Designing Regulatory Policy to Induce the Efficient Choice of Capital Structure

by

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Abstract

Regulated firms are alleged to adopt excessive debt, particularly when they operate under price cap regulation. We demonstrate how regulators can prevent excessive leverage without ceding rent to the regulated firm when the regulator can impose substantial penalties on the firm should it experience financial distress. When these penalties are more limited, the regulated firm secures rent from its privileged ability to assess the riskiness of the prevailing capital structures. If these penalties are sufficiently limited, the regulator optimally affords the firm no choice among capital structures. Consequently, the regulated firm prefers moderate penalties to very limited penalties.

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1 Introduction

Price cap regulation has become a popular alternative to rate of return regulation in many industries. The popularity of price cap regulation (PCR) stems in part from its ability to provide strong incentives for cost reduction by severing the link between regulated prices and realized production costs.[1] However, in severing this link, PCR also can invite strategic behavior by regulated firms. For example, the firms may be tempted to allow service quality to deteriorate in order to reduce short-term operating costs.[2]

In recent years, regulators have become concerned that PCR may also encourage regulated firms to adopt excessive levels of debt financing. This concern has arisen in the UK water sector, for example. When the newly privatized water utilities were first regulated in 1989, they were financed almost entirely with equity. OFWAT, the sector regulator, advised the utilities to employ some debt financing in order to reduce capital costs.[3] The utilities apparently took this advice to heart – the sector's capital structure was more than 40 percent debt by the turn of the century, and nearly 60 percent debt by 2006. (OFWAT, 2001, p. 19; 2010, p. 17).

Although debt financing can limit the risk that investors face, it can impose costs on consumers of regulated services and society more generally. When a regulated firm's revenue falls short of its debt obligations, the regulator usually is highly reluctant to incur the service disruptions and other costs and inconveniences that bankruptcy proceedings can entail. Instead, the regulator typically seeks ways to alleviate the realized shortfall, sometimes by requiring consumers to bear higher prices and sometimes by seeking financial support from the government, for example. These considerations have introduced concern about the current high levels of debt financing in the UK water sector (Cowan, 2013). In 2012, debt accounted for nearly 70 percent of utility financing on average, and the leverage was nearly

[1] Braeutigam and Panzar (1993), Crew and Kleindorfer (1996, 2002), Sappington (2002), Vogelsang (2002), and Cowan (2013), among others, discuss the rationale for PCR, as well as its design and implementation.

[2] See Sappington and Weisman (2010), for example, and the references cited therein.

[3] Private discussions with Sir Ian Byatt, the first director of OFWAT (April 10, 2013). Debt financing typically is less costly than equity financing because debt holders face less financial risk than equity holders.

80 percent for several companies (OFWAT, 2013). Concern about these debt levels led the chairman of OFWAT's board, Jonson Cox, to urge a swift change in OFWAT policy.

> "The regulator has previously taken the view that the capital structure of the companies (and consequent risks) is for the boards and shareholders to determine. This remains the case only as long as a structure does not create risks (sic) which could, on failure of a company to meet its obligations, pass liability or risk back to customers or to the public purse – or indeed damage the legitimacy of the entire sector. Public interest rightly expects the economic regulator to ensure that vital public services today and the ability to fund investment in future are not put at risk by corporate structures. The regulator has a role in ensuring structural risks are managed effectively." (Cox, 2013)

The purpose of this research is to begin to help understand the regulator's role in this regard. We examine the issues of concern to Mr. Cox in a stylized setting where the regulated firm can operate under either the current ("original") capital structure or a ("new") more highly leveraged capital structure. The new structure lowers the firm's capital costs by $S > 0$, but increases the probability that the firm will be unable to meet its debt obligations, and so will experience financial distress. Such distress entails social cost D, which includes the cost of any public funds employed to "bail out" the firm, for example. The expected benefit (S) of adopting the new capital structure exceeds the corresponding expected cost if the probability of financial distress under the new capital structure is low (p_L), but not if this probability is high (p_H). The regulated firm can determine whether this probability (p) is low or high before choosing its capital structure, but must incur cost k to do so. The regulator cannot observe whether the firm has incurred this cost to learn p and cannot verify any claim the firm makes about the magnitude of p.

Despite these limitations, if the regulator can credibly threaten to punish the firm severely should it experience financial distress after adopting the new capital structure, then the regulator can induce the firm to learn p and adopt the new capital structure if and only if $p = p_L$. The regulator also can achieve this desirable outcome without affording the firm any rent. When the regulator's ability to penalize the firm is more limited, she can still induce the firm to learn p and adopt the appropriate capital structure. However, she must cede rent to the firm in order to do so. When the regulator's ability to penalize the firm is sufficiently limited, the regulator finds it too costly to motivate the firm to learn p. Instead, she simply instructs the firm to operate with the original capital structure, and she affords the firm no choice among capital structures.

The optimal regulatory policy leaves the firm with no rent when the regulator has substantial or very limited ability to penalize the firm. In contrast, the firm secures rent when the regulator can impose moderate penalties on the firm. Consequently, the firm benefits from expanded regulatory ability to penalize the firm, within limits. The firm may enhance this ability by, for example, posting a moderate financial bond that it forfeits should it experience financial distress after adopting the new capital structure.

Our analysis complements other studies of the capital structure of regulated enterprises by focusing on the design of incentives to induce the firm to learn the prevailing risks before choosing a capital structure. Some studies (e.g., Spiegel, 1994; Spiegel and Spulber, 1994) examine how a regulated firm that is well informed about the risks of potential capital structures will choose its capital structure before the regulator sets consumer prices. These studies conclude that the firm may implement excessive debt because the debt can induce the regulator to raise consumer prices in order to limit the risk of insolvency.[4] Other studies (e.g., Jensen and Meckling, 1976; Ross, 1977; Spiegel and Spulber, 1997) examine how a well-informed firm might choose its capital structure in order to signal future financial prospects or limit managerial moral hazard.[5] Our analysis incorporates as a special case the setting in which the regulated firm is well informed from the outset about the risks inherent in the capital structures it might implement. However, we focus on the arguably more relevant setting in which costly study is required to acquire this information. Therefore, our formal analysis reflects principles developed in the literature that examines the design of reward

[4] Bortolotti et al. (2011) provide empirical evidence that supports this prediction. De Fraja and Stones (2004) and Cowan (2013) examine the design of pricing policies and the choice of capital structure in models closer to our model in that the regulator can commit to policy parameters before the regulated firm chooses its capital structure. These important studies are discussed further in section 5.

[5] Harris and Raviv (1991) review the early literature along these lines.

structures to induce an agent to undertake costly study of the environment in which he operates before acting (e.g., Lewis and Sappington, 1997; Crémer et al., 1998; Szalay, 2009). Our analysis complements these studies in part by focusing on the impact of a regulator's limited ability or incentive to impose penalties and by identifying conditions under which the firm can gain as the penalties it faces become more severe.

The analysis proceeds as follows. Section 2 describes the stylized model that we analyze. Section 3 identifies conditions under which the regulator's inability to monitor both the firm's study of the new capital structure or the results of the firm's findings is not constraining. Section 4 characterizes the optimal regulatory policy in settings where the regulator's limited information is constraining. Section 5 provides concluding observations and suggests directions for future research. The proofs of all formal conclusions are presented in the Appendix.

2 The Model

We consider a setting in which a profit-maximizing regulated firm can either operate with the prevailing ("original") capital structure or implement an alternative ("new") capital structure that entails more extensive debt financing. The firm incurs capital cost K_0 if it operates under the original capital structure. This cost declines to $K_0 - S$ if the firm adopts the new capital structure. Although the new capital structure provides cost saving $S > 0$, it entails an increased probability that the regulated firm will be unable to meet its debt obligations, and so will experience financial distress. Such distress generates social cost D. This cost includes losses from service disruptions or reduced service quality that customers suffer when the regulated firm experiences financial distress. This cost can also include the social cost of funds (e.g., tax revenue) employed to avoid bankruptcy or to "bail out" the bankrupt firm. In addition, this social cost can include relevant restructuring costs or increased future borrowing costs that the regulated firm incurs, and the personal losses that the regulator experiences (due to a tarnished reputation and reduced future employment prospects, for example) when the firm that she regulates experiences financial distress.

