Asymmetric Competition, Capital Structure and Agency Cost: A Real Option Approach

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Abstract

We consider the optimal investment, financing, and bankruptcy decisions of firms in an asymmetric duopoly. We employ a duopolistic real option model to investigate the interaction between product market competition and the optimal investment and financing strategies of both firms. Based on the asymmetry of our model, we investigate whether the firm with profit advantage will be the first firm enters the market by a trade-off between interest tax shields and monopolistic profits. Moreover, we consider two types of maximization principles the firm's manager will follow to make their investment decision in this paper. The first one is the manager will choose an investment policy to maximize total firm value, and the other one is that he may take an investment strategy to maximize equity value only instead of total firm value. According to the equilibrium results derived under these two different principles, we examine that the interaction between product-market competition and agency problem of debt.

1 Introduction

The linkage between the investment decision and financial structure of a firm has been emphasized in both the economic and financial literatures since a conflict of interest between bond and equity holders, created by the limited

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liability effect was shown in Jensen and Meckling (1976) and Myers (1977). They show that under this kind of agency problem, total firm value will be distorted by firm's risky debt due to the asset substitution effect and debt overhang problem, respectively.[1] Moreover, firm value will also be reduced by bankruptcy costs of debt. But, on the other hand, the benefit of debt, e.g. the interest tax shield, will enhance firm value. (Kraus and Litzenberger, 1973) Hence, the equityholders of a firm will determine the firm's optimal capital structure by tradeoff tax benefits of corporate debt with both bankruptcy costs and agency costs of debt. Ravid (1988) provide a review of earlier literature on interactions of investment and financing decisions. Recently, this topic has continuously developed in a dynamic contingent claims analysis framework. Leland (1998) is the first one that uses a continuous time real option model with an exogenous dynamics of firm asset value to show that equityholders have an incentive to overinvest in risky assets to transfer wealth from bondholders to themselves when investment policies are chosen to maximize equity value after debt is in place. In contrast with Leland's model, Mauer and Sarkar (2005) provide an alternative structural model where firm value is endogenously determined by equityholders' investment and financing decisions to find that an equity-maximizing firm exercises the investment option too early relative to a firm value-maximizing decision. This implies that the overinvestment problem, similarly to Leland (1998), is also raised and reduces the optimal total firm value. On the other hand, Sundaresan and Wang (2007) show that if equityholders of a firm has multiple investment and financial decisions, then existing debt may induce not only an overinvestment problem, but also a debt overhang problem on the firm's investment.

This line of literature usually omits or ignores the market competitive situation existing between the firms. But each of firms in the same product market should consider how the rivals react or what their strategies are when the investment and financial strategies are set up. For instance, when there are two firms want to pursue a new technology to improve their production process and reduce their production costs, whether the patent for this new technology was registered by one of the two firms will be important information for the other. On the other hand, a firm also needs to think that whether the rival will take the opportunity to do something (e.g. price cutting) to force the firm insolvent if it wants to issue a large amount of debt to finance a new R&D project. In this paper, we will incorporate the strategic interaction between firms into our model to investigate whether market competition will exacerbate or mitigate the agency costs of corporate debt.

[1] The asset substitution effect shows that leveraged firms who act in the interest of their equityholders, will like to take risky investment decisions even if they have negative expected returns because part of the equityholders' downside risk are eliminated by the limit liability effect. On the other hand, debt overhang problem or underinvestment problem emerges if the equityholders of a company may intentionally forgo an investment opportunity with positive net present value (NPV) after they issue risky debt to investors.

In this paper, we consider the optimal investment, financing, and bankruptcy decisions of firms in an asymmetric duopoly. We employ a duopolistic real option model to investigate the interaction between product market competition and the firms' optimal investment and financing strategies. In this model, we assume that the two firms in the market face a stochastic industry's demand function and produce their products with different marginal costs (or profits). Each firm's manager has to make three decisions in this model. First, he must decide when to spend a fixed irreversible investment cost to enter the market (the investment decision), and he then chooses a financial structure at the entry time (the financing decision). Finally, he must decide when to leave after they enter the market (the bankruptcy decision). Based on the asymmetry of our model, we can investigate whether the firm with profit advantage will must be the first firm enters the market by a trade-off between interest tax shields and monopolistic profits. We consider two types of maximization principles the manager will follow to make their investment decision in this paper. The first one is the manager will choose an investment policy to maximize total firm value, and the other one is that he may take an investment strategy to maximize equity value only instead of total firm value. According to the equilibrium results derived under these two different principles, we can examine that the interaction between product-market competition and agency problem of debt.

There are several articles that examine the interaction between optimal capital structure, investment decision and competition in product markets. Brander and Lewis (1986) provide the first formal duopoly model to incorporate a relation between production and financial decisions derived from the limit liability effect.[2] They find that limit liability of equityholders may commit a leverage firm to make a more aggressive output size. Maksimovic (1988) adopts a repeated oligopoly model to also find debt acts as a pre-commitment device and makes product-market competition tougher. In contrast to both the two articles, Lambrecht (2001), Zhdanov (2008) and Chu (2009) perform the analyses under a continuous-time real option framework. Lambrecht (2001) studies the effect of capital structure on entry and bankruptcy decisions in an asymmetric duopoly. Zhdanov (2008) extends Lambrecht's (2001) analysis by endogenizing both investment and financing decisions in a symmetric duopoly where firms must take their optimal investment, financing and bankruptcy decisions in the first-best concept, that is to choose these strategies to maximize total firm value. He constructs a preemption equilibrium in the proposed model, and finds that in that equilibrium the follower has higher leverage than the leader and exits first which implies the last-in-first-out (LIFO) regime is expected to prevail. This shows that a firm's position within the market is

[2]Brander and Lewis (1986) show their results by proposing a two-period duopoly model where firms under profit uncertainty, first decide their debt levels in the first period, and perform Cournot competition in the second period. In contrast with the analysis of Brander and Lewis, Showalter (1995) considers the case of Bertrand competition and cost uncertainty.

an important determinant of its capital structure. Moreover, Chu (2009) further endogenizes capacity choice decisions in a dynamic symmetric duopoly model. He assumes that both firms choose their first-best entry, financing and bankruptcy decisions and second-best capacity levels, i.e. to take a capacity size to maximize equity value, and investigates the interaction between product-market competition and capital structure. In a constructed sequential investment equilibrium, the author finds that not only the leader firm will choose a higher capacity than the follower, but also has a lower leverage ratio than the follower.[3] On the other hand, Jou and Lee (2008) accomplish an equilibrium analysis in a symmetric oligopoly model, and show that under the first-best symmetric (simultaneous investment) equilibrium, competition will decrease the output price and encourage a firm to postpone his investment for a higher market demand. In contrast with the equilibrium analyses performed in the above articles, we will base on an asymmetric dynamic duopoly model similar to Lambrecht (2001), and endogenize entry, exit and financial decisions to study the interaction between product-market competition, agency problem of corporate debt, and capital structure under product-market equilibrium.

The paper is organized as follows. Section two describes the model. Section three explores the optimal strategies of the leader and follower firms. Section four introduces the market equilibria and the measures for the concerned indexes. Section five concludes. Technical proofs are gathered in the Appendix.

2 The Model

We consider an industry with two competing firms, called by firm 1 and firm 2, that can potentially operate in the industry. Each of the two firms can spend a fixed irreversible investment cost $I > 0$ to enter the market and to produce one homogenous product. We follow Lambrecht (2001) to assume that firm i, $i = 1, 2$, can generate a net operating incomes of $\Pi_i z_t$ if it is the only one firm in the market at time $t \geq 0$, where the "market condition" z_t follows a geometric Brownian motion:

$$dz_t = \mu_z z_t dt + \sigma_z z_t dB_t, \tag{1}$$

with $z_0 = z > 0$, where constants $\mu_z < r$, $\sigma_z > 0$, $\mu_z < \sigma_z^2/2$, and B_t is a standard Brownian motion.[4] On the other hand, when there are the two firms in the market, firm 1 and firm 2 generates net operating profits $\pi_1 z_t$ and $\pi_2 z_t$ at time t, respectively. Without loss of generality, we assume that the constants

[3] There are another type of literature that investigates firms' optimal capital structures and investment decisions in a perfect competitive industry. See e.g., Williams (1995), Fries, Miller and Perraudin (1997), Miao (2005), and Zhdanov (2007).

[4] The condition $\mu_z < \sigma_z^2/2$ guarantees that each firm has a finite expected time to hit the corresponding bankruptcy threshold.

