tilde{z}),$$

where  $r_E$  is the entrant's marginal cost,  $\hat{Z}_E$  is the entrant's debt default point:

$$\left(a + \hat{Z}_E - b(q_I + q_E)\right) q_E - r_E k_E + \alpha_E - F_E = 0,$$

and  $B_E$  is the fair market value of the entrant's debt offering:<sup>7</sup>

$$B_E = \int_{\hat{Z}_E}^{\bar{Z}} F_E d\Phi(\tilde{z}) + \int_{-\bar{Z}}^{\hat{Z}_E} [(a + \tilde{z} - b(q_I + q_E)) q_E - r_E k_E + \alpha_E] d\Phi(\tilde{z}).$$

Substituting in for  $B_E$ , the second-stage equity flow coincides with the total firm value:

$$\begin{aligned} & \int_{-\bar{Z}}^{\bar{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_E - r_E k_E + \alpha_E] d\Phi(\tilde{z}) \\ &= (a - b(q_I + q_E)) q_E - r_E k_E + \alpha_E, \end{aligned}$$

where the entrant produces within the capacity constraint  $q_E \leq k_E$ . This is just the usual linear-demand Cournot duopolist's profit plus the initial equity base  $\alpha_E$ . The entrant's best reply therefore has the usual functional form:<sup>8</sup>

$$q_E(q_I) = \frac{a - bq_I - r_E}{2b}. \quad (1)$$

The entrant's capacity is set equal to its production, and its capital structure is irrelevant for the traditional reasons (no interaction with risk or production, no tax benefit of debt, no default cost, no information asymmetry, etc.)

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<sup>7</sup>Despite the fact that the  $r_E k_E$  payment is senior to the bond payment, we have not modeled the bond as a limited liability security. It remains, however, fairly valued.

<sup>8</sup>A slight time gap between the entrant's choices of debt and capacity and its choice of production would not change the result as long as the entrant's debt and capacity remain unobservable to the incumbent.

### 3.2 The Incumbent's Best Reply

There are two inherited characteristics from the first stage that must be incorporated into the second stage equity flow for the incumbent. First, the debt proceeds  $B_I$  were distributed in the first stage as a recapitalization dividend and its face value  $F_I$  must now be paid. Second, the capacity  $k_I$  was contractually acquired in the first stage and its associated cost  $r_I k_I$  must now be paid. In order to compare our version of a capacity-free Brander and Lewis debt deterrence model, the capacity cost must be paid out of second-stage revenues.<sup>9</sup> Without capacity, the variable cost takes the form of a production cost which must be paid out of production revenues.

For the inherited debt and capacity  $F_I$  and  $k_I$ , we can write the incumbent's second-stage equity flow as:

$$\int_{\hat{Z}_I}^{\bar{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_I - r_I k_I + \alpha_I - F_I] d\Phi(\tilde{z}),$$

where  $r_I$  is the incumbent's marginal cost, and  $\hat{Z}_I$  is the entrant's debt default point:

$$(a + \hat{Z}_I - b(q_I + q_E)) q_I - r_I k_I + \alpha_I - F_I = 0.$$

In contrast with the entrant's second-stage problem, note that incumbent's debt proceeds have already been paid out at this stage (no analogue of  $B_E$  here). As the incumbent inherits the maximum possible production (at capacity) from the first stage, the incumbent is constrained in its production choice. We can write the incumbent's second-stage optimization problem as:

$$\max_{\{q_I\}} \int_{\hat{Z}_I}^{\bar{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_I - r_I k_I + \alpha_I - F_I] d\Phi(\tilde{z})$$

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<sup>9</sup>Paying capacity costs out of production revenues also allows us to consider  $\alpha_I = 0$  since it eliminates any first-stage net outflow.

subject to  $q_I \leq k_I$ .

Because the default point  $\hat{Z}_I$  is the zero of the integrand, Leibniz's rule greatly simplifies the incumbent's (Karish-Kuhn-Tucker) first order conditions. To provide for explicit solutions of the incumbent's best reply, we assume for the remainder of our analysis that  $\tilde{z} \sim U[-\bar{Z}, \bar{Z}]$ . It is convenient to first define the unconstrained best reply:

$$q_I^u(q_E) = \frac{2a - 2bq_E + \bar{Z} + \hat{Z}_I}{4b}. \quad (2)$$

Then, the best reply is:<sup>10</sup>

$$q_I(q_E) = \begin{cases} q_I^u(q_E), & \text{when } q_I^u(q_E) \leq k_I \\ k_I, & \text{when } q_I^u(q_E) \geq k_I. \end{cases} \quad (3)$$

### 3.3 Cournot Subgame Equilibria as Functions of $k_I$ and $F_I$

While best replies specified in equations (1) to (3) are functions of the incumbent's default point and capacity, therefore suggesting debt and capacity deterrence, we must remember that the incumbent's default point  $\hat{Z}_I$  is itself a function of  $q_I$  and  $q_E$ . If we substitute in the definition for the incumbent's default point  $\hat{Z}_I$  and solve the best reply functions for the Nash equilibrium, we find a quadratic in  $q_I^u$  which solves to:

$$q_I^u = \frac{a + r_E + 2\bar{Z} + R(k_I, F_I)}{10b}, \quad (4)$$

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<sup>10</sup>We have chosen to present the best reply in this implicit case format rather than as  $\min(k_I, q_I^u(q_E))$  to facilitate the application of constraint multipliers in our subsequent derivations.

where  $R(k_I, F_I) = \sqrt{(a + r_E + 2\bar{Z})^2 + 40b(F_I + r_I k_I - \alpha_I)} > 0$ .<sup>11</sup> The entrant policy when the incumbent is unconstrained is:

$$q_E^u = \frac{9a - 11r_E - 2\bar{Z} - R(k_I, F_I)}{20b},$$

giving reduced form equilibrium production policies of:

$$\begin{aligned} q_I^* &= \begin{cases} q_I^u, & \text{when } q_I^u \leq k_I \\ k_I, & \text{when } q_I^u \geq k_I \end{cases} \\ q_E^* &= \begin{cases} q_E^u, & \text{when } q_I^u \leq k_I \\ q_E^c, & \text{when } q_I^u \geq k_I, \end{cases} \end{aligned} \quad (5)$$

where  $q_E^c$  denotes the entrant policy when the incumbent is constrained:

$$q_E^c = \frac{a - bk_I - r_E}{2b}.$$

### 3.4 Two-Factor Deterrence Production

It is now possible to see the influence of the incumbent's first-mover advantages in debt ( $F_I$ ) and capacity ( $k_I$ ) on the entrant in the production subgame equilibrium. In particular, one easy way

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<sup>11</sup>We assume that  $R(k_I, F_I)$  is non-zero in the derivations that follow. This assumption requires only a "small enough" initial equity base  $\alpha_I$ .

to verify that debt and capacity deter is to note that:

$$\begin{aligned} \frac{dq_I^*}{dF_I} &= \begin{cases} \frac{2}{R(k_I, F_I)} > 0, & \text{when } q_I^u < k_I \\ 0, & \text{when } q_I^u > k_I \end{cases} \\ \frac{dq_I^*}{dk_I} &= \begin{cases} \frac{2r_I}{R(k_I, F_I)} \geq 0, & \text{for } r_I \geq 0 \text{ when } q_I^u < k_I \\ 1 > 0, & \text{when } q_I^u > k_I \end{cases} \\ \frac{dq_E^*}{dF_I} &= \begin{cases} \frac{-1}{R(k_I, F_I)} < 0, & \text{when } q_I^u < k_I \\ 0, & \text{when } q_I^u > k_I \end{cases} \\ \frac{dq_E^*}{dk_I} &= \begin{cases} \frac{-r_I}{R(k_I, F_I)} \leq 0 & \text{for } r_I \geq 0 \text{ when } q_I^u < k_I \\ \frac{-1}{2} < 0, & \text{when } q_I^u > k_I \end{cases} \end{aligned}$$

Additional capacity always provide the *incentive* and *means* to deter the entrant's production. Additional capacity, with its associated sunk costs, increases the amount that the incumbent can produce at no marginal cost. Additional capacity costs  $r_I k_I$  also decrease the equity payoff, thereby increasing the convexity-related incentive to produce. Importantly, for the case of capacity, the incentives to deter the entrant's production go in tandem with the means to act on those incentives.

In contrast, additional debt always provides the *incentive* to deter the entrant's production through the convexity effect, but it has no direct impact on the *means* to respond. When capacity is available to accommodate the unconstrained production level ( $k_I > q_I^u$ ), the incumbent can act on the incentive: additional debt increases the convexity and the incumbent's production. When capacity is insufficient ( $k_I < q_I^u$ ), the incumbent cannot act on the incentive: additional debt increases the convexity but the incumbent's production is constrained at capacity. The incumbent's incentive to deter the entrant's production cannot be satisfied and the marginal deterrence of that additional debt is zero.