Because adoption of the new capital structure entails both benefits (S) and costs (D), the merits of such adoption depend on the magnitudes of S and D and on the probabilities of distress under the two capital structures. The probability of financial distress is known to be $p_0 \in (0,1)$ under the original capital structure. The probability of distress under the new capital structure (p) is either low ($p_L \in (p_0, 1)$) or high ($p_H \in (p_L, 1)$). The probability that $p = p_i$ is $\phi_i \in (0,1)$, for $i = L, H$. Consequently, the *ex ante* expected probability of distress under the new capital structure is $\widetilde{p} \equiv \phi_L p_L + \phi_H p_H > p_0$.

The social benefit of adopting the new capital structure is assumed to exceed the corresponding social cost if and only if the probability of distress under the new capital structure is low (p_L). The social benefit of adopting the new capital structure is the associated reduction in capital costs, S. The corresponding cost is the increased expected social cost due to financial distress, $[\, p - p_0 \,] D$. Formally, we assume:

$$[\, p_L - p_0 \,] D \; < \; S \; < \; [\, \widetilde{p} - p_0 \,] D \; < \; [\, p_H - p_0 \,] D \, . \tag{1}$$

Inequality (1) implies that if the probability of distress under the new capital structure (p) is not known, social surplus is maximized when the original capital structure, not the new capital structure, is implemented.

Although the probability of distress under the new capital structure (p) is initially unknown, the regulated firm can employ its unique industry experience and knowledge to learn p by incurring personal cost k. This cost includes the firm's opportunity cost of developing accurate forecasts of the likelihood that the sum of production costs and debt obligations costs will exceed authorized revenues. The regulator is presumed unable to discover p herself. The regulator is also unable to verify whether the firm has incurred cost k to learn the realization of p.[6]

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[6]In practice, a regulator can observe whether the regulated firm has produced a report that purports to assess the risk of financial distress under the new capital structure. However, the regulator may lack the resources required to determine the validity and accuracy of the report, and thus whether the firm has put forth the effort required to fully assess the relevant risks.

We will refer to the policy under which the firm incurs cost k to learn p and adopts the new capital structure if and only if $p = p_L$ as the *efficient capital structure policy.* This policy is efficient because, by assumption, the social value of learning p exceeds the corresponding cost, k. This social value is the expected reduction in social cost from pursuing the efficient capital structure policy. The social cost in question is the sum of the firm's capital cost and the expected social loss from financial distress. Thus, the social value of learning p is:

$$V \equiv \phi_L [p_L D + K_0 - S] + \phi_H [p_0 D + K_0] - (p_0 D + K_0) .$$

We assume:

$$k < V \quad \Leftrightarrow \quad k < \phi_L [(p_L - p_0) D - S] . \tag{2}$$

The firm's decision about whether to incur cost k to learn p before choosing its capital structure is affected by the revenue it is permitted to earn under the two capital structures and the associated penalties it faces should financial distress arise. Although the regulator cannot discern whether the firm has learned p before it chooses a capital structure, the regulator can observe the firm's choice of capital structure. The regulator also eventually observes whether the firm experiences financial distress under the selected capital structure. Consequently, the regulator can link the firm's authorized revenue to the capital structure it implements and whether the firm ultimately experiences financial distress. R_0 will denote the firm's revenue when it adopts the original capital structure and distress does not arise. $\underline{R}_0$ will denote the firm's revenue when distress arises under the original capital structure. R_d will denote the firm's revenue when it implements the new capital structure and distress does not arise. $\underline{R}_d$ will denote the firm's revenue when distress arises under the new capital structure.[7] C will denote the firm's physical production cost under both the original and the new capital structure.[8]

[7]The subscript "d" denotes an increased level of debt.

[8]We do not model formally the firm's effort to minimize its physical production cost. In practice, a firm's authorized revenue typically is not linked to its realized physical production cost when it operates under price cap regulation. Therefore, the profit-maximizing firm will seek to minimize these costs. Consequently, the firm in our model can be viewed as operating under a variant of price cap regulation in which allowed

If she decides to induce the firm to pursue the efficient capital structure policy, the regulator will seek to do so in the manner that minimizes the expected sum of the firm's revenue and the social cost of financial distress. Formally, the regulator's problem, [RP-I], in this setting is to choose R_0, $\underline{R}_0$, R_d, and $\underline{R}_d$ to:

$$Minimize \quad \phi_L\,[\,p_L\,(\underline{R}_d + D) + (1-p_L)\,R_d\,] + \phi_H\,[\,p_0\,(\underline{R}_0 + D) + (1-p_0)\,R_0\,] \tag{3}$$

subject to:

$$\pi \;\equiv\; \phi_L\,[\,p_L\,\underline{R}_d + (1-p_L)\,R_d + S\,] + \phi_H\,[\,p_0\,\underline{R}_0 + (1-p_0)\,R_0\,] - K_0 - C - k \;\geq\; 0\,; \tag{4}$$

$$\pi \;\geq\; p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0 - K_0 - C\,; \tag{5}$$

$$\pi \;\geq\; \widetilde{p}\,\underline{R}_d + [\,1-\widetilde{p}\,]\,R_d - (K_0 - S) - C\,; \tag{6}$$

$$p_L\,\underline{R}_d + [\,1-p_L\,]\,R_d + S \;\geq\; p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0\,; \tag{7}$$

$$p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0 \;\geq\; p_H\,\underline{R}_d + [\,1-p_H\,]\,R_d + S\,; \tag{8}$$

$$R_0 - K_0 - C \;\geq\; -\,\Delta\,; \qquad \underline{R}_0 - K_0 - C \;\geq\; -\,\Delta\,; \tag{9}$$

$$R_d - (K_0 - S) - C \;\geq\; -\,\Delta\,; \quad \text{and} \quad \underline{R}_d - (K_0 - S) - C \;\geq\; -\,\Delta\,. \tag{10}$$

Constraint (4) ensures that the regulated firm anticipates at least the profit it requires to operate in the industry. This profit is normalized to 0. Constraints (5) and (6) ensure that the firm prefers to learn the realization of p than to remain uninformed about p and: (i) always implement the original capital structure; or (ii) always implement the new capital structure. Constraints (7) and (8) ensure that the firm will: (i) implement the new capital structure when it knows that the probability of financial distress under this structure is relatively low (i.e., $p = p_L$); and (ii) implement the original capital structure when it knows that the probability of financial distress under the new capital structure is relatively high (i.e., $p = p_H$).[9]

revenues are linked to the firm's chosen capital structure, and C can be viewed as the minimum physical production cost that the firm can reasonably be expected to achieve.

[9]When it is indifferent among actions, the firm is assumed to undertake the action preferred by the regulator.

Constraints (9) and (10) ensure that the firm's profit never falls below $-\Delta$. Thus, Δ represents the maximum financial loss the regulator can credibly force the regulated firm to bear. If $\Delta = 0$, for instance, then the regulator is effectively unable penalize the firm even when it experiences financial distress. In practice, political or legal considerations can limit the financial penalty that a regulator can credibly threaten to impose on a regulated firm. A regulator may also decline to impose a large financial penalty on the firm in order to avoid any associated deleterious consequences for consumers. When she has limited ability or incentive to impose severe financial penalties on the firm, the regulator can find it difficult to motivate the firm to undertake the efficient capital structure policy. When the firm knows that it will not be punished severely should financial distress arise, it may find it profitable to avoid the cost of learning p and simply adopt the less costly, but more risky, capital structure without knowing whether it is "safe" to do so.

3 Preliminary Findings

We begin our analysis of the optimal regulatory policy in this environment by identifying conditions under which the regulator's limited ability to monitor the firm's activities is not constraining. Proposition 1 explains when the *full-information outcome* is feasible. Under this outcome, the regulator induces the firm to undertake the efficient capital structure policy and cedes no rent to the firm.