Π_1, Π_2, π_1 and π_2 are strictly positive, and satisfy the following conditions:

$$\Pi_1 > \Pi_2, \tag{2}$$

$$\pi_1 = \eta\Pi_1, \;\text{ and }\; \pi_2 = \eta\Pi_2, \tag{3}$$

where $\eta \in (0,1)$. Inequality (2) can be justified by assuming that firm 1 has a superior production technology than firm 2, and inequalities (3) states that firms are better off operating in a monopoly than in a duopoly, and the advantage of firm 1 is unchanged. Let the corporate tax rate be $\tau \in (0,1)$, and let the recovery rate upon bankruptcy be $\alpha \in (0,1)$. We suppose that both firms can issue a permanent defaultable bond at the entry/investment time under which bondholders receive a perpetual flow of coupon payment b until the firm bankrupts. Moreover, we assume that all investors including equity holders and bondholders, are risk neutral and discount their future payoff at a constant interest rate r. Assume further that all firm's decisions (entry/investment, financing and exit/bankruptcy) are made by the firm's manager, and that there does not exist the agency problem between the manager and equity holders. Hence the manager will make decisions to maximize equity value of the firm unless otherwise specified. We can summarize the setting for two firms' instantaneous net profits into the following assumption.

Assumption 1. For $i = 1, 2$, total equality holders of firm i receive the instantaneous net profits $(1-\tau)(\Pi_i z_t - b_i)$ at time t when it is the monopolistic firm in the market, and they receive $(1-\tau)(\pi_i z_t - b_i)$ at time t if there are two firms in the market, where $b_i \geq 0$ is the instantaneous coupon payment to the firm i's bondholders.

Furthermore, we make the following assumptions to specify the market conditions for the two firms operating.

Assumption 2. The two firms have complete information with respect to all model parameters.[5]

Assumption 3. Both firms are restricted to a double entry-exit trigger strategy, such that the firm enters to the market if the state variable z_t is above the entry trigger, and stays in the market until the state variable is below (or at) the exit trigger. At the start of the game, the state variable is low enough to ensure that both firms want to stay out the market.

Assumption 4. If both firms decide to enter (or to default) at the same time, then each firm either acquires the right to become monopolist, with probability one half, or else, has to wait to enter (to leave) the market.

[5] Hopenhayn and Squintani (2011) and Lambrecht and Perraudin (2003) provide two equilibrium analyses on real option preemption games with incomplete information. But, unlike our paper, the firm's financial decision is ignored in both papers.

These assumptions greatly simplifies the analysis. Assumption 2 means that both firms know every thing about themselves and each other, and assumption 3 is only a decision rule to resolve ties. Assumption 4 is a common assumption in literatures on real options, e.g. Zhdanov (2007, 2009), Mauer and Sarkar (2005) and Lambrecht (2001), and this assumption can be justified by the following two points as stated in Lambrecht (2001). First, the trigger strategy is a very simple strategy which requires firms to have only a very low level of rationality, and second, it will become intractable if we do not restrict the analysis to this trigger strategy.

Since the value of each firm will depend on whether it is the first firm to enters the market and whether it exits the market first, we denote in the remainder of this paper that the firm first (last) entering the market as the "leader" ("follower"), and the first (last) exiting firm as the "loser" ("winner"). We use the subscripts "L", "F", "l" and "w" to stand for leader, follower, loser and winner, respectively.

The time line of this timing game is as follows. In the first stage, leader decides the entry time. Upon entry, the firm makes the financing decision (the coupon payment rate b_L) and decides when to exit the market if the other firm does not enter the market. It then may decide to exit the market by bankruptcy if market condition is not favorable or stay in the market otherwise. In the second stage, follower decides when to enter, and makes financing decision (b_F). Next, both firms decide when to exit the market, and then the game ends. We assume that the coupon payment rate once made, are fixed over the life time of the firms.

We solve the game to derive the equilibrium strategies of both players backwards. First, assuming that both firms have already entered and are active, we derive their optimal bankruptcy strategies. Then we consider a situation when the leader has entered the market while the follower still stays out, and focus on the optimal entry and financing decision of the latter. Finally, we construct the equilibrium of the whole game and solve for the optimal strategy of the leader.

Before proceeding to the equilibrium analysis, we simply sketch the intuition behind the market equilibrium as follows. In the beginning of the game, if the market condition is not so good (z is low), then the profits that the firms expect to get for their product will be low. Thus, both firms prefer to stay out. However, as the market condition is improved (z rises and reaches a firm's entry trigger), the firm enters the market and becomes the leader, and the other firm automatically becomes the follower. After the leader enters the market, the market condition may go down seriously such that the leader bankrupts before the follower enters the market. Otherwise, the market condition may be improved continuously such that the follower likes to enter the market. Subsequently, as the market condition worsens, and reaches a firm's exit trigger, the firm exits the market and becomes the loser, and the other firm turns into the winner. Finally, the market closes down, and the game ends if the market condition still goes down to let the winner leaves the market.

3 The Optimal Strategies of Firms

Both firms must set three strategies to maximize the corresponding values of firms, that is the entry, financial and exit strategies. Both firms exit the market when they default on their debt obligations at the first passage time of the market condition z to a certain (lower) threshold. At the time of default, the value of equity is equal to zero, and the residual value of the firm in liquidation is received by bondholders. In this paper, two types of entry strategies are considered. On the one hand, we assume that the manager of a firm sets the entry strategy to maximize the total discounted value of his firm ex-ante, and we call the corresponding optimal strategy by the "first-best" entry strategy. On the other hand, we consider the case where the manager of a firm make the entry strategy to maximize the discounted equity value of his firm ex-ante, and call the corresponding optimal strategy by the "second-best" entry strategy. The manager of a firm is assumed to choose the coupon payment (financial strategy) so as to maximize the total discounted value of his firm ex-ante.

3.1 The optimal bankruptcy strategies of firms

We first consider the case where both firms have entered the market and made the financing and investment decisions, with the leader firm having a coupon rate of b_L, and the follower with b_F. We need to solve the default decisions of both firms. The following proposition summarizes the default decisions in this case.

Proposition 1. *1. Suppose firm j, $j = 1, 2$ is the leader, and firm i is the follower. If firm j, $j = 1, 2$ leaves the market before i, $i \neq j$, then firm j defaults when the market condition z_t reaches its duopoly exit trigger*

$$z_d(\pi_j, b_{Lj}) = \frac{\lambda}{1-\lambda} \frac{r-\mu_z}{\pi_j} \frac{b_{Lj}}{r}, \tag{4}$$

while firm i defaults as z_t falls below its monopoly exit trigger

$$z_d(\Pi_i, b_{Fi}) = \frac{\lambda}{1-\lambda} \frac{r-\mu_z}{\Pi_i} \frac{b_{Fi}}{r}, \tag{5}$$

where λ is the negative root of the quadratic equation: $\sigma_z^2 \lambda(\lambda - 1)/2 + \mu_z \lambda - r = 0$.

2. Suppose firm j, $j = 1, 2$ is the follower, and firm i is the leader. If firm j, $j = 1, 2$ leaves the market before i, $i \neq j$, then firm j defaults when *the market condition z_t reaches its duopoly exit trigger*

$$z_d(\pi_j, b_{Fj}) = \frac{\lambda}{1-\lambda}\frac{r-\mu_z}{\pi_j}\frac{b_{Fj}}{r}, \tag{6}$$

while firm i defaults as z_t falls below its monopoly exit trigger

$$z_d(\Pi_i, b_{Li}) = \frac{\lambda}{1-\lambda}\frac{r-\mu_z}{\Pi_i}\frac{b_{Li}}{r}. \tag{7}$$

Proof. See appendix.

The bankruptcy triggers in this proposition have the following properties. The default thresholds increases when the coupon payment increases, or the growth rate and volatility of the market condition decrease. Low growth rate and low volatility of the market condition erode the value of the option to wait. Moreover, the bankruptcy triggers also increase with the discount rate r. When the discount rate is high, the equity holders are more concerned about immediate losses than about potential future profits, and exercise their default option sooner. It is clear that $z_d(\Pi_j, b_j) < z_d(\pi_j, b_j)$, $j = 1, 2$ when the other firm is bankrupt and exits the market, a firm enjoys higher profits and therefore is less willing to default.

Given this proposition, it remains to be determined which firm defaults first in equilibrium. We adopt the subgame perfect Nash equilibrium as our equilibrium concept. The following proposition which is based on proposition 4 in Lambrecht (2001), gives the sub-game perfect default sequence.

Proposition 2. *Any subgame perfect Nash equilibrium strategy of the bankruptcy game is given as follows. Firm j, $j = 1, 2$ defaults first if and only if it has a higher coupon-profit ratio, i.e., $b_j/\pi_j > b_i/\pi_i$, $i \neq j$.*

Proof. See appendix.