Moving along production subgame equilibria (say by changing  $F_I$  or  $k_I$ ) changes the production levels in fixed proportions. The entrant's best reply function (1) implies that a new production equilibrium involves an increase in incumbent production if and only if it also involves a decrease in entrant production at half the magnitude. Our Cournot subgame is, after all, a game of strategic substitutes. Such a mechanistic relationship between incumbent and entrant production levels suggests it might be useful to think of debt and capacity as alternative ways to influence the entrant's second-stage production. Any market share vacated by the entrant is cannibalized by the incumbent as part of a new production equilibrium. In addition to the entrant's cannibalized market share, there is also a net expansion equal in size to the cannibalization. The cannibalization and the net expansion together comprise the incumbent's production change, which is twice the magnitude of the entrant's production change (and opposite in sign). We view this vacated market space as an incumbent's "intermediate good" created by the first-stage debt and capacity choices. This allows us to conduct a traditional two-factor production analysis.

We define a baseline notion of deterrence produced by the incumbent's first-mover advantages. If we were to collapse our two-stage game into one simultaneous move for both firms, we would be in a traditional Cournot duopoly game. In this collapsed game, both firms would exhibit capital structure irrelevance and both firms would produce at capacity.<sup>12</sup> Production levels in this collapsed duopoly game are the baseline levels from which we will measure deterrence, i.e., the change in

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<sup>12</sup>By way of clarification, Brander and Lewis, in a staged debt-then-production game, allow rivals to condition on each others' debt levels. Consequently, their firms do not exhibit capital structure irrelevance even though the two stages are played simultaneously.

production generated by the incumbent's first-mover advantages in debt and capacity. We denote the baseline Cournot-Nash production strategies by superscript  $N$ :

$$\begin{aligned} q_I^N &= \frac{a + r_E - 2r_I}{3b} \\ q_E^N &= \frac{a + r_I - 2r_E}{3b}. \end{aligned}$$

These are symmetric when firms face the same costs ( $r_I = r_E$ ). We define the entrant's deterred production,  $\Delta$ , the incumbent's expanded production,  $X$ , and the market expansion,  $\Sigma$ , by:

$$\begin{aligned} \Delta &= -(q_E^* - q_E^N) \\ X &= q_I^* - q_I^N \\ \Sigma &= X - \Delta = (q_I^* + q_E^*) - (q_I^N + q_E^N). \end{aligned}$$

As we previously argued for our model, the entrant's best reply (1) implies that the incumbent deters the entrant's production by half as much as it expands its own production,  $\Delta = X/2$ . The market therefore expands by an amount equal to the entrant's deterred production,  $\Sigma = \Delta$ . Consequently, the production deterred from the entrant,  $\Delta$ , through the incumbent's first-mover advantages is a sufficient statistic. Specifically, we are interested in the production function of that deterrence  $\Delta(k_I, F_I)$ .

The functional form for the entrant's deterred production,  $\Delta$ , in our model is:

$$\Delta(k_I, F_I) = \begin{cases} \frac{-7a - 7r_E + 20r_I + 6Z + 3R(k_I, F_I)}{60b}, & \text{when } q_I^u \leq k_I \\ \frac{-a - r_E + 2r_I + 3bk_I}{6b}, & \text{when } q_I^u \geq k_I. \end{cases}$$

Figure 3 displays two isodeterrence curves, where the leftmost curve graphs a lower level of deterrence. Much of the intuition behind our two-factor deterrence analysis can be argued from this

figure:

(1) We know from Dixit that making an incumbent's capacity costs sunk by production time is analogous to giving the incumbent a cost advantage in the subsequent Cournot competition. Mechanically, the cost advantage shifts the incumbent's reaction function to the right.<sup>13</sup> We know from Brander and Lewis that introducing risky debt makes equity claimants disregard the worst states of the world. This truncation of the worst states also shifts the incumbent's reaction function to the right. In our model, capacity costs and risky debt deter the entrant's production in precisely the same way - by allowing the incumbent to shift its reaction function prior to playing a Cournot-Nash production subgame. More to our point, however, Figure 3 shows that the debt face value and capacity costs can be perfect substitutes in the determination of the incumbent's default point,  $\hat{Z}_I$ . Another way to see this is with equation (2), where  $\hat{Z}_I$  is a relevant location parameter for the incumbent's reaction function. Figure 3 labels this as the "Perfect Substitutes Segment."

(2) Figure 3 also labels a "Leontief Segment." Along this segment, adding debt above the threshold level cannot increase the incumbent's production. This can be viewed as a technology constraint to the production of deterrence. At a given capacity level, if the incumbent is geared up sufficiently to produce at capacity, additional gearing cannot increase the incumbent's production as there is no capacity to accommodate the increased production.

(3) In our model, as in Dixit, it is always technologically feasible for deterrence to rise with increases in capacity. By way of distinction, however, Figure 3 indicates that, holding the debt constant, increases in capacity always lead to a higher incumbent production and a lower entrant production. This is quite distinct from Dixit. In his equity-only case, if the incumbent considers a defection from zero excess capacity, the extra capacity is not a credible threat to increase production. Capacity does not always have a positive marginal deterrence product in Dixit's context. Zero excess capacity is an immediate equilibrium result with costly capacity. In contrast to Dixit's all-equity analysis, our model with risky debt assures that capacity increases are a credible threat to increase production. Credibility arises with the additional role capacity costs play in determining the incumbent's default point  $\hat{Z}_I$ . Higher capacity costs raise the probability of default and therefore induce convexity-related deterrence. Even though our context involves capacity increases that are credible threats to increase production, it remains to be seen whether the benefits of such threats exceed their costs.

(4) Our model assumes no cost to debt financing, only a capacity cost. Debt is the cheapest way to influence the convexity effect in the equity payoff and any resulting convexity-related deterrence. In terms of its influence on convexity, excess capacity is equivalent to money-burning. This suggests

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<sup>13</sup>Dixit uses the phrase "generalised Stackelberg" behavior to describe models where one of the duopolists can use irreversible capacity to dictate its own reaction function in a future production subgame.

that the incumbent will choose zero excess capacity and costlessly increase gearing to produce any remaining desirable deterrence. On Figure 3, the equilibrium with zero excess capacity is situated at the kink. Importantly, in equilibrium, rather than establishing zero excess capacity because it is not a credible threat to increase production as in Dixit, we establish zero excess capacity due to debt's significant cost advantage in deterrence production. This suggests that debt financing costs or additional positive capacity externalities could lead to equilibrium excess capacity even when entry is certain.

## 4 The Incumbent's Optimal Debt and Capacity

To confirm our intuition from examining the isodeterrence curves, we roll the production subgame equilibrium policies back into the first-stage optimization problem where the incumbent determines which debt and capacity the subgame will inherit. This is the mechanism through which the incumbent is granted first-mover advantages - it takes the production subgame equilibrium functions of  $k_I$  and  $F_I$  as given when considering its debt and capacity choices.

For arbitrary productions  $q_I$  and  $q_E$ , we can write the incumbent's equity flow over the two stages as:

$$B_I + \int_{\hat{Z}_I}^{\bar{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_I - r_I k_I + \alpha_I - F_I] d\Phi(\tilde{z}),$$

where  $B_I$  is the fair market value of the incumbent's debt offering:

$$B_I = \int_{\hat{Z}_I}^{\bar{Z}} F_I d\Phi(\tilde{z}) + \int_{-\bar{Z}}^{\hat{Z}_I} [(a + \tilde{z} - b(q_I + q_E)) q_I - r_I k_I + \alpha_I] d\Phi(\tilde{z}).$$

Substituting in for  $B_I$ , the equity flow coincides with the total firm value:

$$\begin{aligned} & \int_{-\bar{Z}}^{\bar{Z}} [(a + \tilde{z} - b(q_I + q_E)) q_I - r_I k_I + \alpha_I] d\Phi(\tilde{z}) \\ &= (a - b(q_I + q_E)) q_I - r_I k_I + \alpha_I. \end{aligned} \tag{6}$$

Unlike the case for the entrant, the assumption that incumbent's debt and capacity choices are common knowledge prior to production needs to be considered formally. For example, capital structure becomes relevant (as it is in Brander and Lewis). Consequently, we recognize the functional dependencies  $q_I(k_I, F_I)$  and  $q_E(k_I, F_I)$ .