Proposition 1. *The full-information outcome is a feasible solution to [RP-I] if and only if*

$$\Delta \ \geq \ \Delta_F \ \equiv \ \frac{[1 - \widetilde{p}]\, k}{\phi_L\, [\widetilde{p} - p_L]}\,.$$

Proposition 1 indicates that the regulator can achieve the full-information outcome when the penalty that she can impose on the firm in the event of financial distress (Δ) is sufficiently large relative to the firm's cost (k) of learning p. In this case, the regulator achieves her preferred outcome by imposing a large penalty on the firm if it experiences financial distress under the new capital structure. This large penalty can be offset by substantial rent under the new capital structure in the absence of financial distress. When Δ is large, R_d can be set well above $\underline{R}_d$ while ensuring zero expected profit for the firm when it undertakes the efficient capital structure policy. The large difference between R_d and $\underline{R}_d$ ensures that the firm's expected profit under the new capital structure is much greater when the firm knows that distress is unlikely (i.e., that $p = p_L$) than when the firm does not know p. Consequently, even when the payment structure under the new capital structure is set to deliver enough rent to the informed firm to compensate it for incurring cost k, the firm will find it unprofitable to simply adopt the new capital structure without learning p.

Corollary 1 identifies changes in the environment that enhance the regulator's ability to achieve the full-information outcome.

Corollary 1. *The set of Δ values for which the full-information outcome is feasible (i.e., $[\Delta_F, \infty)$) increases as k declines, as p_H increases, or as p_L decreases, ceteris paribus.*

When k is relatively small, the regulator does not need to promise the firm substantial rent when it adopts the new capital structure in order to compensate the firm for learning p. Consequently, the firm will not find it highly profitable to simply adopt the new capital structure without learning p, and so the regulator is able to achieve the full-information outcome even when Δ is relatively small.

When p_H is relatively large, $\widetilde{p} - p_L$ is also relatively large. Consequently, the assessed likelihood of financial distress under the new capital structure is substantially greater when the firm does not know p than when the firm knows that $p = p_L$. Therefore, for a given value of $R_d - \underline{R}_d > 0$, the difference between the firm's expected profit under the new capital structure when the firm knows $p = p_L$ and when the firm does not know p is large. As a result, the regulator is better able to induce the firm to learn p without affording the firm any rent.

In contrast, when p_L is relatively large, $\widetilde{p} - p_L$ is relatively small. Consequently, for a given value of $R_d - \underline{R}_d$, the difference between the firm's expected profit under the new capital structure when the firm knows $p = p_L$ and when the firm is uninformed about p is small. Consequently, it is more difficult to induce the firm to learn p without affording the firm rent.

Corollary 2 emphasizes an additional implication of Proposition 1.

Corollary 2. *Suppose $\Delta \geq 0$, so the regulator can always hold the firm to zero profit. Then the full-information outcome is feasible if $k = 0$.*

Corollary 2 indicates that if the regulator can always limit the firm to its reservation profit level of zero and if it is not costly for the firm to learn p, then the regulator can secure the full-information outcome. She can do so simply by setting the firm's revenue to match the sum of its capital and production costs regardless of the selected capital structure and regardless of whether financial distress occurs. Under such a reward structure, the firm is willing to (costlessly) learn the realization of p and implement the new capital structure if and only if $p = p_L$.

Corollary 2 implies that the optimal regulatory policy typically is straightforward when the regulated firm is fully informed (or can costlessly become informed) about the relevant risks of a more highly leveraged capital structure. The regulator can simply adjust the firm's authorized revenue to fully reflect the reduction in capital costs that the firm secures if it adopts the new capital structure. Such a policy leaves the firm indifferent among capital structures. Consequently, the firm is willing to adopt the capital structure that provides the largest difference between social benefits and costs. In essence, the regulator's problem only becomes challenging when it is costly for the firm to assess the inherent risks of more highly leveraged capital structures and when the regulator seeks to induce the firm to better assess these risks before choosing a capital structure.

4 Main Findings

The findings in section 3 establish that the regulator can achieve her preferred outcome when she has substantial ability to penalize the firm if it experiences financial distress and/or when it is not very costly for the firm to learn the likelihood of financial distress under the new capital structure. We now proceed to characterize the optimal regulatory policy when, as is often the case in practice, these conditions are not met. In practice, regulators often lack the authority to impose large financial penalties on the firms they regulate. Regulators also can lack the will to do so if such penalties threaten to disrupt service or otherwise diminish service quality in the industry. Instead, regulators can find it more expedient to bail the firm out of its financial difficulties.[10]

Proposition 2 describes how the regulator optimally induces the firm to pursue the efficient capital structure policy when she cannot do so without affording the firm some rent.

Proposition 2. *Suppose $\Delta < \Delta_F$, so the full-information outcome is not feasible. Then at the solution to [RP-I]:*

(i) if the firm adopts the new capital structure, it anticipates strictly positive profit, but receives the minimum feasible profit if it experiences financial distress (i.e., $\underline{R}_d = K_0 - S + C - \Delta$, $R_d = \underline{R}_d + \frac{k}{\phi_L [\widetilde{p} - p_L]}$, and $\pi_{dL} \equiv p_L \underline{R}_d + [1 - p_L] R_d - (K_0 - S) - C > 0$);

(ii) the firm's ex ante expected profit is exactly the profit it could secure without learning p and always implementing either the original or the new capital structure (i.e., $\pi = p_0 \underline{R}_0 + [1 - p_0] R_0 - K_0 - C = \widetilde{p} \underline{R}_d + [1 - \widetilde{p}] R_d - (K_0 - S) - C$); and

(iii) after learning p, the firm strictly prefers to implement the new capital structure when $p = p_L$ and to implement the original capital structure when $p = p_H$ (i.e., $p_L \underline{R}_d + [1 - p_L] R_d + S > p_0 \underline{R}_0 + [1 - p_0] R_0$ and $p_0 \underline{R}_0 + [1 - p_0] R_0 > p_H \underline{R}_d + [1 - p_H] R_d + S$).

[10] See Kornai (1986) and Kornai et al. (2003) for discussions of the origins of and problems with such "soft budget constraints."

Proposition 2 reflects the following considerations. To provide the firm with the strongest incentives to determine when the more highly leveraged capital structure should be adopted, the regulator sets $\underline{R}_d$ to impose a large penalty on the firm when it experiences financial distress under the new capital structure. The regulator also sets R_d to allow the the firm to recover its entire information acquisition cost (k) when it implements the new capital structure. In particular, R_d is set to ensure $\pi_{dL} \equiv p_L \underline{R}_d + [1 - p_L] R_d - (K_0 - S) - C = \frac{k}{\phi_L}$. This profit of $\frac{k}{\phi_L}$, coupled with zero profit when the firm adopts the original capital structure (i.e., $\pi_0 \equiv p_0 \underline{R}_0 + [1 - p_0] R_0 - K_0 - C = 0$) generates zero *ex ante* expected profit for the firm (i.e., $\pi = \phi_L \pi_{dL} + \phi_H \pi_0 - k = \phi_L \pi_{dL} - k = 0$).

A reward structure of this form can induce the firm to learn p without ceding any *ex ante* rent to the firm when the maximum penalty that can be imposed on the firm is sufficiently large (i.e., when $\Delta \geq \Delta_F$). In this case, the regulator can set $\underline{R}_d$ sufficiently far below R_d to ensure that the firm would anticipate negative profit if it adopted the new capital structure without learning p (i.e., to ensure $\widetilde{\pi}_d \equiv \widetilde{p} \underline{R}_d + [1 - \widetilde{p}] R_d - (K_0 - S) - C < 0$).[11] Therefore, the firm will not be tempted to adopt the new capital structure unless it knows that $p = p_L$.