The logic underlying the result is straightforward. Suppose that firm i has a lower coupon-profit ratio, and assume for the moment that $z_d(\Pi_i, b_i)$ is hit while firm i still stay in the market. Then there is no reason for firm i to continue retaining the control of the firm, regardless of whether its rival has already defaulted or not. Firm i will default no later than at the first stopping time of z_t upon reaching $z_d(\Pi_i, b_i)$. The default of firm i leads to a higher profit to firm j. Hence, firm j will never want to default while z_t stays in the upside of a neighborhood of $z_d(\Pi_i, b_i)$. But then the optimal bankruptcy time for firm i is no later than upon hitting the upper bound of the neighborhood for the first time. Using similar arguments iteratively leads to the result established in this proposition.

3.2 The optimal entry and financial strategies of the follower firm

In the remainder of this paper, we assume that firm j, $j = 1, 2$ is the follower firm, and firm i, $i \neq j$ automatically becomes the leader firm. Before proceeding to find the follower's optimal entry and financial strategies, we first characterize its equity and debt values. Based on the result of proposition 2 and given different scenarios the follower firm may face, we can characterize these values, respectively. There are three possible cases. In the first case, the leader firm exits the market before the follower enters. Thus, the follower will be the only firm in the market, and the corresponding values are just the usual values for a monopoly firm. In the second case, both firms are active in the market, and the follower firm has a higher coupon-profit ratio. Hence, proposition 2 shows that the follower firm will default first, and its equity and debt values will be the usual values for a duopoly firm, and the values can be represented as the sum of the values without default and the adjustment factor upon default. In the the final case, both firms are operating in the market, and the follower firm has lower coupon-profit ratio. Therefore, the leader firm will default first, and the corresponding values are then the value without default plus adjustment upon the leader's exit and adjustment upon his own exit. We characterize the follower's equity and debt value by the following proposition.

Proposition 3. *Suppose that firm j, $j = 1, 2$ is the follower firm and stays in the market. Then its equity and debt values with the market condition z are given as the following:*

1. [**Monopoly case**] *Suppose that the leader firm has already leaved the market, the equity value of firm j is*

$$\begin{aligned} E^j_{Fm}(z, b_{Fj}) &= (1-\tau)\frac{\Pi_j z}{r-\mu_z} - (1-\tau)\frac{b_{Fj}}{r} \\ &\quad + \left[(1-\tau)\frac{b_{Fj}}{r} - (1-\tau)\frac{\Pi_j}{r-\mu_z} z_d(\Pi_j, b_{Fj})\right]\left[\frac{z}{z_d(\Pi_j, b_{Fj})}\right]^\lambda \end{aligned} \tag{8}$$

and its debt value is

$$D^j_{Fm}(z, b_{Fj}) = \frac{b_{Fj}}{r} - \left[\frac{b_{Fj}}{r} - (1-\alpha)(1-\tau)\frac{\Pi_j}{r-\mu_z} z_d(\Pi_j, b_{Fj})\right]\left[\frac{z}{z_d(\Pi_j, b_{Fj})}\right]^\lambda \tag{9}$$

2. [**LIFO case**] *Suppose that both firm are active in the market and $b_{Fj}/\pi_j > b_{Li}/\pi_i$, $i \neq j$, then the equity and debt values of firm j under the market condition z are*

$$E^j_{Fl}(z, b_{Fj}) = (1-\tau)\frac{\pi_j z}{r-\mu_z} - (1-\tau)\frac{b_{Fj}}{r}$$

$$+\left[(1-\tau)\frac{b_{Fj}}{r}-(1-\tau)\frac{\pi_j}{r-\mu_z}z_d(\pi_j,b_{Fj})\right]\left[\frac{z}{z_d(\pi_j,b_{Fj})}\right]^{\lambda} \quad (10)$$

and

$$D^j_{Fl}(z,b_{Fj}) = \frac{b_{Fj}}{r}-\left[\frac{b_{Fj}}{r}-(1-\alpha)(1-\tau)\frac{\pi_j}{r-\mu_z}z_d(\pi_j,b_{Fj})\right]\left[\frac{z}{z_d(\pi_j,b_{Fj})}\right]^{\lambda} \quad (11)$$

respectively.

3. **[FIFO case]** *Suppose that both firm are active in the market and* $b_{Fj}/\pi_j < b_{Li}/\pi_i$, $i \neq j$, *then the equity and debt values of firm* j *under the market condition* z *are*

$$\begin{aligned} E^j_{Fw}(z,b_{Fj}) &= (1-\tau)\frac{\pi_j z}{r-\mu_z}-(1-\tau)\frac{b_{Fj}}{r} \\ &+(1-\tau)\frac{(\Pi_j-\pi_j)z_d(\pi_i,b_{Li})}{r-\mu_z}\left[\frac{z}{z_d(\pi_i,b_{Li})}\right]^{\lambda} \\ &+\left[(1-\tau)\frac{b_{Fj}}{r}-(1-\tau)\frac{\Pi_j}{r-\mu_z}z_d(\Pi_j,b_{Fj})\right]\left[\frac{z}{z_d(\Pi_j,b_{Fj})}\right]^{\lambda} \quad (12)\end{aligned}$$

and

$$D^j_{Fw}(z,b_{Fj}) = \frac{b_{Fj}}{r}-\left[\frac{b_{Fj}}{r}-(1-\alpha)(1-\tau)\frac{\Pi_j}{r-\mu_z}z_d(\Pi_j,b_{Fj})\right]\left[\frac{z}{z_d(\Pi_j,b_{Fj})}\right]^{\lambda} \quad (13)$$

respectively.

Proof. See appendix.

It can be seen from equations (11) and (13) that the bondholders of the winner firm are always better off, since the winner firm defaults last so its bondholders will receive their coupon payments for a longer period of time. This implication can not be deduced for the equity values.

Let the total value of the follower firm at the entry time z_{eFj} be the sum of its equity and debt values net of the investment cost I, i.e.,

$$V^j_F(z_{eFj},b_{Fj}) \equiv E^j_F(z_{eFj},b_{Fj})+D^j_F(z_{eFj},b_{Fj})-I. \quad (14)$$

Suppose that the spot market condition is z, and the follower has not enter the market. Then there are two types of entry strategies available to the follower once the leader has entered the market. First, the follower can enter the market at a later date ($z_{eFj}=z^m_{eFj}$) after the leader defaults, and second, it can join the leader while it is still active ($z_{eFj}=z^d_{eFj}$). Hence, the total value of the follower is given by the appropriately discounted weighted average of its values in these two cases. Denote the entry trigger of the leader firm by z_{eLi}, and assume that the leader's entry does not immediately lead its default or to the entry of the follower, i.e. $z_{eLi} \in (z_d(\Pi_i, b_L), z^d_{eFj})$. For all $\underline{z} \le z \le \overline{z}$, let $\mathcal{B}(z; \underline{z}, \overline{z})$ ($\mathcal{U}(z; \underline{z}, \overline{z})$) be the present value of \$1 to be received at the first time the market condition z reaches the lower (upper) threshold $\underline{z}$ ($\overline{z}$), conditional on z reaching $\underline{z}$ ($\overline{z}$) before reaching the upper (lower) threshold $\overline{z}$ ($\underline{z}$).[6] Then we can characterize the investment value of the follower under the market condition z as follows.

Proposition 4. *Let the leader's entry trigger be z_{eLi}, and let its coupon payment rate be b_{Li}. Suppose that the market condition is $z < z_{eLi}$.*

1. **[LIFO case]** *If $b_{Li}/\pi_i < b^d_{Fj}/\pi_j$, then the investment value of the follower is given by*

$$\begin{aligned} & V^j_{Fl}(z, z^m_{eFj}, z^d_{eFj}, b^m_{Fj}, b^d_{Fj}) = \qquad (15) \\ & \left[\frac{z}{z_{eLi}}\right]^\beta \Big\{\mathcal{U}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj}) \left[E^j_{Fl}(z^d_{eFj}, b^d_{Fj}) + D^j_{Fl}(z^d_{eFj}, b^d_{Fj}) - I\right] \\ & \qquad + \mathcal{B}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj}) \left[\frac{z_d(\Pi_i, b_{Li})}{z^m_{eFj}}\right]^\beta \\ & \qquad \times \left[E^j_{Fm}(z^m_{eFj}, b^m_{Fj}) + D^j_{Fm}(z^m_{eFj}, b^m_{Fj}) - I\right]\Big\}, \end{aligned}$$

where z^m_{eFj} and b^m_{Fj} are the follower's entry triggers and coupon payment rate, respectively, when the leader has exited the market before the follower enters the market, and z^d_{eFj} and b^d_{Fj} are the follower's entry triggers and coupon payment rate, respectively if the leader is still active.

