The dynamics of stock repurchases*

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Preliminary and incomplete. Please do not circulate.

Abstract

We develop a dynamic model of the timing of share repurchases within a duopolistic industry to analyze the dynamics of share repurchases in the context of the 'peer effect' documented in the extant empirical literature. Share repurchase decisions are taken as part of a broader liquidity management policy but also take into account *i*) the firm's financial resources needed to invest in a potential growth opportunity, and *ii*) the feedback effect of the competitor's investment threat on the firm's willingness to hold cash to respond to such a threat. We derive the equilibrium timing of such strategic repurchases of both firms, demonstrate that repurchase triggers depending on parameter values can be either strategic complements or strategic substitutes, and generate a number of empirical predictions regarding the expected strength of the peer effect, defined as the distance between the leader and follower repurchase thresholds. Subsequently, based on the universe of Compustat firms, we find empirical support for the model predictions: the peer effect is weakened by the degree of product market competition, financial constraints, and stock illiquidity. Finally, we also present evidence of several cross-effects that are consistent with model predictions.

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1 Introduction

We develop a theory of industry payout dynamics based on product market considerations in the presence of financial market imperfections. To this end, we propose a model of stock repurchases in which a firm's repurchase decision is affected by strategic capital investment considerations. Specifically, we adopt the view that a firm's ability to undertake capital investment is affected by its cash balance. Consequently, in our model, a decision to repurchase stock leads to the firm being unable to benefit from an investment opportunity if it subsequently arises. The decision to repurchase stock has therefore two direct consequences. First, the firm cannot acquire the project to capture its positive net present value (NPV). Second, it is not able to respond when its competitor undertakes investment.

As a result, stock repurchases occur later that in a standard liquidity management model as there is an additional benefit of waiting associated with the ability to invest and/or mitigate the consequences of the investment undertaken by the firm's competitor (industry peer). To obtain the solution to the strategic stock repurchase problem, we first obtain each firm's reaction functions, which involve solving for the optimal stock repurchase threshold conditional on the action taken by the peer. We demonstrate that strategic repurchase decisions can be either strategic substitutes (i.e., a delayed repurchase by a firm's peer leads to its own earlier payout) or strategic complements (in which case the opposite is true), a fact that has generally been overlooked in the literature (see, e.g., Adhikari and Agrawal, 2018; Grennan, 2019; Massa et al., 2007). We also generate a number of empirical predictions regarding the relationship between the strength of the peer effect (that is, the reciprocal of the distance between repurchase thresholds) and firm- and industry-specific variables that can be mapped to model parameters. From the empirical design perspective, the strength of the peer effect should not only be viewed as a function of the follower's repurchase timing since it is also affected by the repurchase timing of the leader. As a consequence, a change of a parameter value may only affect the repurchase timing of the former. In such a case, the strength of the peer effect will change despite the repurchase timing of the follower *not* being affected by the parameter change.

[...]

2 The model

[...]

2.1 Non-strategic benchmark

The purpose of this section is to provide a benchmark solution for what follows later and generating basic comparative statics results, in particular regarding the share repurchase trigger $\overline{C}$.

2.1.1 No investment option

The presented model of cash management and repurchase decisions in the presence of a potential growth opportunity is inspired by stochastic cash management literature (Décamps et al., 2011), as well as earlier contributions on the control of Brownian motion (e.g., Harrison and Taksar, 1983).

In the model, the amount of liquid assets C held by a risk-neutral firm follows an arithmetic Brownian motion:

$$dC = \mu dt + \sigma dz_t, \tag{1}$$

where μ is the expected (net) cash flow per period, σ is its standard deviation, dz_t is a Wiener increment, r is the riskless return rate.[1] It is therefore assumed that cash balance

[1]Under the assumption that the dividend policy is fixed, μ can be interpreted as cash flow minus the dividend flow. In such a case, any lumpy payout is equivalent to share repurchases.

held *within* the firm yields no interest.[2] At each instant, the firm can undertake one of three actions regarding its cash management. First, it can raise external financing to increase its cash balance, C. Second, it can pay out a fraction of its cash balance (repurchase stock), which would lead to the reduction of C. Finally, it can do nothing. The decision taken by the firm results from the following trade-off. On the one hand, holding cash is costly due to the return shortfall on its cash balance. On the other hand, cash balance serves as a safety cushion reducing the costs rasing external financing.