When Δ is smaller (i.e., when $\Delta < \Delta_F$), the regulator cannot reduce $\underline{R}_d$ sufficiently far below R_d to ensure that the firm: (i) recovers cost k when it learns that $p = p_L$ and adopts the new capital structure; but (ii) anticipates negative profit if it adopts the new capital structure without learning p. In this case, when the regulator sets R_d and $\underline{R}_d$ to ensure that the firm is able to recover k when it adopts the new capital structure after learning that $p = p_L$, she (unavoidably) delivers additional rent $\pi_{dL} = \frac{k}{\phi_L} + \Delta_F - \Delta$ to the firm. The regulator is then compelled to deliver the same incremental rent to the firm under the original capital structure ($\pi_0 = \Delta_F - \Delta$) to ensure that the firm does not simply always adopt the new capital structure without learning p. As a result, the firm's *ex ante* expected profit increases dollar for dollar as the maximum penalty that the regulator can impose on

[11] Observe that $\pi_{dL} - \widetilde{\pi}_d = [\widetilde{p} - p_L][R_d - \underline{R}_d]$, which is increasing in $R_d - \underline{R}_d$.

the firm declines below Δ_F. In essence, the firm enjoys the full benefit of any reduction in the regulator's ability to penalize the firm, provided the regulator continues to induce the firm to undertake the efficient capital structure policy.

These observations are recorded formally in Corollary 3.

Corollary 3. *Suppose $\Delta < \Delta_F$, so the full-information outcome is not feasible. Then at the solution to [RP-I]:*

(i) $\pi(\Delta)$, the firm's expected profit, given Δ, is $\Delta_F - \Delta$;

(ii) $\pi_0(\Delta)$ ($\equiv p_0 \underline{R}_0 + [1 - p_0] R_0 - K_0 - C$), the firm's expected profit if it ultimately adopts the original capital structure (after learning that $p = p_H$), is also $\Delta_F - \Delta$; and

(iii) $\pi_{dL}(\Delta)$ ($\equiv p_L \underline{R}_d + [1 - p_L] R_d - (K_0 - S) - C$), the firm's expected profit if it ultimately adopts the new capital structure (after learning that $p = p_L$), is $\Delta_F - \Delta + \frac{k}{\phi_L}$.

The systematic increase in the firm's rent as Δ declines below Δ_F at the solution to [RP-I] implies that regulator eventually finds it prohibitively costly to induce the firm to learn p. Once Δ declines below a critical level, the regulator no longer attempts to motivate the firm to learn p. Instead, she simply instructs the firm to implement the original capital structure. The efficient capital structure policy would generate greater surplus. However, when limits on the penalties that can be imposed on the firm make it unduly costly to induce the firm to pursue this policy, the regulator optimally employs her own limited information to choose the firm's capital structure and denies the firm any choice among capital structures. This conclusion is recorded formally in Proposition 3.

Proposition 3. *The regulator will afford the firm a non-trivial choice between capital structures (and induce the firm to learn p) if $\Delta > \widehat{\Delta} \equiv \Delta_F - (\phi_L [S - (p_L - p_0) D] - k)$. In contrast, the regulator will instruct the firm to always operate with the original capital structure if $\Delta < \widehat{\Delta}$.*

Corollary 4. *The range of penalties* ($\Delta_F - \widehat{\Delta}$) *for which the firm earns rent as it is optimally optimally induced to undertake the efficient capital structure policy: (i) increases as* S *or* ϕ_L *increases; and (ii) decreases as* p_L*,* D*, or* k *increases.*

Corollary 4 reflects the following considerations. Recall from Corollary 3 and Proposition 3 that the firm's rent increases dollar for dollar as Δ declines between Δ_F and $\widehat{\Delta}$. Therefore, Corollary 4 identifies the factors that render the regulator willing to concede greater rent to the firm in order to induce it to pursue the efficient capital structure policy. This policy generates greater expected surplus when the new capital structure provides a more substantial reduction in capital costs (so S is larger), when it is less likely to produce financial distress (so p_L is smaller), and when the social cost of distress (D) is smaller. The efficient capital structure policy is also more valuable when it is less costly to deliver (so k is smaller) and when the new capital structure is relatively likely to entail the small distress probability (so ϕ_L is larger).

Because the regulator affords the firm no choice among capital structures when the maximum penalty that she can impose on the firm (Δ) is below $\widehat{\Delta}$, the firm's equilibrium profit is a non-monotonic function of Δ. Recall from Proposition 1 that when Δ exceeds Δ_F, the regulator is able to limit the firm's *ex ante* expected profit to zero even as she induces the firm to pursue the efficient capital structure policy. Also, recall from Corollary 3 that as Δ declines below Δ_F, the regulator optimally continues to induce the firm to learn p, but is forced to cede some rent to the firm. As Figure 1 illustrates, this rent continues to increase as Δ declines further below Δ_F until Δ reaches the critical value, $\widehat{\Delta}$. When Δ is less than $\widehat{\Delta}$, the regulator finds it unduly costly to undertake the efficient capital structure policy. Instead, the regulator simply instructs the firm to operate under the original capital structure, and does not afford the firm any choice among capital structures. The firm secures no rent in this case.

The implications of this regulatory policy for the firm's equilibrium profit are summarized formally in Corollary 5.

Corollary 5. *The firm's equilibrium ex ante expected profit,* $\pi^*(\Delta)$*, its equilibrium expected profit when it implements the original technology,* $\pi_0^*(\Delta)$ *, and its equilibrium expected profit when it implements the new technology,* $\pi_{dL}^*(\Delta)$*, are all non-monotonic functions of* Δ*. In particular:*

$$\pi^*(\Delta) = \begin{cases} 0 & \text{if } \Delta < \widehat{\Delta} \\ \Delta_F - \Delta & \text{if } \Delta \in [\,\widehat{\Delta},\, \Delta_F\,] \\ 0 & \text{if } \Delta > \Delta_F\,. \end{cases}$$

Furthermore, $\pi_0^*(\Delta) = \pi^*(\Delta)$ *and* $\pi_{dL}^*(\Delta) = \pi^*(\Delta) + \frac{k}{\phi_L}$.

Corollary 5 implies that although the firm benefits when the penalties that it can be forced to bear are limited, the firm does not wish these penalties to be too limited. When the regulator is unable to impose meaningful penalties on the firm, she optimally rescinds the firm's discretion to choose among capital structures, and thereby eliminates the rent that the firm can otherwise secure from its privileged ability to discern the prevailing risk of financial distress under the new capital structure.[12] When she can impose more substantial penalties on the firm, the regulator affords the firm some discretion in choosing its capital structure, and provides some rent to the firm in order to induce it to use this discretion in the best interests of consumers.

A regulated firm may sometimes be able to enhance a regulator's ability and incentive to impose moderate financial penalties by posting a moderate financial bond. If the firm posts the bond when its revenues exceed its costs, then the act of posting the bond is unlikely to jeopardize the firm's financial integrity or limit its ability to deliver uninterrupted, high-quality service to consumers. Then, should financial distress arise under the new capital structure, the regulator can use the bond to ensure that scheduled debt payments are made, and thereby avoid a costly, disruptive bankruptcy. The firm suffers a financial penalty when it experiences financial distress under such a policy, and so is inclined to pursue the efficient

[12] Lewis and Sappington (1995) also find that a regulator may optimally decline to offer a regulated firm a choice among capital structures. This behavior reflects the regulator's risk aversion, though, rather than a limited ability to impose substantial penalties on the regulated firm.

capital structure policy. However, the penalty does not introduce costly service disruptions that the regulator seeks to avoid, and so the regulator may fulfill the threat to impose the penalty. Such a credible threat can encourage the regulator to offer the firm a meaningful choice among capital structures, to the benefit of consumers and the firm alike.

5 Conclusions

We have examined the optimal design of regulatory policy in settings where the regulated firm can acquire privileged knowledge of the likelihood that a new, more highly leveraged, capital structure will result in financial distress. We found that if the regulated firm can acquire this information costlessly, then the regulator typically can simply adjust the firm's authorized revenues to reflect the firm's realized capital costs. Such a policy induces the firm to adopt the new capital structure if and only if doing so increases the difference between expected social benefits and social costs.