2. **[FIFO case]** *If $b_{Li}/\pi_i > b^d_{Fj}/\pi_j$, then the investment value of the follower is given by*

$$\begin{aligned} & V^j_{Fw}(z, z^m_{eFj}, z^d_{eFj}, b^m_{Fj}, b^d_{Fj}) = \qquad (16) \\ & \left[\frac{z}{z_{eLi}}\right]^\beta \Big\{\mathcal{U}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj}) \left[E^j_{Fw}(z^d_{eFj}, b^d_{Fj}) + D^j_{Fw}(z^d_{eFj}, b^d_{Fj}) - I\right] \\ & \qquad + \mathcal{B}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj}) \left[\frac{z_d(\Pi_i, b_{Li})}{z^m_{eFj}}\right]^\beta \\ & \qquad \times \left[E^j_{Fm}(z^m_{eFj}, b^m_{Fj}) + D^j_{Fm}(z^m_{eFj}, b^m_{Fj}) - I\right]\Big\}. \end{aligned}$$

[6] These two quantities can be derived as

$$\begin{aligned} \mathcal{B}(z; \underline{z}, \overline{z}) &= \frac{\overline{z}^\beta z^\lambda - \overline{z}^\lambda z^\beta}{\overline{z}^\beta \underline{z}^\lambda - \overline{z}^\lambda \underline{z}^\beta}; \\ \mathcal{U}(z; \underline{z}, \overline{z}) &= \frac{z^\beta \underline{z}^\lambda - z^\lambda \underline{z}^\beta}{\overline{z}^\beta \underline{z}^\lambda - \overline{z}^\lambda \underline{z}^\beta}, \end{aligned}$$

where β is the positive root of the quadratic equation: $\sigma_z^2 \lambda(\lambda - 1)/2 + \mu_z \lambda - r = 0$.

Proof. See appendix.

Following the results of proposition 4, we can see that given the entry and financial strategies of the leader firm, z_{eLi} and b_{Li}, the follower's first-best entry and financial strategies are to maximize its total value V_F^j. Given the leader's entry trigger z_{eLi} and its coupon payment b_{Li}, and let the market condition $z < z_{eLi}$. Then the follower's first-best financial and entry strategies

$$[z_{eFj}^{m*}, z_{eFj}^{d*}, b_{Fj}^{m*}, b_{Fj}^{d*}],$$

can be derived by the following two-stage optimization.

- **Stage 1.** To obtain $(z_{eFj}^{m*}, b_{Fj}^{m*})$ by solving

$$\max_{(z_{eFj}^{m}, b_{Fj}^{m})} \left\{ (z_{eFj}^{m})^{-\beta} \left[E_{Fm}^{j}(z_{eFj}^{m}, b_{Fj}^{m}) + D_{Fm}^{j}(z_{eFj}^{m}, b_{Fj}^{m}) - I \right] \right\}.$$

  Then we have that

$$\begin{aligned} b_{Fj}^{m*} &= b^*(\Pi_j, z_{eFj}^{m*}), && (17)\\ z_{eFj}^{m*} &= \frac{\beta}{\beta-1}\frac{\xi I}{\Pi_j}, && (18) \end{aligned}$$

  where

$$b^*(\Pi, z) \equiv \frac{\lambda-1}{\lambda}\frac{r}{r-\mu_z}\frac{\Pi z}{\delta},$$

  $\xi \equiv [1+\tau/[(1-\tau)\delta]]^{-1}$, and $\delta \equiv [1-\lambda(1-\alpha+\alpha/\tau)]^{-1/\lambda}$.

- **Stage 2.** To derive $(z_{eFj}^{d*}, b_{Fj}^{d*})$ by solving the following maximization problem:[7]

$$\max_{(z_{eFj}^{d}, b_{Fj}^{d})} V_F^j(z, z_{eFj}^{m*}, z_{eFj}^{d}, b_{Fj}^{m*}, b_{Fj}^{d}).$$

The timing of the entry decision is assumed to be entirely at the discretion of the firm's manager. Thus, we further assume that bondholders have rational expectations and fully anticipate that the manager may choose an entry strategy which harms the debt value of the firm to maximize its equity value. This implies that bondholders will require that their future capital commitment of K to finance the firm to enter the market be fairly evaluated relative to the promised coupon payment rate and entry strategy applied by the manager.

[7] In this stage, since there are two possible equilibrium paths, *LIFO* and *FIFO* cases, we must conjecture type of the true path first. Then we obtain the optimal strategies $(z_{eFj}^{d*}, b_{Fj}^{d*})$ by adopting V_{Fl}^j or V_{Fw}^j as the objective function. Finally, we check that whether the derived optimal strategies $(z_{eFj}^{d*}, b_{Fj}^{d*})$ satisfy the required equilibrium conditions $b_{Li}/\pi_i < b_{Fj}^{d*}/\pi_j$ or $b_{Li}/\pi_i > b_{Fj}^{d*}/\pi_j$. If the condition is satisfied, then the work is done. Otherwise, we change our conjecture, and repeat the procedure again.

Therefore, given the entry and financial strategies of the leader firm, z_{eLi} and b_{Li}, we obtain the follower's second-best entry and financial strategies

$$[z_{eFj}^{m2}, z_{eFj}^{d2}, b_{Fj}^{m2}, b_{Fj}^{d2}],$$

by the following two-stage optimization.

- **Stage 1.** For obtaining $(z_{eFj}^{m2}, b_{Fj}^{m2})$, we first solve that

  $$\max_{b_{Fj}^{m}} \left\{ (z_{eFj}^{m})^{-\beta} \left[E_{Fm}^{j}(z_{eFj}^{m}, b_{Fj}^{m}) + D_{Fm}^{j}(z_{eFj}^{m}, b_{Fj}^{m}) - I \right] \right\},$$

  then we have that

  $$b_{Fj}^{m2} = b^*(\Pi_j, z_{eFj}^{m}). \qquad (19)$$

  Next, we solve that

  $$\max_{z_{eFj}^{m}} \left\{ (z_{eFj}^{m})^{-\beta} \left[E_{Fm}^{j}(z_{eFj}^{m}, b_{Fj}^{m2}) + K_j^m - I \right] \right\},$$

  where the constant $K_j^m \equiv D_{Fm}^{j}(z_{eFj}^{m2}, b_{Fj}^{m2}(0))$. This implies that

  $$z_{eFj}^{m2} \equiv \frac{\beta}{\beta - 1} \frac{I - K_j^m}{\zeta}, \qquad (20)$$

  where $\zeta \equiv \left[1 - (\lambda - 1)/(\lambda\delta) - \delta^{\lambda-1}/\lambda\right]$.

  Therefore, we can use the above two results to derive z_{eFj}^{m2} by solving the following equation:

  $$z_{eFj}^{m2} \quad = \quad \frac{\beta}{\beta - 1} \frac{I - D_{Fm}^{j}(z_{eFj}^{m2}, b_{Fj}^{m2})}{\zeta}. \qquad (21)$$

- **Stage 2.** Similarly, we apply a two-step maximization to obtain $(z_{eFj}^{d2}, b_{Fj}^{e2})$. In the first stage, we solve that

  $$\max_{b_{Fj}^{d2}} V_F^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d}),$$

  to get b_{Fj}^{d2}. Then we derive z_{eFj}^{d2} by solving the following problem:[8]

  $$\max_{z_{eFj}^{d}} V_F^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2}),$$

[8] Given (z_{eLi}, b_{Li}), we can perform the following procedure to derive z_{eFj}^{d2} numerically, in the LIFO case.

Step 1. Given K_{jFl}^{d}, we first find that $z_{eFj}^{d2k} \equiv arg\max_{z_{eFj}^{d}} V_{Fl}^{j2}(z, z_{eFj}^{m2}, Z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2})$.

Step 2. If

$$V_{Fl}^{j2}(z, z_{eFj}^{m2}, Z_{eFj}^{d2k}, b_{Fj}^{m2}, b_{Fj}^{d2}) = V_{Fl}^{j}(z, z_{eFj}^{m2}, z_{eFj}^{d2k}, b_{Fj}^{m2}, b_{Fj}^{d2}),$$

then we have that $z_{eFj}^{d2} = z_{eFj}^{d2k}$.