The incumbent's optimal production policy (5) is not differentiable in  $k_I$  at a critical point. Figure 4 presents a graph of the unconstrained policy, the constraint, and the combination yielding the non-differentiable optimal policy specified in (5), for a given debt level  $F_I$ . We proceed by considering first-stage debt and capacity choices separately for: the excess capacity region,  $k_I \geq q_I^u(k_I, F_I)$ , which contains the rightmost flat segment; and the exhausted capacity region,  $k_I \leq q_I^u(k_I, F_I)$ , which contains the leftmost 45° segment.<sup>14</sup>

**Case 1: Excess Capacity Region ( $k_I \geq q_I^u(k_I, F_I)$ )**

For the excess capacity region, we want to assure that the optimal unconstrained production policy  $q_I^* = q_I^u$  remains active. Accordingly, we must constrain the optimization to choices that generate excess capacity,  $k_I \geq q_I^u(k_I, F_I)$ . From equation (6), we can write the incumbent's Lagrangian for this region as:

$$(a - b(q_I^u(k_I, F_I) + q_E^u(k_I, F_I))) q_I^u(k_I, F_I) - r_I k_I + \alpha_I + \lambda_1(k_I - q_I^u(k_I, F_I)). \quad (7)$$

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<sup>14</sup>Even though non-differentiability makes a unified analysis infeasible, continuity of the optimal policy does mean that we will not have to treat the point of non-differentiability separately from its adjacent regions.

The Karish-Kuhn Tucker first order conditions for debt  $F_I$  and capacity  $k_I$  are:

$$\begin{aligned} \frac{2(2a - 5\lambda_1 + 2r_E - \bar{Z}) - R(k_I, F_I)}{5R(k_I, F_I)} &= 0 \text{ (FOC for } F_I) \\ \frac{2r_I(2a - 5\lambda_1 + 2r_E - \bar{Z}) + (5\lambda_1 - 6r_I)R(k_I, F_I)}{5R(k_I, F_I)} &= 0 \text{ (FOC for } k_I) \\ \lambda_1 &\geq 0 \\ k_I &\geq q_I^u(k_I, F_I) \\ \lambda_1(k_I - q_I^u(k_I, F_I)) &= 0. \end{aligned}$$

**Subcase 1a:** Excess Capacity Region with  $k_I > q_I^u(k_I, F_I)$  (interior)

For this region, it must be that  $\lambda_1=0$ . The first order conditions for  $F_I$  and  $k_I$  imply the following:

$$\begin{aligned} R(k_I, F_I) &= 2(2a + 2r_E - \bar{Z}) \\ R(k_I, F_I) &= \frac{1}{3}(2a + 2r_E - \bar{Z}). \end{aligned}$$

For general cases of the parameters  $a$ ,  $r_E$ , and  $\bar{Z}$ , there is no  $R(k_I, F_I)$  that solves both equations as they are parallel lines. This contradiction indicates that there is no solution with excess capacity.

This is our analogue to Dixit's no excess capacity result.

**Subcase 1b:** Excess Capacity Region with  $k_I = q_I^u(k_I, F_I)$  (boundary)

For this region, there is no a priori restriction on the multiplier  $\lambda_1$  other than non-negativity.

However, we do have  $k_I = q_I^u(k_I, F_I)$ . Using the incumbent's unconstrained production policy in

(4) and the first order conditions, we can solve for the candidate equilibrium of debt, capacity and

productions:

$$\begin{aligned}
F_I &= \frac{3(a + r_E)^2 - (a + r_E)(20r_I + 4\bar{Z}) + 8\alpha_I b + 8r_I \bar{Z} + 28r_I^2}{8b} \\
k_I &= \frac{a + r_E - 2r_I}{2b} \\
q_I &= \frac{a + r_E - 2r_I}{2b} \\
q_E &= \frac{a + 2r_I - 3r_E}{4b},
\end{aligned}$$

where  $\lambda_1 = r_I$ .

**Case 2:** Exhausted Capacity Region ( $k_I \leq q_I^u(k_I, F_I)$ )

For the exhausted capacity region, we want to assure that the optimal capacity production policy  $q_I^* = k_I$  remains active. Accordingly, we must constrain the optimization to choices that exhaust capacity,  $k_I \leq q_I^u(k_I, F_I)$ . From equation (6), we can write the incumbent's Lagrangian for this region as:

$$\left( a - b \left( k_I + \frac{a - bk_I - r_E}{2b} \right) \right) k_I - r_I k_I + \alpha_I + \lambda_2 (q_I^u(k_I, F_I) - k_I).$$

It is important to note, particularly if contrasting with (7), that we have substituted in  $k_I$  for  $q_I$  but put  $q_I^u(k_I, F_I)$  in the constraint. The unconstrained production quantity  $q_I^u(k_I, F_I)$  is what must remain infeasible if we are analyzing equilibria where the production is constrained. The multiplier reflects that an unconstrained incumbent would wish to produce at least as much as the capacity

$(q_I^u(k_I, F_I) \geq k_I)$ . The Karish-Kuhn Tucker first order conditions for debt  $F_I$  and capacity  $k_I$  are:

$$\begin{aligned} \frac{2\lambda_2}{R(k_I, F_I)} &= 0 \text{ (FOC for } F_I) \\ a + r_E - 2r_I - 2bk_I + \lambda_2 \left( -2 + \frac{4r_I}{R(k_I, F_I)} \right) &= 0 \text{ (FOC for } k_I) \\ \lambda_2 &\geq 0 \\ q_I^u(k_I, F_I) &\geq k_I \\ \lambda_2(q_I^u(k_I, F_I) - k_I) &= 0. \end{aligned}$$

**Subcase 2a:** Exhausted Capacity Region with  $k_I < q_I^u(k_I, F_I)$  (interior)

For this region, it must be that  $\lambda_2 = 0$ . The first order condition for  $k_I$  immediately implies:

$$\begin{aligned} k_I &= \frac{a + r_E - 2r_I}{2b} \\ q_I &= \frac{a + r_E - 2r_I}{2b} \\ q_E &= \frac{a + 2r_I - 3r_E}{4b}. \end{aligned}$$

The constraint  $k_I < q_I^u(k_I, F_I)$  implies a lower bound which debt must strictly exceed:

$$F_I > \frac{3(a + r_E)^2 - (a + r_E)(20r_I + 4\bar{Z}) + 8\alpha_I b + 8r_I \bar{Z} + 28r_I^2}{8b}.$$

This is precisely the same debt level that showed up previously. It must be strictly exceeded so that debt provides enough convexity-related production incentive to make the unconstrained production level infeasible within the capacity constraint.

**Subcase 2b:** Exhausted Capacity Region with  $k_I = q_I^u(k_I, F_I)$  (boundary)

As for Subcase 1b, there is no a priori restriction on the multiplier  $\lambda_2$  in this region other than non-negativity. However, we do have  $k_I = q_I^u(k_I, F_I)$ . Using the incumbent's unconstrained production policy in (4) and the first order conditions, we can solve for the same candidate equilibrium of debt, capacity and productions:

$$\begin{aligned}
F_I &= \frac{3(a + r_E)^2 - (a + r_E)(20r_I + 4\bar{Z}) + 8\alpha_I b + 8r_I \bar{Z} + 28r_I^2}{8b} \\
k_I &= \frac{a + r_E - 2r_I}{2b} \\
q_I &= \frac{a + r_E - 2r_I}{2b} \\
q_E &= \frac{a + 2r_I - 3r_E}{4b},
\end{aligned}$$

where  $\lambda_2 = 0$ .

Together Subcases 1a, 1b, 2a, and 2b can be combined to give the following specification of equilibria for our two-factor deterrence production model:

$$\begin{aligned}
F_I^* &\geq \frac{3(a + r_E)^2 - (a + r_E)(20r_I + 4\bar{Z}) + 8\alpha_I b + 8r_I \bar{Z} + 28r_I^2}{8b} \\
k_I^* &= \frac{a + r_E - 2r_I}{2b} \\
q_I^* &= \frac{a + r_E - 2r_I}{2b} \\
q_E^* &= \frac{a + 2r_I - 3r_E}{4b}.
\end{aligned} \tag{8}$$

Excess capacity does not arise. The incumbent therefore builds capacity only to make its production feasible. Debt is the least expensive way to deter. The incumbent therefore sets the debt at or above a specific threshold level in order to achieve the optimal deterrence.<sup>15</sup> Debt dominates capacity as

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<sup>15</sup>For a completely different motivation for debt thresholding in a model where uncertainty is resolved prior to

a factor of deterrence production in our simple model.

We can characterize the optimal level of deterrence of our two-factor model:

$$\Delta = \frac{a + r_E - 2r_I}{12b} > 0.$$

The entrant's deterred production is significant as it amounts to a sixth of the incumbent's production.