The amount of cash raised, C^*, is selected optimally as a result of the tradeoff between the cost of doing so, ϕ, and its benefit, which is the reduction in the present value of the cost of seeking external financing in future.[3]

If the cash level is sufficiently high, the firm eventually finds it optimal to may find it optimal to reduce it through repurchasing its shares. The associated fixed cost of such a reduction is ψ. Consequently, each time the cash balance hits upper barrier $\overline{C}$, the firm optimally reduces it to the optimal target level $C^* < \overline{C}$.[4] If there is no fixed cost of share repurchases (i.e., if $\psi = 0$), then the firm with excess cash makes no discrete changes in its cash balance and uses only the amount in excess of the upper level $\overline{C}$ to repurchase stock.[5] Figure 1 presents a graphical representation of the liquidity management policy considered.

[Please insert Figure 1 about here]

A strictly positive sum of $(\psi + \phi)$ is a necessary condition for the firm to hold cash and

[2] The return shortfall has been interpreted as a result of market imperfections, such as tax distortions (Faulkender and Wang, 2006; Riddick and Whited, 2009), transaction costs leading to liquidity premia (Kim et al., 1998; Vayanos and Vila, 1999) or agency costs of cash stock (Jensen, 1986).

[3] As there is no time lag between the decision to seek external financing and the receipt of funds, the firm does not issue new equity until cash balance reaches zero. Obviously, if $\phi = 0$, the firm would just issue an infinitesimal amount of new equity every time liquidity is exhausted to avoid the shortfall on internally held cash.

[4] Since the opportunity cost of cash outside the firm is always r, cash balance is always reset to the same level irrespective whether resetting results from new equity issues or repurchasing the stock, see Harrison (1985).

[5] In such a case, barriers $\overline{C}$ and C^* coincide.

for the policy analyzed in this section to be non-degenerate. A strictly positive interest rate precludes the existence of the trivial optimal policy of raising an infinite amount of external financing in order to avoid the fixed cost of future external financing rounds and ensures that stock repurchase is optimal for a sufficiently high cash balance.

The value the firm from shareholder's perspective, $W(C)$, is equal to the difference between the present value of all future stock repurchases and the present value of all future equity issuances, all taking into account the associated transaction costs and discounted at rate r. Given the liquidity dynamics (1), the value of the firm can be derived using standard dynamic programming techniques (see, e.g., Dixit (1993)). In general, $W(C)$ is given by

$$W(C) = A_1 e^{\beta_1 C} + A_2 e^{\beta_2 C}, \tag{2}$$

where A_1 and A_2 are constants to be determined. Parameters β_1 and β_2 are the negative and positive root, respectively, of the following equation:

$$r - \mu x - \frac{1}{2}\sigma^2 x^2 = 0. \tag{3}$$

Consequently, the problem boils down to finding the target cash balance C^* and the share repurchase trigger $\overline{C}$ as well as constants A_1 and A_2, which is done using the following system of boundary conditions for $W(C)$:

$$W(0) = W(C^*) - C^* - \phi, \tag{4}$$

$$W(\overline{C}) = W(C^*) + \overline{C} - C^* - \psi, \tag{5}$$

$$W_C(C^*) = 1, \tag{6}$$

$$W_C(\overline{C}) = 1, \tag{7}$$

The value-matching condition (4) requires that the difference between the value of the firm at C^* and zero be exactly equal to the total cost of restoring cash balance to C^* (from zero). Condition (5) requires that the value of the firm at the target level C^* be smaller than the value at the stock repurchase trigger $\overline{C}$ exactly by the amount equal to the gain from reducing the cash balance $\overline{C}$ to C^* (which equals the present value of proceeds from share repurchase program, $\overline{C} - C^*$, net of the fixed transaction cost, ψ). Equations (6) and (7) are smooth-pasting conditions ensuring the optimality of the barriers. Consequently, at each of the barriers the marginal benefit of changing the cash balance (represented by the first-order derivative of $V(C)$) is equal to the marginal cost of such a change (equal to 1).