Step 3. If there are more than one K_{jFl}^{d} such that the first equation in step 2 is satisfied, then we define $z_{eFj}^{d2} = arg\max_{z_{eFj}^{d2k}} V_{Fl}^{j}(z, z_{eFj}^{m2}, z_{eFj}^{d2k}, b_{Fj}^{m2}, b_{Fj}^{d2})$.

where

$$
\begin{aligned}
V_F^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2}) &= V_{Fl}^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2}) \qquad (22)\\
&\equiv \left[\frac{z}{z_{eLi}}\right]^{\beta} \Big\{\mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z_{eFj}^{d}) \big[E_{Fl}^{j}(z_{eFj}^{d}, b_{Fj}^{d}) \\
&\qquad + K_{jFl}^{d} - I\big] \\
&\qquad + \mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z_{eFj}^{d}) \left[\frac{z_d(\Pi_i, b_{Li})}{z_{eFj}^{m2}}\right]^{\beta} \\
&\qquad \times \big[E_{Fm}^{j}(z_{eFj}^{m2}, b_{Fj}^{m2}) + K_j^m - I\big]\Big\}
\end{aligned}
$$

if $b_{Li}/\pi_i < b_{Fj}^{d2}/\pi_j$, and

$$
\begin{aligned}
V_F^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2}) &= V_{Fw}^{j2}(z, z_{eFj}^{m2}, z_{eFj}^{d}, b_{Fj}^{m2}, b_{Fj}^{d2}) \qquad (23)\\
&\equiv \left[\frac{z}{z_{eLi}}\right]^{\beta} \Big\{\mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z_{eFj}^{d}) \big[E_{Fw}^{j}(z_{eFj}^{d}, b_{Fj}^{d}) \\
&\qquad + K_{jFw}^{d} - I\big] \\
&\qquad + \mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z_{eFj}^{d}) \left[\frac{z_d(\Pi_i, b_{Li})}{z_{eFj}^{m2}}\right]^{\beta} \\
&\qquad \times \big[E_{Fm}^{j}(z_{eFj}^{m2}, b_{Fj}^{m2}) + K_j^m - I\big]\Big\}
\end{aligned}
$$

if $b_{Li}/\pi_i > b_{Fj}^{d2}/\pi_j$. The constants K_{jFl}^{d} and K_{jFw}^{d} are defined as follows.

$$
\begin{aligned}
K_{jFl}^{d} &\equiv D_{Fl}^{j}(z_{eFj}^{d2}, b_{Fj}^{d2}),\\
K_{jFw}^{d} &\equiv D_{Fw}^{j}(z_{eFj}^{d2}, b_{Fj}^{d2}).
\end{aligned}
$$

3.3 The optimal entry and financial strategies of the leader firm

Given the optimal strategies of the follower firm, we now turn to the leader firm's entry and financial decisions. Since the manager of the leader firm can anticipate that the follower's optimal strategies when he makes these decisions, he will takes into account the strategies of the follower that will make. We derive the equity and debt values of the leader firm under the following three scenarios, respectively. In the first scenario, the leader firm defaults immediately upon the follower's entry, that is, the follower's entry trigger z_{eFj} is low enough such that the leader has to default at the follower's entry time. In the second scenario, the leader firm does not default when the follower enters the market, but it defaults when the follower is still active. In the final scenario, the leader defaults after the follower exits the market. Hence, the equity value of the leader firm is the sum of the monopoly rents to be received before the follower's entry and the possible duopoly profits to be received thereafter. The following proposition offers the leader's equity and debt values when the follower has been active.

Proposition 5. *Suppose that both firms have entered the market, and let the leader's financial strategies be b_{Li}. Assume that the spot market condition z is larger than the exit trigger of the firm which defaults earlier.*

1. [**Monopoly case**] *If the leader firm defaults immediately upon the entry of the follower, i.e., $z^*_{eFj} \le z_d(\pi_i, b_{Li})$, then the leader's equity value is*

$$E^i_{Lm}(z, b_{Li}) = 0, \tag{24}$$

and its debt value at the entry time of the follower firm is[9]

$$D^i_{Lm}(z^*_{eFj}, b_{Li}) = \frac{(1-\alpha)(1-\tau)\pi_i z^*_{eFj}}{r-\mu_z}. \tag{25}$$

2. [**LIFO case**] *If the leader firm defaults after the follower enters the market, i.e., $z^*_{eFj} > z_d(\pi_i, b_{Li})$ and $b^{d*}_{Fj}/\pi_j > b_{Li}/\pi_i$, then the leader's equity and debt values are given by*

$$\begin{aligned} E^i_{Lw}(z, b_{Li}) &= (1-\tau)\frac{\pi_i z}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r} \\ &+ \left[\frac{z}{z_d(\pi_j, b^{d*}_{Fj})}\right]^\lambda \left\{(1-\tau)\frac{(\Pi_i - \pi_i) z_d(\pi_j, b^{d*}_{Fj})}{r-\mu_z}\right. \\ &- \left.\left[\frac{z_d(\pi_j, b^{d*}_{Fj})}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[(1-\tau)\frac{\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} + (1-\tau)\frac{b_{Li}}{r}\right]\right\}, \end{aligned} \tag{26}$$

and

$$D^i_{Lw}(z, b_{Li}) = \frac{b_{Li}}{r} + \left[\frac{z}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[\frac{(1-\alpha)(1-\tau)\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} - \frac{b_{Li}}{r}\right], \tag{27}$$

respectively, where z^*_{eFj} and b^{d*}_{Fj} are the follower's optimal entry and financial strategies in this case.

3. [**FIFO case**] *If the leader firm defaults after the follower enters the market, i.e., $z^*_{eFj} > z_d(\pi_i, b_{Li})$ and $b^{d*}_{Fj}/\pi_j < b_{Li}/\pi_i$, then the leader's equity and debt values are given by*

$$E^i_{Ll}(z, b_{Li}) = (1-\tau)\frac{\pi_i z}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r} \tag{28}$$

[9] Because it is assumed that a firm is liquidated and its residual value is given to bondholders once it defaults, we can only derive the corresponding debt value at the firm's default time.

$$-\left[\frac{z}{z_d(\pi_i, b_{Li})}\right]^\lambda \left[(1-\tau)\frac{\pi_i z_d(\pi_i, b_{Li})}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r}\right],$$

and

$$D^i_{Ll}(z, b_{Li}) = \frac{b_{Li}}{r} + \left[\frac{z}{z_d(\pi_i, b_{Li})}\right]^\lambda \left[\frac{(1-\alpha)(1-\tau)\pi_i z_d(\pi_i, b_{Li})}{r-\mu_z} - \frac{b_{Li}}{r}\right], \quad (29)$$

respectively, where z^*_{eFj} *and* b^{d*}_{Fj} *are the follower's optimal entry and financial strategies in this case.*

Proof. See appendix.

Based on this proposition, we can characterize the investment value of the leader firm as a function of its entry trigger z_{eLi} and its coupon payment rate b_{Li} as follows.

Proposition 6. *Suppose that the leader's entry trigger is* z_{eLi}*, and its coupon payment rate be* b_{Li}*. Let the corresponding optimal entry and financial strategies of the follower firm be* z^*_{eFj} *and* b^*_{Fj}*, respectively.*

1. [**Monopoly case**] *If* $z_d(\Pi_i, b_{Li}) \geq z^*_{eFj}$*, then the investment value of the leader firm at the spot market condition* $z < z_{eLi}$ *is*

$$V^i_{Lm}(z, z_{eLi}, b_{Li}) = \left[\frac{z}{z_{eLi}}\right]^\beta \left\{E^i_m(z_{eLi}, b_{Li}) + D^i_m(z_{eLi}, b_{Li}) - I\right\}, \quad (30)$$

where

$$E^i_m(z_{eLi}, b_{Li}) = (1-\tau)\left\{\left[\frac{\Pi_i z_{eLi}}{r-\mu_z} - \frac{b_{Li}}{r}\right] - \left[\frac{z_{eLi}}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[\frac{\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} - \frac{b_{Li}}{r}\right]\right\}, \quad (31)$$

and

$$D^i_m(z_{eLi}, b_{Li}) = \frac{b_{Li}}{r} + \left[\frac{z_{eLi}}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[(1-\tau)(1-\alpha)\frac{\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} - \frac{b_{Li}}{r}\right]. \quad (32)$$

2. [**LIFO case**] *If* $z_d(\Pi_i, b_{Li}) < z^*_{eFj}$ *and* $b_{Li}/\pi_i < b^*_{Fj}/\pi_j$*, then the investment value of the leader firm at the spot market condition* $z < z_{eLi}$ *is*

$$V^i_{Lw}(z, z_{eLi}, b_{Li}) = \left[\frac{z}{z_{eLi}}\right]^\beta \left\{E^{i*}_{Lw}(z_{eLi}, b_{Li}) + D^{i*}_{Lw}(z_{eLi}, b_{Li}) - I\right\}, \quad (33)$$

where

$$E^{i*}_{Lw}(z_{eLi}, b_{Li}) = (1-\tau)\frac{\Pi_i z_{eLi}}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r} \quad (34)$$

$$+\mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[E^i_{Lw}(z^*_{eFj}, b_{Li}) - (1-\tau)\left(\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right)\right]$$
$$-\mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[(1-\tau)\left(\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right)\right],$$

and

$$\begin{aligned} D^{i*}_{Lw}(z_{eLi}, b_{Li}) &= \frac{b_{Li}}{r} + \mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[D^i_{Lw}(z^*_{eFj}, b_{Li}) - \frac{b_{Li}}{r}\right] \\ &\quad + \mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[(1-\tau)(1-\alpha)\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right]. \end{aligned} \tag{35}$$