We further compare the optimal production levels to those obtained from a traditional Stackelberg game where the incumbent is the first-mover in production. The optimal production levels with a traditional Stackelberg leader coincide with those of our two-factor deterrence model specified in (8):  $q_I^S = q_I^*$  and  $q_E^S = q_E^*$ , where the superscript  $S$  denotes the Stackelberg policies. The incumbent can achieve the same profitability with first-mover advantages in debt and capacity as it can with a first-mover advantage in production.

In order to examine the benefit of debt deterrence over capacity deterrence, it is useful to consider two modified versions of our model with: debt only and capacity only. We demonstrate more clearly how debt deterrence (in the tradition of Brander and Lewis) and our two-factor deterrence allow the incumbent to achieve full Stackelberg leadership, whereas capacity deterrence in isolation (as in Dixit) may be inadequate to achieve full Stackelberg leadership.

#### 4.1 Deterring with Debt Only

Given that, in our context, debt is the least expensive way to deter, we examine whether or not the first-mover option in capacity has any value. We alter our model to allow both firms to choose production see Williams 1995.

capacities at the same time as production. Using a similar analysis to what we used for our two-factor model of deterrence, it is straightforward to show the debt-only deterrence equilibrium requires a debt level of:

$$F_I^F = \frac{3(a + r_E)^2 - (a + r_E)(12r_I + 4\bar{Z}) + 8\alpha_I b + 8r_I \bar{Z} + 12r_I^2}{8b},$$

where the superscript  $F$  denotes the debt-only deterrence policies. For this equilibrium level of debt, the incumbent and entrant productions are precisely the same as under the two-factor model.

The debt level,  $F_I^F$ , is higher than the two-factor debt threshold,  $F_I^*$ , by:

$$F_I^F - F_I^* = 2r_I q_I^*. \quad (9)$$

To understand how this debt difference arises, we compare the incumbent's best reply in equation (2) to its equivalent in the debt-only model. With debt only, the incumbent's best reply becomes:

$$q_I^F(q_E) = \frac{2a - 2r^I - 2bq_E^* + \bar{Z} + \hat{Z}_I^F}{4b}.$$

To maintain its production, the incumbent's debt becomes riskier when it also faces a marginal capacity cost of  $r_I$  in the second stage. Comparing the two best reply functions indicates that the increase in convexity is twice the marginal capacity cost:  $2r_I = \hat{Z}_I^F - \hat{Z}_I^*$ . Substituting for the default point definitions, the increase in debt levels is expressed in terms of capacity costs as in equation (9).

Even though the incumbent has lost the first-mover advantage in capacity, it still achieves the same profitability by increasing its gearing. The first-mover option in capacity is worthless. Because

debt can costlessly achieve the desired optimal deterrence through equity convexity, the incumbent is indifferent about choosing capacity in the first stage or contemporaneously with production in the second stage. The capacity first-mover option, as it were, is “at the money.” This contrasts with the “in the money” nature of Dixit’s capacity first-mover option for an all equity financed firm. We do not, however, want to leave the impression that being a first-mover in capacity is never valued in our context. As we demonstrate below, in the absence of a first-mover option in debt, the incumbent will value the ability to be a first-mover in capacity.

## 4.2 Detering with Capacity Only

Dixit considers first-mover advantages in a two-stage capacity model where the incumbent can deploy capacity in two stages and the entrant deploys capacity only in the second stage at the time when both duopolists produce. Dixit’s incumbent deploys all capacity in the first stage.<sup>16</sup> Consequently, Dixit’s second stage capacity investment option is “out of the money” and corresponds to our single-stage capacity investment structure.

A similar analysis to what we used for our two-factor model of deterrence indicates that the second stage production policies are:

$$q_I^k = \begin{cases} q_I^{uk}, & \text{when } q_I^{uk} \leq k_I \\ k_I, & \text{when } q_I^{uk} \geq k_I \end{cases}$$

$$q_E^k = \begin{cases} q_E^{uk}, & \text{when } q_I^{uk} \leq k_I \\ q_E^{ck}, & \text{when } q_I^{uk} \geq k_I, \end{cases}$$

where the superscript  $^k$  denotes the capacity-only deterrence policies,  $q_I^{uk}$ , the unconstrained in-

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<sup>16</sup>“We have seen above that at all points that are ever going to be observed without or with entry, the established firm will be producing an output equal to its chosen pre-entry capacity.” Dixit, p. 100.

cumbent's production,  $q_E^{uk}$ , the associated entrant's production, and  $q_E^{ck}$ , the entrant's production when the incumbent is constrained:

$$\begin{aligned} q_I^{uk} &= \frac{a + r_E}{3b} \\ q_E^{uk} &= \frac{a - 2r_E}{3b} \\ q_E^{ck} &= \frac{a - bk_I - r_E}{2b}. \end{aligned}$$

As before, the analysis of the first stage equilibrium proceeds through cases around the non-differentiable kink. Subcase 1a, the excess capacity region where  $k_I > q_I^{uk}$ , still yields a contradiction. This is Dixit's result of no excess capacity.

Subcases 1b and 2b, where capacity is equal to the unconstrained production,  $k_I = q_I^{uk}$ , by definition gives the candidate equilibrium of capacity and productions:

$$\begin{aligned} k_I &= \frac{a + r_E}{3b} \\ q_I &= \frac{a + r_E}{3b} \\ q_E &= \frac{a - 2r_E}{3b}. \end{aligned}$$

For this candidate equilibrium, the entrant's deterred production is:

$$\Delta = \frac{r_I}{3b} > 0.$$

Deterrence requires that the incumbent's marginal capacity cost be positive  $r_I > 0$ . Subcase 2a, the exhausted capacity region where  $k_I < q_I^{uk}$ , produces a different candidate equilibrium of capacity

and productions, precisely the full Stackelberg leadership equilibrium of our two-factor deterrence model:

$$\begin{aligned} k_I^* &= \frac{a + r_E - 2r_I}{2b} \\ q_I^* &= \frac{a + r_E - 2r_I}{2b} \\ q_E^* &= \frac{a + 2r_I - 3r_E}{4b}, \end{aligned}$$

if and only if the following condition on parameters is satisfied:  $a + r_E - 6r_I < 0$ . The condition arises by verifying that the equilibrium lies within the exhausted capacity region

$$\begin{aligned} k_I^* &< q_I^{uk} \\ \frac{a + r_E - 2r_I}{2b} &< \frac{a + r_E}{3b} \\ a + r_E - 6r_I &< 0. \end{aligned}$$

The parameter condition may not always be satisfied. Full Stackelberg leadership, the candidate equilibrium that generates the incumbent's highest profit, may therefore not always be achieved without debt deterrence. In contrast, when the incumbent uses debt and capacity to deter, the incumbent is able to gear up so that the unconstrained production increases above the capacity level. Without debt, the incumbent can no longer influence the unconstrained production level. The equilibrium of the exhausted capacity region may not be feasible.

To shed light on the puzzling parameter condition, we return to the incumbent's second stage unconstrained production choice. Without the capacity constraint, the incumbent's second stage

production solves the problem:

$$\max_{q_I} (a - b(q_I + q_E)) q_I - r_I k_I + \alpha_I.$$

The first order condition,

$$(a - b(q_I + q_E)) - bq_I = 0,$$

involves two effects: one more unit of production increases the incumbent's revenues by the market price  $((a - b(q_I + q_E)))$ , but the increased production also decreases the price on the entire production  $(-bq_I)$ . In the exhausted capacity region, the first stage capacity solves the problem:

$$\max_{k_I} \left( a - b \left( k_I + \frac{a - bk_I - r_E}{2b} \right) \right) k_I - r_I k_I + \alpha_I.$$

The first order condition,

$$\left( a - b \left( k_I + \frac{a - bk_I - r_E}{2b} \right) \right) - b \left( 1 - \frac{1}{2} \right) k_I - r_I = 0,$$

involves three effects. First, as in the unconstrained second-stage optimization, an additional unit increases the incumbent's revenues by the price  $\left( a - b \left( k_I + \frac{a - bk_I - r_E}{2b} \right) \right)$ . Second, it also directly decreases the price on all production  $(-bk_I)$ . However, in this first-stage capacity optimization, the incumbent incorporates the entrant's second-stage production best reply. That is, the incumbent knows that an increase in its capacity by one unit will lead to a production subgame equilibrium where the entrant decreases its production by a half unit. Therefore, relative to the incumbent's second-stage unconstrained production problem, the incumbent choosing capacity within the exhausted capacity region in the first period perceives less price erosion from the total production

(with the term  $b\left(\frac{1}{2}\right)k_I$ ). The final effect of a unit increase in capacity is its marginal cost ( $-r_I$ ). To remain in the exhausted capacity region where capacity is less than the unconstrained production level ( $k_I < q_I^{uk}$ ), it must be the case that the additional marginal benefit of a unit increase in capacity ( $b\left(\frac{1}{2}\right)k_I$ ) is less than the additional marginal cost ( $r_I$ ):

$$\begin{aligned} b\left(\frac{1}{2}\right)k_I - r_I &< 0 \\ \iff \frac{b}{2}\left(\frac{a+r_E-2r_I}{2b}\right) - r_I &< 0 \\ \iff a+r_E-6r_I &< 0. \end{aligned}$$

Full Stackelberg leadership with capacity-only deterrence is achieved only for this configuration of costs. Otherwise, capacity-only deterrence is inferior from the incumbent's point of view to debt-only or two-factor deterrence.