The value of the firm, $W(C)$ can therefore be represented as the following function of the model parameters as well as of barriers $\overline{C}$ and C^* (Cunha et al., 2011):

$$W(C) = \overline{\Theta}(0, \overline{C}; C) \left[\overline{C} - C^* - \psi\right] - \underline{\Theta}(0, \overline{C}; C) \left[C^* + \phi\right] \tag{8}$$

where $\overline{\Theta}(0, \overline{C}; C)$ and $\underline{\Theta}(0, \overline{C}; C)$, defined in Appendix A, are annuity-like factors representing the present value of a series of \$1 payments received each time the share repurchase trigger $\overline{C}$ is hit or liquidity is exhausted, respectively. The first component of (8) represents the present value of all share repurchases minus the associated transaction costs, whereas the second component equals the present value of cash injections (equity issuance programs) into the firm, including transaction costs.[6]

[...]

2.1.2 A model with investment option

Now, we introduce the possibility of the firm acquiring a profitable investment project. It is assumed that the single opportunity to invest in a value-enhancing project arrives with

[6]If μ is interpreted as expected cash flow net of dividend flow, the present value of the latter needs to be separately added to the firm value.

a Poisson rate λ.[7] Investment in the project is associated with a lump sum cost I. If undertaken, the investment project increases firm value by a fixed amount, $v > I$. We assume that $v - I$ is sufficiently high so that the investment is optimally undertaken when the investment opportunity arrives. The investment opportunity expires immediately after its arrival so the firm faces a now-or-never investment decision. The firm can only invest in the project if it has sufficient cash to do so, that is, if $C \geq I$. In addition, arrival rate associated with the project becomes zero once a share repurchase program is initiated or the cash balance drops to zero.[8]

We can now derive the value and the optimal timing of initiating a share repurchase program of the firm that has access to a potential investment opportunity, as described above. The value of such a firm, $V(C)$, where

$$V(C) = \begin{cases} V^{(1)}(C) & C \in [0, I) \\ V^{(2)}(C) & C \in [I, \overline{C}] \end{cases} \tag{9}$$

satisfies the ordinary differential equation (ODE):

$$rV(C) = \mu V_C(C) + \frac{1}{2}\sigma^2 V_{CC}(C) + \mathbf{1}_{C>I}\lambda\left(v - I + W(C) - V(C)\right), \tag{10}$$

[7] See Hugonnier et al. (2015) for a set-up where the arrival of financing opportunities for investment is modeled in an analogous way as well as Couzoff et al. (2022).

[8] The first assumption may be associated with the fact that, at that point, the management of the firm shifts focus away from trying to identify a suitable investment opportunity, which is also exemplified by the decision to distribute cash. The motivation behind the second one is both economic and technical. First, even without initiating the stock repurchase program, cash balance may fall to a level for which investment opportunity will not be undertaken or sought. Second, for tractability of the strategic model of Section 2.2 cash balances of both firms need to co-move in lockstep and be the same level (possibly up to a scaling factor) at all times, to avoid the need to introduce a second state variable. The link between the cash balances is broken once at either 0 or $\overline{C}$ firms reset their cash balances to (generally different) target levels.

subject to the following boundary conditions:

$$
\begin{aligned}
V^{(1)}(0) &= W(C^*) - C^* - \phi, && (11)\\
V^{(2)}(\overline{C}) &= W(C^*) + \overline{C} - C^* - \psi, && (12)\\
\lim_{C\to I} V^{(1)}(C) &= V^{(2)}(I), && (13)\\
\lim_{C\to I} V_C^{(1)}(C) &= V_C^{(2)}(I), && (14)\\
V_C^{(2)}(\overline{C}) &= 1. && (15)
\end{aligned}
$$