3. **[FIFO case]** *If $z_d(\Pi_i, b_{Li}) < z^*_{eFj}$ and $b_{Li}/\pi_i > b^*_{Fj}/\pi_j$, then the investment value of the leader firm at the spot market condition $z < z_{eLi}$ is*

$$V^i_{Ll}(z, z_{eLi}, b_{Li}) = \left[\frac{z}{z_{eLi}}\right]^\beta \left\{E^{i*}_{Ll}(z_{eLi}, b_{Li}) + D^{i*}_{Ll}(z_{eLi}, b_{Li}) - I\right\}, \tag{36}$$

where

$$\begin{aligned} E^{i*}_{Ll}(z_{eLi}, b_{Li}) &= (1-\tau)\frac{\Pi_i z_{eLi}}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r} \\ &\quad + \mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[E^i_{Ll}(z^*_{eFj}, b_{Li}) - (1-\tau)\left(\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right)\right] \\ &\quad - \mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[(1-\tau)\left(\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right)\right], \end{aligned} \tag{37}$$

and

$$\begin{aligned} D^{i*}_{Ll}(z_{eLi}, b_{Li}) &= \frac{b_{Li}}{r} + \mathcal{U}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[D^i_{Ll}(z^*_{eFj}, b_{Li}) - \frac{b_{Li}}{r}\right] \\ &\quad + \mathcal{B}(z_{eLi}, z_d(\Pi_i, b_{Li}), z^*_{eFj})\left[(1-\tau)(1-\alpha)\frac{\Pi_i z^*_{eFj}}{r-\mu_z} - \frac{b_{Li}}{r}\right]. \end{aligned} \tag{38}$$

Proof. See appendix.

For any given entry trigger z_{eLi} and coupon payment rate b_{Li} of the leader firm, we uniquely determine the investment value of the follower as a function of the market condition and its entry and financial strategies by proposition 4. Thus, we can derive the corresponding optimal entry and financial strategies of the follower by the procedure stated in the previous section. At the time of entry the leader issues its bond and can set a coupon payment rate to maximize the firm value. Hence, the maximal firm value of the leader upon entry is then given by

$$V^i_L(z_{eLi}, z_{eLi}, b^*_{Li}(z_{eLi})) = \max_{b_{Li}} V^i_L(z_{eLi}, z_{eLi}, b_{Li}), \tag{39}$$

where $b^*_{Li}(z_{eLi})$ is the leader's optimal coupon payment rate when his entry trigger is z_{eLi}. On the other hand, since the leader faces the threat of preemption from the follower, it can not arbitrarily choose its entry trigger to unconditionally maximize its value. Thus, we must consider two types of the leader's optimal entry strategies as follows. Let z^o_{eLi} be the leader's entry trigger which unconditionally maximize it value, i.e.,

$$z^o_{eLi} \equiv arg \max_{z_{eLi}} V^i_L(z, z_{eLi}, b^*_{Li}(z_{eLi})), \tag{40}$$

and let z^r_{eLi} be the preemption entry triggers of firm i, i.e.,

$$z^r_{eLi} \equiv \inf\{z_{eLi} \geq 0 | V^i_L(z, z_{eLi}, b^*_{Li}(z_{eLi})) = V^i_F(z, z^{m*}_{eFi}, z^{d*}_{eFi}, b^{m*}_{Fi}, b^{d*}_{Fi}) \text{ with } z_{eLj} = z_{eLi}\}. \tag{41}$$

If $z^r_{eLi} < z^r_{eLj}$, then we define

$$z^p_{eLi} \equiv \min\{z^o_{eLi}, z^r_{eLj}\} \tag{42}$$

to be the leader's first-best preemption entry trigger. Similarly, we can adopt this method and the procedure introduced in the previous section to find the leader's second-best preemption entry trigger.

4 The Market Equilibria

Four possible types of market equilibria may prevail in the model. The first two types of market equilibria are that firm 1 plays the role of the leader firm in the equilibrium. The other two types involve that firm 2 plays the leader's role, and firm 1 automatically becomes the follower firm in equilibrium. In each of these two subclass of equilibria, we can further classify them into the LIFO and FIFO types in the equilibrium. The LIFO type of equilibrium presents that the leader firm leaves the market last, and in the FIFO type of equilibrium, the leader exits the market first.

Since the complication of the model, we can not derive the model's general existence of equilibrium. Thus, given a set of the model's parameters, we must use numerical method to check the existence of equilibrium, and to find the optimal strategies of both firms in the corresponding market equilibrium when the equilibrium exists. Moreover, under both firms' optimal strategies, we can evaluate the leader and follower firms' capital structures, credit spreads, and agency costs of investment by the following measures, respectively:

$$(D/E)_L \equiv \frac{D_L(z^p_{eL}, b^*_L(z^p_{eL}))}{E_L(z^p_{eL}, b^*_L(z^p_{eL}))}, \tag{43}$$

$$(D/E)_F \equiv \frac{D_F(z^*_{eF}, b^*_F)}{E_F(z^*_{eF}, b^*_F)}, \tag{44}$$

$$CS_L \equiv \frac{b^*_L(z^p_{eL})}{D_L(z^p_{eL}, b^*_L(z^p_{eL}))} - r, \tag{45}$$

$$
\begin{aligned}
CS_F &\equiv \frac{b_F^*}{D_F(z_{eF}^*, b_F^*)} - r, && (46)\\
AC_L &\equiv \frac{[E_L(z_{eL}^p, b_L^*(z_{eL}^p)) + D_L(z_{eL}^p, b_L^*(z_{eL}^p))] - [E_L(z_{eL}^{p2}, b_L^*(z_{eL}^{p2})) + D_L(z_{eL}^{p2}, b_L^*(z_{eL}^{p2}))]}{E_L(z_{eL}^p, b_L^*(z_{eL}^p)) + D_L(z_{eL}^p, b_L^*(z_{eL}^p))} && (47)\\
AC_F &\equiv \frac{[E_F(z_{eF}^*, b_F^*) + D_F(z_{eF}^*, b_F^*)] - [E_L(z_{eF}^2, b_F^2) + D_F(z_{eF}^2, b_F^2)]}{E_F(z_{eF}^*, b_F^*) + D_F(z_{eF}^*, b_F^*)}. && (48)
\end{aligned}
$$

5 Conclusions

This paper is the first part of our equilibrium analysis on the optimal capital structure in an asymmetric duopoly. In this paper, we derive the optimal entry, financing, and exit decisions of firms in an asymmetric duopoly. A duopolistic real option model is adopted to investigate the interaction between product market competition and the optimal investment and financing strategies of both firms.

In contrast with extant literatures, the asymmetry of the model gives our a way to investigate whether a firm with profit advantage will enter the market first by a trade-off between interest tax shields and monopolistic profits, and whether it will have a lower leverage than the other firm. Moreover, Two types of maximization principles the firm's manager follows to make their entry decision are considered in this paper. The first one is the total value maximization principle under which the manager takes an entry strategy to maximize total firm value, and the other one is the equity value maximization principle under which the optimal entry strategy is to maximize equity value only instead of total firm value. According to the equilibrium results derived under these two different principles, we can examine that the interaction between product-market competition and agency problem of debt.

The complication of the model does not permit us to perform a closed-form analysis of market equilibrium and its comparative static. Hence, we will accomplish this equilibrium analysis numerically in the second part of the project.

Appendix

Proof of Proposition 1. Applying the standard real option arguments, we can see that any arbitrary contingent claim $W(z)$, which yield instantaneous cash inflow $Az+B$, condition on the market condition z, satisfies the following equation:

$$rW(z) = (Az + B) + \frac{1}{dt}E_z[dW(z)],$$

where A and B are real constants and $E_z[\cdot]$ is the expectation operator with respect to z. Then under the assumption that W is twice continuous differential function of z, it is straightforward by Ito's lemma to show that this equation is equivalent to the following ordinary differential equation (ODE):

$$rW(z) = \mu_z zW'(z) + \frac{1}{2}\sigma_z^2 z^2 W''(z) + (Az + B). \tag{49}$$

The general solution of this ODE is given by

$$W(z) = C_1 z^\lambda + C_2 z^\beta + \left(\frac{Az}{r - \mu_z} + \frac{B}{r}\right), \tag{50}$$

where C_1 and C_2 are real constants to be determined from boundary conditions specific to each claim, and λ and β are the negative and positive roots of the quadratic equation $\sigma_z^2\lambda(\lambda - 1)/2 + \mu_z\lambda - r = 0$.