Whether full or limited Stackelberg leadership is achieved with capacity deterrence, it is clear that, in the absence of debt, the first-mover option in capacity is valuable. When the incumbent has a first-mover option in capacity, it generates higher profits than the Nash equilibrium without any first-mover option. In other words, Dixit's capacity first-mover option for an all equity financed firm is "in the money." However, as we have seen the first-mover option in capacity becomes worthless ("at the money") when debt deterrence is also considered.

In contrast, the first-mover option in debt remains valuable. Without debt deterrence, the equilibrium may exhibit a limited first-mover advantage, but this limited advantage is potentially only a fraction of the advantage of the full Stackelberg leader. Because debt is a costless factor

in the production of deterrence, the incumbent is able to achieve full Stackelberg leadership. The first-mover option in debt is “in the money.”

### 4.3 A Numerical Example

To quantify of the differences between the three models, we consider the numerical example  $a = 4$ ,  $b = 1$ ,  $\alpha_I = 0$ ,  $\bar{Z} = 1$ ,  $r_I = r_E = .05$ . In this example,  $a + r_E - 6r_I > 0$  so that

$$q_I^N < q_I^k < q_I^F = q_I^* = q_I^S$$

$$q_E^N > q_E^k > q_E^F = q_E^* = q_E^S.$$

Table 1 shows that the difference between the Baseline Nash quantities and Capacity Only quantities can be “small,” while the difference between the Baseline Nash quantities and the coincident Debt Only, Debt and Capacity, and Stackelberg quantities can be much larger.

## 5 The telecommunications industry

Our simple model predicts that firms produce at capacity and use debt to deter. We test this prediction using the natural experiment of deregulation in the telecommunications industry. The 1996 Act of Telecommunications provides a clear line of demarcation for the change in market structure. Entry and competition in this market were highly regulated before 1996 but free after 1996. Upon deregulation, debt deterrence should simply manifest itself by higher debt levels, over and above changes related to traditional capital structure determinants. To distinguish between the strategic use of debt after the deregulation and the cheaper cost of financing during the “tech

bubble,” we also include a control sample. Software firms have participated to the same “bubble” without being subject the deregulation event.<sup>17</sup>

We construct a sample of telecommunications firms (SIC codes from 4800 to 4899) and software firms (SIC codes from 7370 to 7379) from the 1988 to 2002 period using COMPUSTAT Industrial files. After winsorizing outliers (upper and lower 1%) and deleting firm-year observations with missing data entries, we obtain an unbalanced panel of 8951 firm-year observations. In total, the sample includes 476 telecommunication firms with 2841 firm-year observations and 1160 software firms with 6110 firm-year observations.

We measure debt as the sum of long-term (item 9) and short-term debt (item 34) divided by total assets (item 6). We measure capacity as the gross value of property, plant, and equipment (item 7) to total assets. Figure 5 shows that telecommunication firms increased their debt ratio and decreased their capacity intensity after the deregulation. Figure 6 shows that software firms decreased both their debt and capacity over the same time period.<sup>18</sup> The increased use of debt by telecommunication firms following the deregulation is suggestive of debt deterrence.

## 5.1 Debt Regression Analysis

Traditional non-deterrence determinants of capital structure could explain the increase in debt. We control for changes in the bankruptcy probability using Altman’s (1968) z-score, perceived growth

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<sup>17</sup>Our sample does include the period of the anti-trust lawsuit against Microsoft. It remains unclear whether or not the lawsuit changed the software marketplace.

<sup>18</sup>Because the telecommunications industry, like most other tech industries, experienced a dramatic rise in valuations from 1998 to the beginning of 2000 and a sharp decline afterwards, we assess the robustness of our results by measuring total assets by market value. We obtain similar results.

opportunities using the market-to-book ratio, size using the logarithm of sales, intangibility using the ratio of intangibles to total assets, profitability using income after depreciation divided by sales, volatility using the standard deviation of the last two years of sales, and sector concentration using the Herfindahl index within each four-digit SIC sector. The variables are defined in the appendix.

Table II presents the means of the variables under study. The average market-to-book ratio for telecommunication firms decreased after the deregulation, indicating potentially lower growth opportunities for the average firm competing in the deregulated environment. In contrast, software firms see their average market-to-book ratio increase after 1996.

On average, all other variables behave similarly for telecommunication and software firms. Firms in existence during the 1996 to 2002 period are more likely to go bankrupt, as measured by a lower Altman's z-score, than firms during the 1988 to 1995 period. As proxied by the logarithm of sales, firms grow larger over time. Both telecommunication and software firms rely more heavily on intangibles and depreciate their tangible assets at a faster rate. During the "tech bubble" period, incomes are lower and volatilities are higher. The telecommunication and software industries grew less concentrated on average.

An ideal way to capture the effect of deregulation is through a dummy variable equal to one if the firm year is greater or equal to 1996, and zero otherwise.<sup>19</sup> Additionally, we focus our attention on incumbent firms. Only firms present before and after the regime change can use debt to position their product market aggressiveness.

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<sup>19</sup>Because market participants may have anticipated the deregulation announcement, we exclude all observations from the year 1995 and find similar results.

We regress leverage on the lagged traditional determinants and dummy variables identifying the deregulation period and incumbent firms. Table III presents the debt regression results, where the estimation is performed with a panel-corrected covariance matrix. Consistent with Figure 5, we find that the telecommunication incumbents' use of debt increases after the deregulation when we control for other determinants of capital structure. The incumbents' average debt unexplained by traditional determinants increased from 0.2683 prior to the deregulation to 0.3823 post deregulation. The increase of 0.1140 is statistically significant (p-value of 0.00). The software incumbents' average residual debt increased slightly from 0.0571 to 0.0650, but the increase of 0.0079 is not significant (p-value of 0.61). The debt increase of telecommunication incumbents is consistent with deterrence.

Most of our results on the traditional determinants of capital structure are in line with empirical literature.

- (1) Altman's z-score has a negative and significant coefficient. A firm with a lower Altman's z-score, indicating a higher probability of bankruptcy, should maintain a lower leverage. In contrast, we find that higher probabilities of bankruptcy are associated with more debt. This is not surprising when firms use debt to deter. Debt deterrence requires that firms increase their equity convexity to commit to an aggressive product market behavior.
- (2) Market-to-book has a negative but only marginally significant coefficient (with a p-value of 0.09). A higher ratio is consistent with more valuable investment opportunities. Firms with such opportunities keep their leverage low to mitigate the underinvestment problem.
- (3) Firm size has a negative but insignificant coefficient. Small and large tech firms do not differ in their use of debt.
- (4) Intangibility has a positive and significant coefficient. Firms with more valuable patents and copyrights borrow more.
- (5) Depreciation has a positive and significant coefficient. Firms with assets that depreciate faster rely more heavily on debt financing.

- (6) Profitability has a negative and significant coefficient. Consistent with the pecking order theory, firms with more internal funds borrow less.
- (7) Volatility has a negative and significant coefficient. Firms with a more volatile sales history borrow less.
- (8) Herfindahl Pre-deregulation has a positive but only marginally significant coefficient (with a p-value of 0.06). When a regulated sector became more concentrated, firms within that sector increased their leverage. Herfindahl Post-deregulation has a negative but insignificant coefficient. After the deregulation, firms' use of debt was not a response to the sector concentration.

Finally, Table III also shows that entrants after 1996 have a lower residual debt than incumbents after 1996, and that exits before 1996 have a higher residual debt than incumbents before 1996. This suggests that leverage decreases a firm's probability of survival. In the survival regression analysis below, we show that the benefit of debt deterrence following the deregulation is in fact positive.

## 5.2 Capacity Regression Analysis

In the capacity regression, we again control for changes in the traditional capacity determinants: firm size, volatility, and sector concentration. In addition, we also recognize that capacity may decrease simply because the increase in debt is reflected in total assets, the denominator of capacity. We therefore control for the other capital structure determinants: Altman's z-score, the market-to-book ratio, intangibility, depreciation, and profitability.