It is more challenging for the regulator to induce the firm to acquire superior knowledge of capital structure risk when this knowledge is costly for the firm to acquire. However, if the regulator can credibly threaten to punish the firm severely should it experience financial distress, the regulator can induce the firm to acquire the valuable information and employ it to adopt the more highly leveraged capital structure if and only if doing so generates incremental expected benefits in excess of incremental expected costs. Furthermore, the regulator can do so without ceding any rent to the firm. Some sacrifice of rent is required when the regulator has more limited ability to penalize the firm. If this ability is sufficiently limited, the regulator will not afford the firm any choice among capital structures. Instead, she will simply forbid the adoption of the more highly leveraged capital structure.

The optimal regulatory policy affords the firm no rent if the financial penalties it can be forced to bear are very large or very small. In contrast, the firm secures rent when these penalties are intermediate in magnitude. Therefore, consumers and the firm both gain when the firm can credibly promise to sustain a moderate loss should it experience financial distress. Such a promise can be facilitated if the firm posts a financial bond that it agrees to forfeit should it experience financial distress after adopting a relatively risky capital structure.

Several extensions of our model await future research. For instance, a richer set of capital structures might be admitted and the quality of the firm's information might vary continuously with the firm's information acquisition effort.[13] In addition, the firm might be able to undertake activities that enhance revenues or reduce production costs or otherwise limit the likelihood of financial distress. Furthermore, the optimal simultaneous design of capital structure and retail pricing structure might be considered. De Fraja and Stones (2004) and Cowan (2013) analyze such simultaneous design in settings where the regulated firm is fully informed about the risks inherent in potential capital structures. The authors find that price cap regulation typically does not produce an optimal price structure even when consumers are risk averse. Retail prices that track realized production costs to some extent are desirable because they reduce the risk borne by investors and can reduce the cost of capital.[14]

[13] Szalay (2009) develops useful analytic techniques in this regard.

[14] See Cowan (2004) for related observations.

Appendix

Proof of Proposition 1.

First suppose $\Delta < \Delta_F$. It can be shown (see Proposition 2) that under the reward structure that minimizes the firm's expected profit while inducing the firm to incur k to learn p:

$$\underline{R}_d = C + K_0 - S - \Delta , \quad \text{and} \tag{11}$$

$$p_0 \, \underline{R}_0 + [\, 1 - p_0 \,] \, R_0 = \widetilde{p} \, \underline{R}_d + [\, 1 - \widetilde{p} \,] \, R_d + S \, . \tag{12}$$

If the full-information outcome is feasible, then (4) must hold as an equality. Therefore, when (11) and (12) hold:

$$\phi_L \, [\, p_L \, \underline{R}_d + (1 - p_L) \, R_d + S \,] + \phi_H \, [\, p_0 \, \underline{R}_0 + (1 - p_0) \, R_0 \,] - k = K_0 + C$$

$$\Leftrightarrow \quad \phi_L \, \{\, p_L \, [\, C + K_0 - S - \Delta \,] + [\, 1 - p_L \,] \, R_d + S \,\}$$

$$+ \; \phi_H \, \{\, \widetilde{p} \, [\, C + K_0 - S - \Delta \,] + [\, 1 - \widetilde{p} \,] \, R_d + S \,\} \; = \; K_0 + C + k$$

$$\Leftrightarrow \quad [\, \phi_L \, p_L + \phi_H \, \widetilde{p} \,] \, [\, C + K_0 - S \,] - [\, \phi_L \, p_L + \phi_H \, \widetilde{p} \,] \, \Delta$$

$$+ \; [\, \phi_L \, (1 - p_L) + \phi_H \, (1 - \widetilde{p} \,) \,] \, R_d \; = \; K_0 - S + C + k$$

$$\Leftrightarrow \quad [\, 1 - \phi_L \, p_L - \phi_H \, \widetilde{p} \,] \, R_d$$

$$= \; [\, 1 - \phi_L \, p_L - \phi_H \, \widetilde{p} \,] \, [\, K_0 - S + C \,] + [\, \phi_L \, p_L + \phi_H \, \widetilde{p} \,] \, \Delta + k$$

$$\Leftrightarrow \quad R_d \; = \; K_0 - S + C + \frac{k}{1 - \phi_L \, p_L - \phi_H \, \widetilde{p}} + \left[\frac{\phi_L \, p_L + \phi_H \, \widetilde{p}}{1 - \phi_L \, p_L - \phi_H \, \widetilde{p}} \right] \Delta \, . \tag{13}$$

If the full-information outcome is feasible, then it must be the case that the uninformed firm receives non-positive profit when (11), (12), and (13) hold, so:

$$\widetilde{p} \, \underline{R}_d + [\, 1 - \widetilde{p} \,] \, R_d - (K_0 - S) - C \; \leq \; 0$$

$$\Leftrightarrow \quad \widetilde{p} \, [\, K_0 - S + C - \Delta \,] + [\, 1 - \widetilde{p} \,] \; \{\, K_0 - S + C + \frac{k}{1 - \phi_L \, p_L - \phi_H \, \widetilde{p}}$$

$$+ \left[\frac{\phi_L \, p_L + \phi_H \, \widetilde{p}}{1 - \phi_L \, p_L - \phi_H \, \widetilde{p}} \right] \Delta \,\} \; \leq \; K_0 - S + C$$

$$\Leftrightarrow \quad -\,\widetilde{p}\,\Delta + \frac{[\,1-\widetilde{p}\,]\,k}{1-\phi_L\,p_L-\phi_H\,\widetilde{p}} + \frac{[\,1-\widetilde{p}\,]\,[\,\phi_L\,p_L+\phi_H\,\widetilde{p}\,]\,\Delta}{1-\phi_L\,p_L-\phi_H\,\widetilde{p}} \;\leq\; 0$$

$$\Leftrightarrow \quad \Delta\,[\,\widetilde{p}\,(1-\phi_L\,p_L-\phi_H\,\widetilde{p}\,)-(1-\widetilde{p})\,(\phi_L\,p_L+\phi_H\,\widetilde{p}\,)\,] \;\geq\; [\,1-\widetilde{p}\,]\,k$$

$$\Leftrightarrow \quad \Delta\,[\,\widetilde{p}-\phi_L\,p_L-\phi_H\,\widetilde{p}\,] \;\geq\; [\,1-\widetilde{p}\,]\,k$$

$$\Leftrightarrow \quad \Delta\,[\,\widetilde{p}\,(1-\phi_H)-\phi_L\,p_L\,] \;\geq\; [\,1-\widetilde{p}]\,k \quad \Leftrightarrow \quad \Delta \;\geq\; \frac{[\,1-\widetilde{p}\,]\,k}{\phi_L\,[\,\widetilde{p}\,-\,p_L]}\,. \tag{14}$$

Hence, by contradiction, the full-information outcome is not a feasible solution to [RP-I] if $\Delta < \frac{[1-\widetilde{p}]k}{\phi_L[\,\widetilde{p}-p_L]} \equiv \Delta_F$.

To show that the full-information outcome can be secured when $\Delta \geq \Delta_F$, suppose the regulator sets $\underline{R}_d$ as in (11), R_d as in (13), and $\underline{R}_0$ and $\underline{R}_0$ as in (12). Then, by construction, the informed firm secures exactly 0 expected profit. Furthermore, (14) ensures that the uninformed firm secures negative profit, so the firm will prefer to become informed. In addition, since $R_d > \underline{R}_d$, (12) ensures that the informed firm will implement the new capital structure if and only if $p = p_L$. ■

<u>Proof of Corollary 1</u>.