Therefore, we can derive the equity value of firm j in case 1 as

$$E_{Ll}^j(z, b_{Lj}) = C_1 z^\lambda + C_2 z^\beta + (1 - \tau)\left(\frac{\pi_j z}{r - \mu_z} + \frac{b_{Lj}}{r}\right),$$

and the corresponding value-matching and smooth-pasting conditions are

$$\begin{aligned} E_{Ll}^j(z_d(\pi_j, b_{Lj}), b_{Lj}) &= 0, \\ \frac{1}{\partial z}\partial E_{Ll}^j(z_d(\pi_j, b_{Lj}), b_{Lj}) &= 0. \end{aligned}$$

Moreover, the probability of default becomes negligibly small when the market condition z goes up to infinity. Hence these three conditions imply that

$$\begin{aligned} C_1 &= (1 - \tau)\left[\frac{b_{Lj}}{r} - \frac{\pi_j z_d(\pi_j, b_{Lj})}{r - \mu_z}\right]\left[\frac{1}{z_d(\pi_j, b_{Lj})}\right]^\lambda, \\ C_2 &= 0, \end{aligned}$$

and

$$z_d(\pi_j, b_{Lj}) = \frac{\lambda}{1 - \lambda}\frac{r - \mu_z}{\pi_j}\frac{b_{Lj}}{r}. \tag{51}$$

Since firm i is still active when firm j leaves the market in this case, we can use the similar method with the instantaneous cash inflow $(1-\tau)\Pi_i z - b_{Fi}$ to show that the exit trigger of firm i to be

$$z_d(\Pi_i, b_{Fi}) = \frac{\lambda}{1-\lambda}\frac{r-\mu_z}{\Pi_i}\frac{b_{Fi}}{r}. \tag{52}$$

The proof for case 2 is similar to case 1, and it therefore omitted.■

Proof of Proposition 2. We adopt the argument used in the proof of Zhdanov's (2008) proposition 3 to prove this result. Without loss of generality, assume that $b_j/\pi_j > b_i/\pi_i$, i.e. firms j and i are looser and winner, respectively. The proof is completed by the following steps.

- We first establish the relationship among different default triggers. It is clear that $z_d(\Pi_j, b_j) < z_d(\pi_j, b_j)$ and $z_d(\Pi_i, b_i) < z_d(\pi_i, b_i)$. If $z_d(\pi_j, b_j) > z_d(\pi_i, b_i)$, then the only equilibrium path is that firm j defaults first at $z_d(\pi_j, b_j)$. Therefore, the only non-trivial case is

$$z_d(\pi_j, b_j) > z_d(\pi_i, b_i) > z_d(\Pi_j, b_j) > z_d(\Pi_i, b_i).$$

- We introduce the notion of a "reservation trigger" of the looser firm, $z_r(\pi_j, b_j)$. The equity holders of the looser firm are ex-post indifferent between defaulting at $z_d(\pi_j, b_j)$ and $z_d(\Pi_j, b_j)$, provided that the winner firm defaults at $z_r(\pi_j, b_j)$. Apparently, $z_d(\Pi_j, b_j) < z_r(\pi_j, b_j) < z_d(\pi_j, b_j)$. The reservation trigger is a point such that the expected losses incurred in result of operating while competing with a stronger firm up until this point are exactly offset by the profits to be received later, once the rival has defaulted. Using standard arguments, it can be shown that $z_r(\pi_j, b_j)$ is given by the solution to the following equation:

$$H_1(z) + H_2(z) = 0, \tag{53}$$

where

$$H_1(z) \equiv \frac{\pi_j z_d(\pi_j, b_j)}{r-\mu_z} - \frac{b_j}{r} - \left[\frac{z_d(\pi_j, b_j)}{z}\right]^{\lambda}\left(\frac{\pi_j z}{r-\mu_z} - \frac{b_j}{r}\right)$$

is the expected loss to be incurred while competing with a stronger rival, and

$$H_2(z) \equiv \left[\frac{z_d(\pi_j, b_j)}{z}\right]^{\lambda}\left[\frac{\Pi_j z}{r-\mu_z} - \frac{b_j}{r} - \left[\frac{z}{z_d(\Pi_j, b_j)}\right]^{\lambda}\left(\frac{\Pi_j z_d(\Pi_j, b_j)}{r-\mu_z} - \frac{b_j}{r}\right)\right]$$

is the gain to be received afterwards. The existence and uniqueness of the solution to equation (53) follows from the monotonicity of $H_1(z) + H_2(z)$ and the corresponding boundary conditions. Indeed, one can easily notice that $H_1(z_d(\Pi_j, b_j)) < 0$, $H_2(z_d(\Pi_j, b_j)) = 0$, $H_2(z_d(\pi_j, b_j)) > 0$, and $H_1(z_d(\Pi_j, b_j)) < 0$. Moreover, we can derive that

$$\frac{dH_1(z)}{z} = -\left[\frac{z_d(\pi_j, b_j)}{z}\right]^{\lambda} \left(\frac{(1-\lambda)\pi_j}{r-\mu_z} - \frac{\lambda b_j}{rz}\right) > 0,$$

for $z < z_d(\pi_j, b_j)$, and similarly

$$\frac{dH_2(z)}{z} < 0,$$

for $z > z_d(\Pi_j, b_j)$. Hence, let $H(z) = H_1(z) + H_2(z)$, then we have that $H(z_d(\Pi_j, b_j)) < 0$, $H(z_d(\pi_j, b_j)) > 0$, and $dH(z)/dz > 0$ for $z_d(\pi_j, b_j) > z > z_d(\Pi_j, b_j)$. Therefore, the continuity of $H(z)$ implies the existence and uniqueness of the reservation trigger $z_r(\pi_j, b_j)$.

- If the reservation trigger $z_r(\pi_j, b_j)$ is greater than the default trigger of firm i, $z_d(\pi_i, b_i)$, then the best that the manager of firm j can do is to default at $z_d(\pi_j, b_j)$, since the other firm will definitely default only after the reservation trigger $z_r(\pi_j, b_j)$ has been hit. Therefore, the only non-trivial case left is when the relation among the various triggers considered above is as follows.

$$z_d(\pi_j, b_j) > z_d(\pi_i, b_i) > z_r(\pi_j, b_j) > z_d(\Pi_j, b_j) > z_d(\Pi_i, b_i).$$

  In fact, the equity holders of firm j may decide to default at $z_d(\Pi_j, b_j)$ only if the above inequality holds. Next, we show that it can never occur in any subgame perfect Nash Equilibrium of this exiting game.

- To show that, we examine what happens if the market condition hits $z_d(\Pi_j, b_j)$, but neither of the firms has defaulted. At $z_d(\Pi_j, b_j)$ the manager of firm j defaults immediately as they have no more incentives to wait. Consequently, firm j is liquidated, resulting in a positive shock to the profit of firm i from π_i to Π_i, whose equity holders are then guaranteed the expected payoff of

$$\phi \equiv (1-\tau)\left[\frac{\Pi_i z_d(\Pi_j, b_j)}{r-\mu_z} - \frac{b_i}{r} - \left[\frac{z_d(\Pi_j, b_j)}{z_d(\Pi_i, b_i)}\right]^{\lambda}\left(\frac{\Pi_i z_d(\Pi_i, b_i)}{r-\mu_z} - \frac{b_i}{r}\right)\right].$$

  Therefore, there exists a reservation trigger z_{r1}, such that the winner firm is indifferent between defaulting at z_{r1} or waiting until $z_d(\Pi_j, b_j)$ is hit, and the looser defaults given it has not defaulted before. z_{r1} can be found as the root of the following equation:

$$(1-\tau)\left[\frac{\Pi_i z_{r1}}{r-\mu_z} - \frac{b_i}{r} - \left[\frac{z_{r1}}{z_d(\Pi_j, b_j)}\right]^{\lambda}\left(\frac{\Pi_i z_d(\Pi_j, b_j)}{r-\mu_z} - \frac{b_i}{r}\right)\right] - \left[\frac{z_{r1}}{z_d(\Pi_j, b_j)}\right]^{\lambda}\phi = 0.$$

The existence and uniqueness of z_{r1} can be derived by using the same method applied to prove the existence and uniqueness of the solution to equation (53).

Hence, the winner firm will never exit when the market condition stays between $z_d(\Pi_j, b_j)$ and z_{r1}. The looser firm's manager is rational, and fully aware of the nature of the game. Therefore, they have no incentive to wait after z_{r1} is hit and they will default at z_{r1}, at the latest. The same argument can be applied again to show that there exists another threshold $z_{r2} > z_{r1} > z_d(\Pi_j, b_j)$ such that the winner firm will never default when z stays between $z_d(\Pi_j, b_j)$ and z_{r2}, and therefore the looser firm must default at the first passage time to z_{r2} or earlier. Using the same argument iteratively, we construct an increasing sequence of thresholds z_{rn}, constraining the equilibrium default strategies of the levered firm. If $z_{rn} > z_r(\pi_j, b_j)$ holds for some $n \in \mathbb{N}$, then the only optimal strategy left for the looser firm is to default at $z_d(\pi_j, b_j)$.