Table IV presents the capacity regression results, where capacity is regressed on the lagged determinants and dummy variables using a panel-corrected covariance matrix. In contrast to Figure 5, we find that the telecommunication incumbents' use of capacity did not change after the

deregulation when we control for the other determinants. The incumbents' average residual capacity actually increased slightly from 0.5733 prior to the deregulation to 0.5815 post deregulation, but the increase is not statistically significant (p-value of 0.62). The software incumbents' average residual capacity decreased slightly from 0.2834 to 0.2821, but the decrease is not statistically significant (p-value of 0.92). Telecommunication incumbents did not change their capacity strategy in response to deregulation, over and above variations explained by traditional capacity determinants. There is no evidence of capacity deterrence.

Our results on the traditional determinants of capacity are:

- (1) Altman's z-score has a negative and significant coefficient, indicating that firms with higher probabilities of bankruptcy reduce their capacity.
- (2) Market-to-book has a negative and significant coefficient. Firms with more future growth opportunities have a lower proportion of assets in place.
- (3) Firm size has a positive and significant coefficient. Consistent with Cabral (1995) pointing out that small firms may prefer to invest gradually to save sunk costs, smaller firms are less invested in capacity than larger firms.
- (4) Intangibility has a negative and significant coefficient. Firms with more intangibles have less tangible assets.
- (5) Depreciation has a positive and significant coefficient. Firms with assets that depreciate faster must install more capacity upfront. (Remember that capacity is measured gross of depreciation.)
- (6) Profitability has a positive and significant coefficient. Firms with more internal funds have larger capacities.
- (7) Volatility has a negative and significant coefficient. Firms with a more volatile sales history have lower capacities.
- (8) Herfindahl has a negative and significant coefficient, both before and after the deregulation. This is consistent with Booth et al (1991) showing that firms do not use capacity strategically in concentrated sectors but instead coordinate and cooperate.

Finally, Table IV also shows that entrants after 1996 have a lower residual capacity than incumbents, and that exits before 1996 have the highest residual capacity.

### 5.3 Survival Regression Analysis

Telecommunication firms responded to the deregulation by increasing their leverage and not changing their capacity strategy. We now present supporting evidence for the optimality of such a response. We focus on the “residual debt” and “residual capacity,” i.e., the observed debt and capacity unexplained by traditional determinants. These residuals should include the strategic effect of deterrence. If the marginal benefit of debt deterrence is positive, the change in the relation between a firm’s survival and its residual debt upon deregulation should be positive.

Firms with positive total assets (data item 6) in 2002 are classified as survivors. The probability of survival is regressed against the firm’s own residual debt and own residual capacity, as well as its rivals’ residual debt and rivals’ residual capacity. We also include our set of explanatory variables, and, very importantly, we control for the natural exit rate through time using time dummies. The estimation uses a probit model.

Table V indicates that own residual debt has a negative and significant coefficient before deregulation ( $-5.20e-4$ ). Using detailed firm and product level data, Chevalier, Khanna and Tice, Kovenock and Phillips, and Phillips conclude that debt generally makes the product market competition softer. Indeed, there are many reasons why debt would decrease a firm’s chance of survival, including overhang, distress costs, etc. In this paper, however, we are interested in isolating *only* the strategic deterrence benefit of debt. We can do so by comparing the coefficient of own residual

debt before and after the deregulation event. While the coefficient of own residual debt is negative and significant before deregulation, it becomes insignificant after the deregulation ( $-0.66e-4$ ). The change ( $4.54e-4$ ) is positive and significant, consistent with a positive benefit of debt deterrence in response to entry fostered by deregulation.

The table also indicates that own residual capacity has a positive and significant coefficient before deregulation ( $0.94e-4$ ), suggesting that increases in capacity in the highly regulated environment raised a firm's chance of survival to 2002. Own residual capacity coefficient after deregulation is insignificant ( $0.24e-4$ ), and, similarly, the change ( $-0.7e-4$ ) is negative but not significant.

Rivals' residual debt and capacity before and after deregulation are not significant and do not change significantly upon deregulation.

Four other determinants are associated with survival. Firms with more growth opportunities, as measured by the market-to-book ratio, are more likely to survive, although the coefficient is only marginal significant. Firms with higher profits are more likely to survive. Firms with higher volatilities appear more likely to survive, but again this coefficient is only marginal significant. Firms operating in less concentrated sectors before the deregulation are more likely to survive through the deregulation and "tech bubble" to 2002.

## 6 Conclusion

Our model considers debt and capacity as factors in the production of deterrence. The debt face value and capacity costs can be perfect substitutes in increasing the convexity of the equity payoff.

As Brander and Lewis point out, equityholders facing larger liabilities produce more aggressively. Producing more increases the firm's equity payoff in good states more than it decreases the payoff in bad states because of limited liability. Because production is constrained by the capacity in place, adding debt above a specific threshold level cannot increase the production. Our deterrence equilibrium is characterized by production at capacity, where the debt is set to achieve the optimal level of deterrence. Our empirical results provide support for our model's emphasis on debt deterrence.

Our model recognizes that capacity plays two roles: it constrains production and its associated costs decrease the equity payoff. In contrast to the all equity financed firm in Dixit, an increase in capacity becomes a credible threat to increase production. Higher capacity costs raise the probability of default and therefore induce convexity-related deterrence. Our equilibrium, however, does not include any excess capacity because debt deterrence is more cost-effective. With debt financing costs or additional positive capacity externalities, it is possible that our equilibrium would include excess capacity.

The incumbent deterring with debt and capacity is able to achieve full Stackelberg leadership, as though the entire traditional Stackelberg leader quantity were precommitted in the first stage with the entrant dutifully following in the second stage. The incumbent is also able to achieve full leadership when it deters with debt only, but not always when the incumbent deters with capacity only. With capacity-only deterrence, the incumbent may suffer a deadweight loss. The first-mover option in debt is therefore valuable ("in the money") while the first-mover option in capacity is

worthless (“at the money”).

Our two-factor deterrence production model suggests that Brander and Lewis analysis of debt deterrence on its own is likely to overstate the amount of debt needed for optimal deterrence. Because capacity is necessary to produce, capacity costs reduce the amount of debt needed to deter. The results also show that Dixit’s analysis of capacity deterrence on its own may be misleading. In fact, when the convexity induced by debt is sufficiently high, the incumbent may not perceive any advantage to paying capacity costs as a first-mover.

Our model suggests that firms produce at capacity and deter with debt. Using the natural experiment of the 1996 deregulation in the telecommunications industry, we observe that firms increased their leverage over and above changes explained by traditional capital structure determinants. Firms did not modify their capacity over and above changes explained by traditional capacity determinants. The change in the relation between a firm’s probability of survival and its debt upon deregulation is positive. While firms may choose debt levels for a number of reasons, we focus on the strategic benefit of deterrence. We argue that this benefit is positive. The evidence suggests that the idea of debt deterrence should be revisited.

## APPENDIX

We construct explanatory variables from the COMPUSTAT Industrial files. Altman's z-score is computed as:

$$\begin{aligned} z = & 0.012 \text{ Working capital to Total assets (data item 6)} \\ & + 0.014 \text{ Retained earnings (item 36) to Total assets} \\ & + 0.033 \text{ Earnings before interest and taxes to Total assets} \\ & + 0.006 \text{ Market value equity to Total liabilities (item 181)} \\ & + 0.999 \text{ Sales (item 12) to Total assets,} \end{aligned}$$

where Working capital is the difference between current assets (item 4) and current liabilities (item 5), Earnings before interest and taxes is the sum of operating income after depreciation (item 178) and non-operating income excluding interest income (item 190), and Market value of equity is the price (item 199) multiplied the number of common shares outstanding (item 25).

The market-to-book ratio is computed as the price divided by the ratio of total common equity (item 60) over the number of common shares outstanding. Both Altman's z-score and the market-to-book ratio are defined only for public firms, which represent 85 percent of the sample. We therefore pre-multiply the score and the market-to-book ratio by a public dummy.

Firm size is measured by the logarithm of sales; intangibility, by the ratio of intangibles (item 33) over total assets; depreciation, by the ratio of depreciation (item 14) over total assets; profitability, by the ratio of operating income after depreciation over sales; and volatility, by the standard

deviation of the firm's sales over the prior two years.

Finally, concentration is measured by the sector Herfindahl index:  $(\sum_{i \in j} \text{Sales}_{it}^2) / (\sum_{i \in j} \text{Sales}_{it})^2$ , where  $i$  denotes a firm within sector  $j$ ,  $t$  denotes the year, and a four-digit SIC code defines a sector.