It is apparent that $\Delta_F \equiv \frac{[1-\widetilde{p}]k}{\phi_L[\,\widetilde{p}-p_L]}$ is increasing in k. Furthermore:

$$\frac{\partial\,\widetilde{p}}{\partial p_H} \;=\; \frac{\partial}{\partial p_H}\,\{\,\phi_L\,p_L+\phi_H\,p_H\,\} \;=\; \phi_H \quad \text{and} \quad \frac{\partial\,\widetilde{p}}{\partial p_L} \;=\; \frac{\partial}{\partial p_L}\,\{\,\phi_L\,p_L+\phi_H\,p_H\,\} \;=\; \phi_L\,.$$

Therefore:

$$\frac{\partial\,\Delta_F}{\partial p_H} \;\stackrel{s}{=}\; [\,\widetilde{p}\,-\,p_L]\left(-\frac{\partial\,\widetilde{p}}{\partial p_H}\right)-[\,1-\widetilde{p}\,]\,\frac{\partial\,\widetilde{p}}{\partial p_H} \;=\; -\,[\,1-p_L\,]\,\frac{\partial\,\widetilde{p}}{\partial p_H} \;=\; -\,\phi_H\,[\,1-p_L\,] \;<\; 0\,;$$

and

$$\frac{\partial\,\Delta_F}{\partial p_L} \;\stackrel{s}{=}\; [\,\widetilde{p}\,-\,p_L]\left(-\frac{\partial\,\widetilde{p}}{\partial p_L}\right)-[\,1-\widetilde{p}\,]\left[\frac{\partial\,\widetilde{p}}{\partial p_H}-1\right] \;=\; -\,[\,1-p_L\,]\,\frac{\partial\,\widetilde{p}}{\partial p_L}+1-\widetilde{p}$$

$$=\; 1-\widetilde{p}-\phi_L\,[\,1-p_L\,] \;=\; 1-\phi_L-\phi_H\,p_H \;=\; \phi_H\,[\,1-p_H\,] \;>\; 0\,. \quad ■$$

Proof of Corollary 2.

Proof. Follows immediately from the statement of Proposition 1. ■

Proof of Proposition 2.

Let λ, λ_0, λ_d, λ_L, λ_H, ξ_0, $\underline{\xi}_0$, ξ_d, and $\underline{\xi}_d$ denote the Lagrange multipliers associated with the constraints in (4), (5), (6), (7), (8), (9), and (10), respectively. Then the necessary conditions for a solution to [RP-I] include:

$$R_0 : \quad -\phi_H [1 - p_0][1 - \lambda - \lambda_0 - \lambda_d] - [1 - p_0][\lambda_0 + \lambda_L - \lambda_H] + \xi_0 = 0; \tag{15}$$

$$\underline{R}_0 : \quad -\phi_H p_0 [1 - \lambda - \lambda_0 - \lambda_d] - p_0 [\lambda_0 + \lambda_L - \lambda_H] + \underline{\xi}_0 = 0; \tag{16}$$

$$\begin{aligned} R_d : \quad & -\phi_L [1 - p_L][1 - \lambda - \lambda_0 - \lambda_d] - \lambda_d [1 - \widetilde{p}] + \lambda_L [1 - p_L] \\ & - \lambda_H [1 - p_H] + \xi_d = 0; \quad \text{and} \end{aligned} \tag{17}$$

$$\underline{R}_d : \quad -\phi_L p_L [1 - \lambda - \lambda_0 - \lambda_d] - \lambda_d \widetilde{p} + \lambda_L p_L - \lambda_H p_H + \underline{\xi}_d = 0. \tag{18}$$

Summing (15) and (16) provides:

$$-\phi_H [1 - \lambda - \lambda_0 - \lambda_d] - \lambda_0 - \lambda_L + \lambda_H + \xi_0 + \underline{\xi}_0 = 0. \tag{19}$$

Summing (17) and (18) provides:

$$-\phi_L [1 - \lambda - \lambda_0 - \lambda_d] - \lambda_d + \lambda_L - \lambda_H + \xi_d + \underline{\xi}_d = 0. \tag{20}$$

Summing (19) and (20) provides:

$$\lambda = 1 - \left[\xi_0 + \underline{\xi}_0 + \xi_d + \underline{\xi}_d \right]. \tag{21}$$

Furthermore, (15) and (16) imply:

$$\frac{\xi_0}{1 - p_0} = \frac{\underline{\xi}_0}{p_0}. \tag{22}$$

In addition, (17) can be written as:

$$-\phi_L [1 - \lambda] - \lambda_H \left[\frac{1 - p_H}{1 - p_L} \right] - \lambda_d \left[\frac{1 - \widetilde{p}}{1 - p_L} - \phi_L \right] + \phi_L \lambda_0 + \lambda_L + \frac{\xi_d}{1 - p_L} = 0$$

$$\Rightarrow \quad -\,\phi_L\,[\,1-\lambda\,] - \lambda_H \left[\frac{1-p_H}{1-p_L}\right] - \lambda_d\,\phi_H \left[\frac{1-p_H}{1-p_L}\right] + \phi_L\,\lambda_0 + \lambda_L + \frac{\xi_d}{1-p_L} \;=\; 0\,. \tag{23}$$

(23) reflects the fact that:

$$\frac{1-\widetilde{p}}{1-p_L} - \phi_L \;=\; \frac{1}{1-p_L}\,[\,1-\widetilde{p}-\phi_L\,(1-p_L)\,] \;=\; \frac{1}{1-p_L}\,[\,1-\phi_L\,p_L-\phi_H\,p_H-\phi_L+\phi_L\,p_L\,]$$

$$=\; \frac{1}{1-p_L}\,[\,1-\phi_L-\phi_H\,p_H\,] \;=\; \phi_H \left[\frac{1-p_H}{1-p_L}\right].$$

Similarly, (18) can be written as:

$$-\phi_L\,[\,1-\lambda\,] - \lambda_H\,\frac{p_H}{p_L} - \lambda_d \left[\frac{\widetilde{p}}{p_L} - \phi_L\right] + \phi_L\,\lambda_0 + \lambda_L + \frac{\underline{\xi}_d}{p_L} \;=\; 0$$

$$\Rightarrow \quad -\,\phi_L\,[\,1-\lambda\,] - \lambda_H\,\frac{p_H}{p_L} - \lambda_d\,\phi_H\,\frac{p_H}{p_L} + \phi_L\,\lambda_0 + \lambda_L + \frac{\underline{\xi}_d}{p_L} \;=\; 0\,. \tag{24}$$

(24) reflects the fact that:

$$\frac{\widetilde{p}}{p_L} - \phi_L \;=\; \frac{1}{p_L}\,[\,\phi_L\,p_L+\phi_H\,p_H-\phi_L\,p_L\,] \;=\; \phi_H\,\frac{p_H}{p_L}\,.$$

(23) and (24) imply:

$$\frac{\underline{\xi}_d}{p_L} \;=\; \frac{\xi_d}{1-p_L} + [\,\lambda_H+\phi_H\,\lambda_d\,]\,\frac{p_H-p_L}{p_L\,[\,1-p_L\,]}\,. \tag{25}$$

(25) reflects the fact that:

$$\frac{p_H}{p_L} - \frac{1-p_H}{1-p_L} \;=\; \frac{1}{p_L\,[\,1-p_L\,]}\,[\,p_H\,(1-p_L)-p_L\,(1-p_H)\,] \;=\; \frac{p_H-p_L}{p_L\,[\,1-p_L\,]}\,.$$

Observation 1. $\lambda_L \;=\; 0$ *and* $p_L\,\underline{R}_d + [\,1-p_L\,]\,R_d + S \;>\; p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0\,.$

Proof. (5) can be written as:

$$p_L\,\underline{R}_d + [\,1-p_L\,]\,R_d + S \;\geq\; p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0 \;+\; \frac{k}{\phi_L} \tag{26}$$

$$\Rightarrow \quad p_L\,\underline{R}_d + [\,1-p_L\,]\,R_d + S \;>\; p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0 \quad\Rightarrow\quad \lambda_L \;=\; 0\,. \quad \blacksquare \tag{27}$$

Observation 2. $\lambda_H \;=\; 0$ *and* $p_0\,\underline{R}_0 + [\,1-p_0\,]\,R_0 \;>\; p_H\,\underline{R}_d + [\,1-p_H\,]\,R_d + S\,.$