- The proof is completed by showing the existence of such n. Suppose contrary that it does not exist. Since the sequence $\{z_{rn}\}$ is increasing and bounded above by $z_r(\pi_j, b_j)$, it converges to some limit $z_{r*} \leq z_r(\pi_j, b_j)$. Thus, for any $\epsilon > 0$, there exists $m \in \mathbb{N}$ such that $z_{rm+1} - z_{rm} < \epsilon$, where given z_{rm}, z_{rm+1} is the root of the following equation:

$$
\begin{aligned}
&(1-\tau)\left[\frac{\pi_i z_{rm+1}}{r-\mu_z} - \frac{b_i}{r} - \left[\frac{z_{rm+1}}{z_{rm}}\right]^{\lambda}\left(\frac{\pi_i z_{rm}}{r-\mu_z} - \frac{b_i}{r}\right)\right] \\
&+(1-\tau)\left(\frac{z_{rm+1}}{z_{rm}}\right)^{\lambda}\left[\frac{\Pi_i z_{rm}}{r-\mu_z} - \frac{b_i}{r} - \left[\frac{z_{rm}}{z_d(\pi_j, b_j)}\right]^{\lambda}\left(\frac{\pi_i z_d(\pi_j, b_j)}{r-\mu_z} - \frac{b_i}{r}\right)\right] \\
&-\left[\frac{z_{rm+1}}{z_d(\pi_j, b_j)}\right]^{\lambda}\phi = 0.
\end{aligned}
$$

The first term of the RHS of the above equation approaches to zero as $z_{rm} \to z_{rm+1}$, and its second term is less than zero. Hence, for all $\theta > 0$, there exists $\epsilon > 0$ such that

$$
\phi < \theta\left[\frac{z_{rm+1}}{z_d(\pi_j, b_j)}\right]^{-\lambda}
$$

when $z_{rm+1} - z_{rm} < \epsilon$. This contradicts the constant $\phi > 0$.■

Proof of Proposition 3. The equity values of firm j in the three cases can be directly derived by applying the same arguments used in the proof of proposition 1. Thus, we omit this part of the proof.

Given the coupon payment rate of firm j, b_{Fj}, the debt of firm j in the LIFO case is a contingent claim $D^j_{Fl}(z, b_{Fj})$ which yielding the instantaneous cash inflow b_{Fj}, and the corresponding boundary conditions are

$$\begin{aligned}
\lim_{z\to\infty} D^j_{Fl}(z, b_{Fj}) &= \frac{b_{Fj}}{r}, \\
D^j_{Fl}(z_d(\pi_j, b_{Fj}), b_{Fj}) &= (1-\tau)(1-\alpha)\frac{\pi_j z_d(\pi_j, b_{Fj})}{r-\mu_z}.
\end{aligned}$$

Hence, the debt value of firm j is obtained by substituting these two boundary conditions, $A = 0$ and $B = b_{Fj}$ into equation (50), i.e.,

$$D^j_{Fl}(z, b_{Fj}) = \frac{b_{Fj}}{r} - \left[\frac{b_{Fj}}{r} - (1-\alpha)(1-\tau)\frac{\pi_j}{r-\mu_z} z_d(\pi_j, b_{Fj})\right]\left[\frac{z}{z_d(\pi_j, b_{Fj})}\right]^{\lambda}.$$

The same approach can be used to derive the debt value of firm j in the remainder cases, so we omit them.■

Proof of Proposition 4. We only derive the investment value of firm j in the LIFO case, and the value in the FIFO case can be obtained by the similar argument.

Let the market condition $z \in (z_d(\Pi_i, b_{Li}), z^d_{eFj})$, then By applying the traditional real-option argument, the investment value of firm j, $V^j_{Fl}(z)$ must satisfy the following ODE:[10]

$$\frac{1}{2}\sigma_z^2 z^2 \frac{\partial^2 V^j_{Fl}(z)}{\partial z^2} + \mu_z z \frac{\partial V^j_{Fl}(z)}{\partial z} - rV^j_{Fl}(z) = 0, \tag{54}$$

with the following two boundary conditions:

$$\begin{aligned}
V^j_{Fl}(z^d_{eFj}) &= E^j_{Fl}(z^d_{eFj}, b^d_{Fj}) + D^j_{Fl}(z^d_{eFj}, b^d_{Fj}) - I, \\
V^j_{Fl}(z_d(\Pi_i, b_{Li})) &= \left[\frac{z_d(\Pi_i, b_{Li})}{z^m_{eFj}}\right]\left[E^j_{Fm}(z^m_{eFj}, b^m_{Fj}) + D^j_{Fm}(z^m_{eFj}, b^m_{Fj}) - I\right].
\end{aligned}$$

The general solution of equation (54) is $V^j_{Fl}(z) = C_1 z^{\lambda} + C_2 z^{\beta}$, where C_1 and C_2 are real constants to be determined from the corresponding boundary conditions. Hence, we can use the above two boundary conditions to obtain the investment value of firm j as

$$\begin{aligned}
&V^j_{Fl}(z, z^m_{eFj}, z^d_{eFj}, b^m_{Fj}, b^d_{Fj}) = \\
&\quad \left[\frac{z}{z_{eLi}}\right]^{\beta} \Big\{\mathcal{U}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj})\left[E^j_{Fl}(z^d_{eFj}, b^d_{Fj}) + D^j_{Fl}(z^d_{eFj}, b^d_{Fj}) - I\right] \\
&\qquad + \mathcal{B}(z_{eLi}; z_d(\Pi_i, b_{Li}), z^d_{eFj})\left[\frac{z_d(\Pi_i, b_{Li})}{z^m_{eFj}}\right]^{\beta}
\end{aligned}$$

[10] To simplify the notations, we ignore the arguments $(z^m_{eFj}, z^d_{eFj}, b^m_{Fj}, b^d_{Fj})$ from the investment value function of firm j in the proof.

$$\times \left[E^j_{Fm}(z^m_{eFj}, b^m_{Fj}) + D^j_{Fm}(z^m_{eFj}, b^m_{Fj}) - I\right]\Big\} . \blacksquare$$

Proof of Proposition 5. The equity and debt values of firm i in the Monopoly case can straightforward be obtained by the assumptions of $z^*_{eFj} \leq z_d(\pi_i, b_{Li})$ and bondholders receiving all liquidation value of the firm.

The same argument in the proof of proposition 3 can be used to obtain the equity and debt values of firm i in the FIFO case, and firm i's debt value of the LIFO case. Hence, in the remainder of this proof, we derive the equity value of firm i in the LIFO case.

Let $z > z_d(\pi_j, b^{d*}_{Fj})$, then the equity value of firm i must satisfy the following ODE:

$$rE^i_{Lw}(z, b_{Li}) = \mu_z z \frac{\partial E^i_{Lw}(z, b_{Li})}{\partial z} + \frac{1}{2}\sigma^2_z z^2 \frac{\partial^2 E^i_{Lw}(z, b_{Li})}{\partial z^2} + [(1-\tau)\pi_i - b_{Li}] \text{ ,} \tag{55}$$

with two boundary conditions:

$$E^i_{Lw}(z_d(\pi_j, b^{d*}_{Fj}), b_{Li}) = (1-\tau)\left\{\frac{\Pi_i z_d(\pi_j, b^{d*}_{Fj})}{r-\mu_z} - \frac{b_{Li}}{r} - \left[\frac{z_d(\pi_j, b^{d*}_{Fj})}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[\frac{\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} - \frac{b_{Li}}{r}\right]\right\},$$

and

$$\lim_{z\to\infty} \frac{E^i_{Lw}(z, b_{Li})}{(1-\tau)\left(\frac{\pi_i z}{r-\mu_z} - \frac{b_{Li}}{r}\right)} = 1.$$

This implies that the equity value of firm i in this case is

$$\begin{aligned}
E^i_{Lw}(z, b_{Li}) &= (1-\tau)\frac{\pi_i z}{r-\mu_z} - (1-\tau)\frac{b_{Li}}{r} \\
&\quad + \left[\frac{z}{z_d(\pi_j, b^{d*}_{Fj})}\right]^\lambda \Bigg\{(1-\tau)\frac{(\Pi_i - \pi_i) z_d(\pi_j, b^{d*}_{Fj})}{r-\mu_z} \\
&\quad - \left[\frac{z_d(\pi_j, b^{d*}_{Fj})}{z_d(\Pi_i, b_{Li})}\right]^\lambda \left[(1-\tau)\frac{\Pi_i z_d(\Pi_i, b_{Li})}{r-\mu_z} + (1-\tau)\frac{b_{Li}}{r}\right]\Bigg\} . \blacksquare
\end{aligned}$$

Proof of Proposition 6. Since the present value of \$1 to be received at the first time the market condition hit z_{eLi} is $[z/z_{eLi}]^\beta$, it is straightforward to obtain the investment value of firm i in the Monopoly case. The results of other cases can be derived by using the same argument applied in the proof of proposition 4.$\blacksquare$

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