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**Table I: Numerical Example**

	Baseline Nash: $N$	Capacity Only: $k$	Debt Only: $F$	Debt and Capacity: $*$	Stackelberg: $S$
$q_I$	1.3167	1.3500	1.9750	1.9750	1.9750
$q_E$	1.3167	1.3000	0.9875	0.9875	0.9875
$k_I$	--	1.3500	--	1.9750	--
$F_I$	--	--	3.8750	3.6784	--
$\hat{Z}_I$	--	--	0.9750	0.8750	--
Profit $_I$	1.7336	1.7550	1.9503	1.9503	1.9503
Profit $_E$	1.7336	1.6900	0.9752	0.9752	0.9752

**Table II: Means**

Variables:	Telecom		Software	
	1988-1995	1996-2002	1988-1995	1996-2002
Debt	0.3706	0.4545	0.1991	0.1888
Capacity	0.8627	0.7413	0.4020	0.3270
Altman's z-score	0.8028	0.6001	1.2332	1.0375
Market-to-Book	2.2886	1.8897	3.5311	5.3450
Size	5.0616	5.3914	3.1780	3.4199
Intangibility	0.1258	0.1919	0.0499	0.0982
Depreciation	0.0749	0.0837	0.0570	0.0810
Profitability	0.0209	-0.0627	-0.0778	-0.2856
Volatility	79.4859	164.5242	24.1820	32.4343
Herfindahl	0.2006	0.1608	0.2752	0.2656

Note: Telecommunications firms have SIC codes between 4800 and 4899, software firms between 7370 and 7379. The means are computed on the winsorized data for the upper and lower 1%. We measure debt as the sum of long-term (item 9) and short-term debt (item 34) divided by total assets (item 6). We measure capacity as the gross value of property, plant, and equipment (item 7) to total assets. Other variables are defined in the appendix.

**Table III: Debt Regression Results**

Variables:	Telecom		Software	
	Coefficients	P-values	Coefficients	P-values
Altman's z-score	-0.0651	0.00***	0.0369	0.00***
Market-to-book	-0.0019	0.09*	-0.0019	0.01***
Size	-0.0060	0.15	-0.0047	0.23
Intangibility	0.4456	0.00***	0.2025	0.00***
Depreciation	0.9582	0.00***	0.4232	0.00***
Profitability	-0.1487	0.00***	-0.2223	0.00***
Volatility	-0.52e-4	0.00***	1.07e-4	0.00***
Herfindahl Pre-dereg.	0.1025	0.06*	0.1908	0.00***
Herfindahl Post-dereg.	-0.0848	0.24	0.0838	0.00***
Exits Pre-dereg.	0.3814	0.00***	0.1418	0.00***
Incumbents Pre-dereg.	<b>0.2683</b>	0.00***	<b>0.0571</b>	0.00***
Incumbents Post-dereg.	<b>0.3823</b>	0.00***	<b>0.0650</b>	0.00***
Entrants Post-dereg.	0.3643	0.00***	-0.0218	0.27
Pre vs Post		0.00***		0.61
Telecom vs Software		0.00***		
R <sup>2</sup>	0.2253			
number of firm-year observations	8951			
number of firms	1636			

Note: \*, \*\*, and \*\*\* indicate statistical significance at 10%, 5% and 1%. Debt is regressed on lagged determinants and dummy variables, using a panel-corrected covariance matrix.

**Table IV: Capacity Regression Results**

Variables:	Telecom		Software	
	Coefficients	P-values	Coefficients	P-values
Altman's z-score	-0.2382	0.00***	0.0284	0.00***
Market-to-book	-0.0025	0.00***	-0.0018	0.00***
Size	0.0438	0.00***	-0.0236	0.00***
Intangibility	-0.9418	0.00***	-0.3642	0.00***
Depreciation	4.6077	0.00***	2.0935	0.00***
Profitability	0.3106	0.00***	-0.0272	0.04**
Volatility	-1.12e-4	0.00***	1.65e-4	0.00***
Herfindahl Pre-dereg.	-0.2120	0.00***	0.2290	0.00***
Herfindahl Post-dereg.	-0.4424	0.00***	0.0556	0.01***
Exits Pre-dereg.	0.6091	0.00***	0.2903	0.00***
Incumbents Pre-dereg.	<b>0.5733</b>	0.00***	<b>0.2834</b>	0.00***
Incumbents Post-dereg.	<b>0.5815</b>	0.00***	<b>0.2821</b>	0.00***
Entrants Post-dereg.	0.5175	0.00***	0.1851	0.00***
Pre vs Post		0.62		0.92
Telecom vs Software		0.65		
R <sup>2</sup>	0.5869			
number of firm-year observations	8951			
number of firms	1636			

Note: \*, \*\*, and \*\*\* indicate statistical significance at 10%, 5% and 1%. Capacity is regressed on lagged determinants and dummy variables, using a panel-corrected covariance matrix.

**Table V: Telecom Survival Regression Results**

Variables:	Coefficients	T-ratios	Marginal Effects
Altman's z-score	-0.0498	-1.1092	-0.0189
Market-to-book	0.0061	1.8341*	0.0023
Size	-0.0198	-1.1588	-0.0075
Intangibility	-0.0703	-0.4783	-0.0267
Depreciation	-0.2108	-0.3516	-0.0801
Profitability	0.3648	3.6134***	0.1386
Volatility	2.69e-4	1.8712*	1.02e-4
Herfindahl Pre-dereg.	-0.8393	-3.0487***	-0.3190
Herfindahl Post-dereg.	-0.09596	-0.2797	-0.0365
Own Residual Debt Pre-dereg.	<b>-5.20e-4</b>	-4.2437***	-1.98e-4
Own Residual Debt Post-dereg.	<b>-0.66e-4</b>	-1.0521	-0.25e-4
Own Residual Capacity Pre-dereg.	<b>0.94e-4</b>	2.8798***	0.36e-4
Own Residual Capacity Post-dereg.	<b>0.24e-4</b>	1.1529	0.09e-4
Rival Residual Debt Pre-dereg.	<b>1.39e-4</b>	0.3629	0.53e-4
Rival Residual Debt Post-dereg.	<b>-1.11e-4</b>	-1.1999	-0.43e-4
Rival Residual Capacity Pre-dereg.	<b>-0.24e-4</b>	-0.2875	-0.09e-4
Rival Residual Capacity Post-dereg.	<b>0.54e-4</b>	1.4763	0.20e-4
Pre vs Post P-values:			
Own Residual Debt	0.00***		
Own Residual Capacity	0.06*		
Rival Residual Debt	0.52		
Rival Residual Capacity	0.39		
Log-likelihood Function	-1648.8		
number of firm-year observations from survivors	1375		
number of firm-year observations	2841		
number of firms	476		

Note: \*, \*\*, \*\*\* indicate statistical significance at 10%, 5% and 1%. “Residual debt” and “residual capacity” refer to the observed debt and capacity unexplained by traditional determinants. Time dummies are included in the probit estimation.