Proof. Suppose $\lambda_H > 0$. Then (8) implies:

$$p_0 \underline{R}_0 + [1 - p_0] R_0 = p_H \underline{R}_d + [1 - p_H] R_d + S .$$

Therefore:

$$\begin{aligned}
&\phi_L [p_L \underline{R}_d + (1 - p_L) R_d + S] + \phi_H [p_0 \underline{R}_0 + (1 - p_0) R_0] - k \\
&= \phi_L [p_L \underline{R}_d + (1 - p_L) R_d + S] + \phi_H [p_H \underline{R}_d + (1 - p_H) R_d + S] - k \\
&= [\phi_L p_L + \phi_H p_H] \underline{R}_d + [\phi_L (1 - p_L) + \phi_H (1 - p_H)] R_d + S - k \\
&= \widetilde{p} \underline{R}_d + [1 - \widetilde{p}] R_d + S - k < \widetilde{p} \underline{R}_d + [1 - \widetilde{p}] R_d + S . \qquad (28)
\end{aligned}$$

(28) contradicts (6). Therefore, $\lambda_H = 0$. ■

Observation 3. $\pi_{dL} \equiv p_L \underline{R}_d + [1 - p_L] R_d - (K_0 - S) - C > 0$.

Proof. Suppose $p_L \underline{R}_d + [1 - p_L] R_d + S \leq K_0 + C$. Then (4) implies $p_0 \underline{R}_0 + [1 - p_0] R_0 > K_0 + C$. Therefore:

$$p_L \underline{R}_d + [1 - p_L] R_d + S \leq K_0 + C < p_0 \underline{R}_0 + [1 - p_0] R_0 . \qquad (29)$$

(29) implies that (7) does not hold, and so the proof is complete, by contradiction. ■

Observation 4. $R_d > \underline{R}_d \geq K_0 + C - S - \Delta$.

Proof. (8) and (27) imply:

$$\begin{aligned}
&p_L \underline{R}_d + [1 - p_L] R_d + S > p_0 \underline{R}_0 + [1 - p_0] R_0 \geq p_H \underline{R}_d + [1 - p_H] R_d + S \\
&\Rightarrow \quad [p_H - p_L][R_d - \underline{R}_d] > 0 \quad \Rightarrow \quad R_d > \underline{R}_d . \quad ■
\end{aligned}$$

Observation 5. $\xi_d = 0$.

Proof. Suppose $\xi_d > 0$. Then $\underline{\xi}_d > 0$, from (25). Consequently, $R_d = \underline{R}_d = K_0 + C - S - \Delta$, which contradicts Observation 4. ■

Observation 6. $\xi_0 = \underline{\xi}_0 = 0$ *and* $\max\{R_0, \underline{R}_0\} > K_0 + C - \Delta$.

Proof. Suppose $\xi_0 > 0$ or $\underline{\xi}_0 > 0$. Then $\xi_0 > 0$ and $\underline{\xi}_0 > 0$, from (22). Therefore, $R_0 = \underline{R}_0 = K_0 + C - \Delta$. Consequently, from (8):

$$K_0 + C - \Delta \;\geq\; p_H\, \underline{R}_d + [\,1 - p_H\,]\, R_d + S \;>\; \underline{R}_d + S \;\geq\; K_0 + C - \Delta\,. \tag{30}$$

The strict inequality in (30) reflects Observation 4. The last inequality in (30) reflects (10). ■

Observation 7. *If the full-information outcome is not feasible, then* $\lambda < 1$.

Proof. Suppose $\lambda = 1$. Then $\xi_0 = \underline{\xi}_0 = \xi_d = \underline{\xi}_d = 0$, from (21). Therefore, from (20):

$$\phi_L\,[\,\lambda_0 + \lambda_d\,] + \lambda_L \;=\; \lambda_d + \lambda_H \quad\Rightarrow\quad \lambda_0 \;=\; \left[\frac{1-\phi_L}{\phi_L}\right]\lambda_d + \frac{1}{\phi_L}\,[\,\lambda_H - \lambda_L\,]\,. \tag{31}$$

Also, (18) implies:

$$\begin{aligned} \phi_L\, p_L\,[\,\lambda_0 + \lambda_d\,] - \lambda_d\,\widetilde{p} + \lambda_L\, p_L - \lambda_H\, p_H \;&=\; 0 \\ \Rightarrow\quad \lambda_0 \;&=\; \left[\frac{\widetilde{p} - \phi_L\, p_L}{\phi_L\, p_L}\right]\lambda_d + \frac{1}{\phi_L}\left[\lambda_H\,\frac{p_H}{p_L} - \lambda_L\right]. \end{aligned} \tag{32}$$

(31) and (32) imply:

$$\left[\frac{\widetilde{p} - \phi_L\, p_L}{\phi_L\, p_L} - \frac{1-\phi_L}{\phi_L}\right]\lambda_d + \frac{1}{\phi_L}\left[\frac{p_H}{p_L} - 1\right]\lambda_H \;=\; 0 \quad\Rightarrow\quad \lambda_d \;=\; \lambda_H \;=\; 0\,. \tag{33}$$

The implication in (33) reflects the fact that $\frac{\widetilde{p} - \phi_L\, p_L}{\phi_L\, p_L} > \frac{1-\phi_L}{\phi_L}$ since $\widetilde{p} > p_L$.

If $\lambda_d = \lambda_H = 0$, then $\lambda_0 = -\frac{1}{\phi_L}\lambda_L$ from (31). Therefore, $\lambda_0 = \lambda_L = 0$. Consequently, (4) is the only constraint that binds at the solution to [RP-I], which implies that the full-information outcome is feasible. ■

Observation 8. $\lambda_0 > 0$ *when the full-information outcome is not feasible.*

Proof. Suppose $\lambda_0 = 0$. Then from (17) and Observations 1 and 5:

$$-\,\phi_L\,[\,1 - p_L\,]\,[\,1 - \lambda\,] - \lambda_d\,[\,1 - \widetilde{p} - \phi_L\,(1 - p_L)\,] - \lambda_H\,[\,1 - p_H\,] \;=\; 0\,. \tag{34}$$

(34) implies $\lambda_d = \lambda_H = 0$ and $\lambda = 1$, since:

$$1-\widetilde{p}-\phi_L\,[\,1-p_L\,] \;=\; 1-\phi_L\,p_L-\phi_H\,p_H-\phi_L+\phi_L\,p_L \;=\; \phi_H\,[\,1-p_H\,] \;>\; 0\,. \tag{35}$$

Therefore, each of the three terms in (35) is non-positive, and so each term must be 0 since their sum is 0. But from the proof of Observation 7, the full-information outcome is feasible when $\lambda = 1$. ■

Observation 9. $\lambda_d > 0$ *when the full-information outcome is not feasible.*

<u>Proof</u>. Suppose $\lambda_d = 0$. Then from (19) and Observations 1, 6, and 8:

$$-\,\phi_H\,[\,1-\lambda-\lambda_0\,]-\lambda_0-\lambda_L+\lambda_H \;=0 \;\;\Rightarrow\; \lambda_H \;=\; \phi_H\,[\,1-\lambda\,]+[\,1-\phi_H\,]\,\lambda_0 \;>\; 0\,. \tag{36}$$

The inequality in (36) contradicts Observation 2. ■

Observation 10. $R_d = \underline{R}_d + \frac{k}{\phi_L[\,\widetilde{p}-p_L\,]}$ *when the full-information outcome is not feasible.*

<u>Proof</u>. From (5), (6), and Observations 8 and 9:

$$p_0\,\underline{R}_0+[\,1-p_0\,]\,R_0 \;=\; \widetilde{p}\,\underline{R}_d+[\,1-\widetilde{p}\,]\,R_d+S\,; \quad \text{and} \tag{37}$$

$$\pi \;=\; \widetilde{p}\,\underline{R}_d+[\,1-\widetilde{p}\,]\,R_d-(K_0-S)-C\,. \tag{38}$$