Figure 1 Number of Telecom Firms

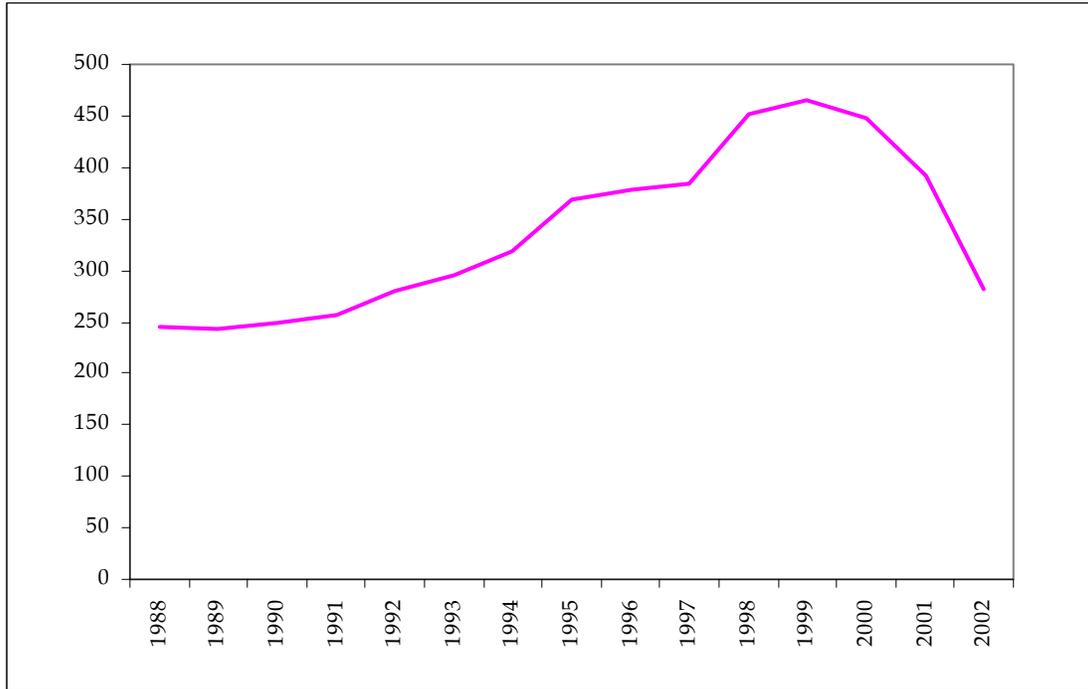


Figure 2 Average Herfindahl Index in Telecom Industry

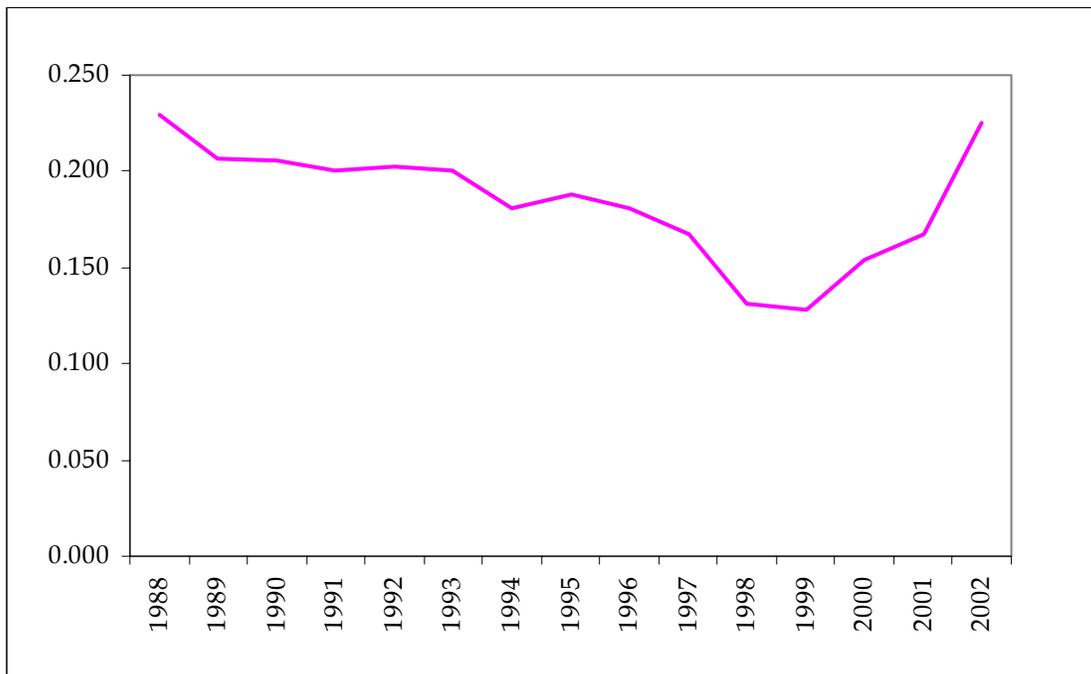


Figure 3: Isodeterrence Curves  $\Delta(k_1, F_1)$

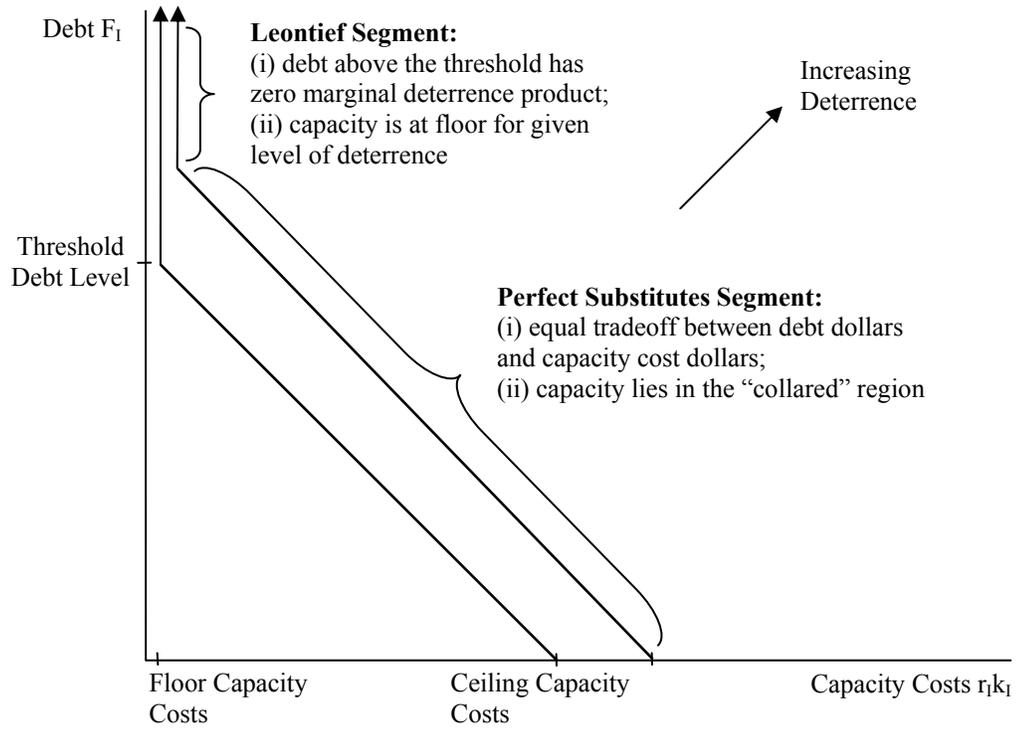


Figure 4: Incumbent's Optimal Production Policy  $q_I^*$  for a Given Debt Level  $F_I$

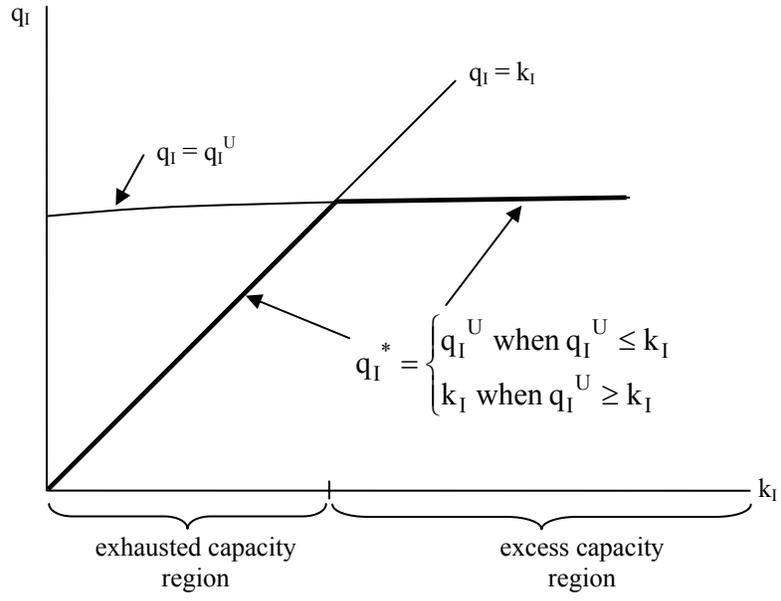


Figure 5 Average Debt and Capacity for Telecom Firms

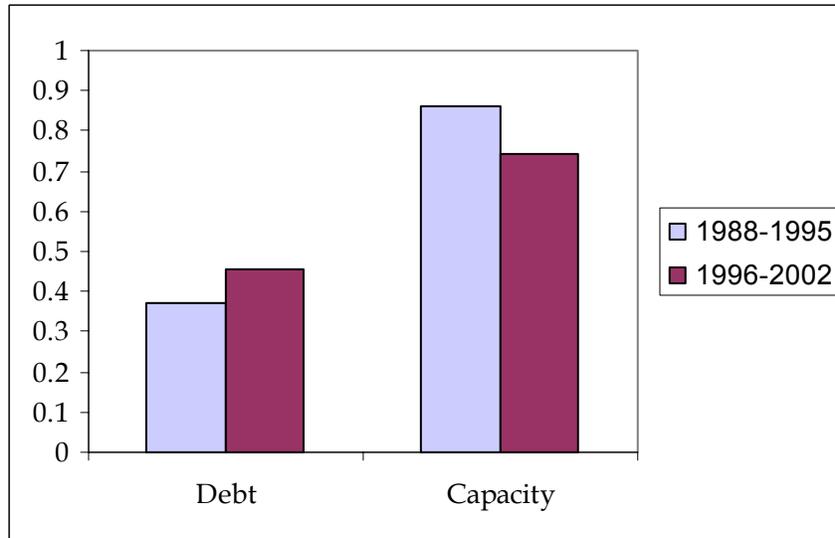


Figure 6 Average Debt and Capacity for Software Firms