(37) and (38) imply:

$$\phi_L\,[\,p_L\,\underline{R}_d+(1-p_L)\,R_d+S\,]+\phi_H\,[\,\widetilde{p}\,\underline{R}_d+(1-\widetilde{p}\,)\,R_d+S\,]-k$$

$$=\; \widetilde{p}\,\underline{R}_d+[\,1-\widetilde{p}\,]\,R_d+S$$

$$\Rightarrow\quad \phi_L\,[\,p_L\,\underline{R}_d+(1-p_L)\,R_d+S\,] \;=\; k+[1-\phi_H]\,[\,\widetilde{p}\,\underline{R}_d+(1-\widetilde{p}\,)\,R_d+S\,]$$

$$\Rightarrow\quad [\,\widetilde{p}-p_L\,]\,R_d \;=\; [\,\widetilde{p}-p_L\,]\,\underline{R}_d+\frac{k}{\phi_L} \quad\Rightarrow\quad R_d \;=\; \underline{R}_d+\frac{k}{\phi_L\,[\,\widetilde{p}-p_L\,]}. \quad ■$$

<u>**Proof of Corollary 3.**</u>

From conclusions (i) and (ii) in Proposition 2:

$$\pi(\Delta) \;=\; \pi_0(\Delta) \;=\; \widetilde{p}\,\underline{R}_d+[\,1-\widetilde{p}\,]\,R_d-(K_0-S)-C$$

$$=\; \widetilde{p}\,\underline{R}_d+[\,1-\widetilde{p}\,]\left[\,\underline{R}_d+\frac{k}{\phi_L\,(\,\widetilde{p}-p_L)}\,\right]-(K_0-S)-C$$

$$= \underline{R}_d + [\,1 - \widetilde{p}\,] \left[\frac{k}{\phi_L\,(\widetilde{p} - p_L)} \right] - (K_0 - S) - C$$

$$= \; - \Delta + \frac{k\,[\,1 - \widetilde{p}\,]}{\phi_L\,[\,\widetilde{p} - p_L\,]} \; = \; \Delta_F - \Delta\,.$$

Furthermore, since $\pi(\Delta) \; = \; \phi_L\,\pi_{dL}(\Delta) + \phi_H\,\pi_0(\Delta) - k$ and $\pi_0(\Delta) \; = \; \pi(\Delta)$:

$$\phi_L\,\pi_{dL}(\Delta) \;=\; [\,1 - \phi_H\,]\,\pi(\Delta) + k \quad \Rightarrow \quad \pi_{dL}(\Delta) \;=\; \pi(\Delta) + \frac{k}{\phi_L}\,. \quad \blacksquare$$

Proof of Proposition 3.

Proof. (2) implies that the social value of inducing the firm to learn p is $\phi_L\,[\,S - (p_L - p_0\,)\,D\,]$. When $\Delta \in [\,\widehat{\Delta},\, \Delta_F\,]$, the regulator's cost of inducing the firm to learn p is $k + \pi(\Delta)$. Therefore, the regulator will induce the firm to learn p if:

$$\phi_L\,[\,S - (p_L - p_0\,)\,D\,] \;>\; k + \pi(\Delta) \;=\; k + \Delta_F - \Delta \tag{39}$$

$$\Leftrightarrow \quad \Delta \;>\; \Delta_F - \phi_L\,[\,S - (p_L - p_0\,)\,D\,]\,.$$

The equality in (39) reflects Corollary 3. $\blacksquare$

Proof of Corollary 4.

From Proposition 3, $\Delta_F - \widehat{\Delta} = \phi_L\,[\,S - (p_L - p_0\,)\,D\,] - k$. It is apparent that this expression is increasing in S and decreasing in p_L and k. The expression is also decreasing in D, since $p_L > p_0$. (2) implies that the expression is increasing in ϕ_L. $\blacksquare$

Proof of Corollary 5.

Proof. The proof follows immediately from Proposition 3 and Corollary 3. $\blacksquare$

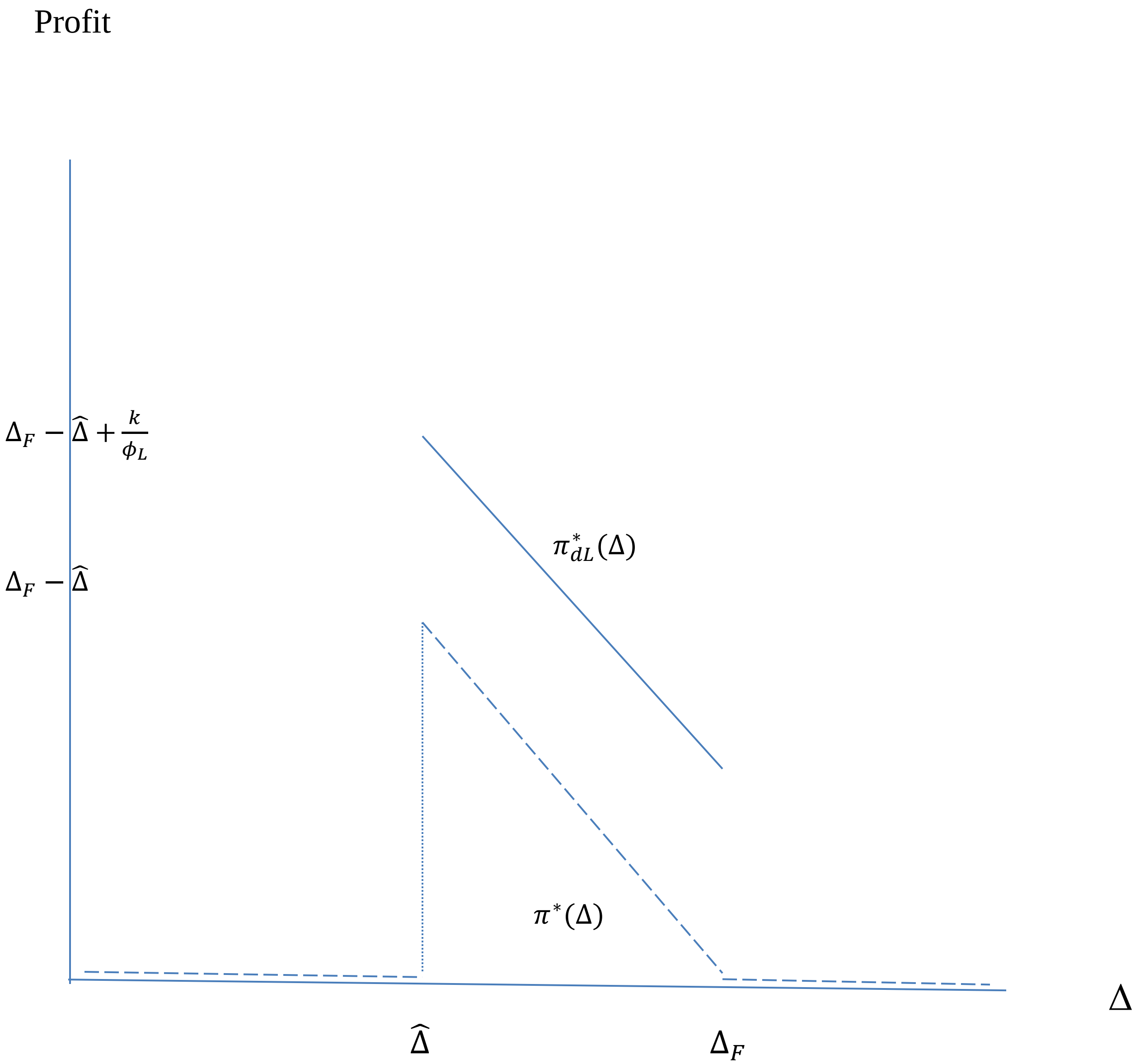

Figure 1. The Firm's *Ex Ante* Expected Profit ($\boldsymbol{\pi^*(\Delta)}$) and its Profit when $\boldsymbol{p = p_L}$ ($\boldsymbol{\pi^*_{dL}(\Delta)}$) under the New Capital Structure.

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