The last component in an otherwise standard equation (10) reflects the fact that with intensity λ, the current value of the firm can be replaced by the sum of the NPV of the project, $v - I$, and the value of a firm with no (remaining) investment option (i.e., one from Section 2.1.1), conditional on $C \geq I$. The value-matching condition (11) corresponds to the respective condition in Section 2.1.1 and takes into account that the firm that exhausts its cash balance ($C = 0$) loses its investment option permanently. The value matching condition (12) requires that the value of the firm *with no investment option* at the target level C^* (which the firm becomes following the implementation of the repurchase program) be smaller than the firm value at the stock repurchase trigger $\overline{C}$ exactly by the amount equal to the gain from reducing the cash balance $\overline{C}$ to C^* (which equals the present value of proceeds from share repurchase program, $\overline{C} - C^*$, net of the fixed transaction cost, ψ). Conditions (13) and (14) ensure the continuity and differentiability of the value function at I (Dumas, 1991), that is, at the point that separates cases for which the firm has and does not have sufficient funds to invest, whereas smooth-pasting condition (15) ensures the optimality of the stock repurchase policy.

As, $V^{(2)}(C)$ increases with λ, in the presence of investment opportunity condition (12) is satisfied for higher $\overline{C}$ than in its absence. Therefore, other things being equal, the presence of a more valuable investment opportunity results in a later initiation of the repurchase program.

2.2 Two firms

Equipped with the valuation framework of the non-strategic scenario, we are in position to derive valuations and repurchase strategies of two competitive firms, $i, j \in 1, 2$, $i \neq j$. The firms can differ with respect to the following parameters: ϕ, ψ, v, I, p, μ and σ, with ratio μ_i/σ_i constrained to be the same and $s \equiv \mu_2/\mu_1$. For $s \neq 1$, without loss of generality, $C_1 \equiv C$ denotes the instantaneous cash flow of Firm 1 and $C_2 \equiv sC$ cash flow of Firm 2. Otherwise, firms are subject to the same cash flow shock and the process governing the arrival of the investment opportunity.

There are two consequences of introducing another firm to the previous set-up. First, if both firms have sufficient liquid reserves when investment opportunity arrives, they both acquire the project, which generates a lump sum net payoff of $\mathbf{1}_{C_i > I_i}(1-\kappa)^{\mathbf{1}_{C_j > I_j}}(v_i - I_i)$, $i \in \{1, 2\}$, to each firm. Parameter $\kappa \in [0, 1]$ is a reduced-form representation of the degree of product market competition. The first (second) indicator function captures the fact that the firm's own (the competitor's) investment is only possible of it (the competitor) has a sufficiently high cash balance. The polar case of $\kappa = 1$ implies therefore that the product market is so competitive that the $v_i = I_i$ and the NPV of the investment is zero, whereas $\kappa = 0$ means that firms operate in perfectly segmented markets.[9] Second, if only one firm has sufficient cash reserves to invest but the competitor does not, its investment not only results in its own positive payoff, v_i, but also in a adverse effect on the value of its competitor. To capture the latter effect, the unilateral investment of the firm reduces the value of its competitor by κp_j, where p_j is the value of the loss incurred by Firm j resulting from Firm i's investment for the polar case of $\kappa = 1$.[10] The net payoffs associated with the arrival of the investment opportunity are summarized in Figure 2.

As a consequence of the dependence of the firm's own payoff on the repurchase decision

[9] There exists a critical level $\hat{\kappa} \in (0, 1)$ above which investment is not optimal for a firm facing financing frictions even if the unconstrained NPV is still positive.

[10] This reduced-form representation can be micro-founded, e.g., with model of investment in capacity or quality in a duopolistic setting.

of its competitor, share repurchase trigger $\overline{C}_i^L$ of Firm i as the leader will be a function of its competitor's follower trigger $\overline{C}_j^F$. The problem therefore boils down to finding a Nash equilibrium in the repurchase timing game.

2.2.1 The follower

As standard in the analyzed type of dynamic games, we begin the analysis from calculating the value and the optimal share repurchase policy of the firm that moves as second (the follower). The follower can still benefit from the potential arrival of investment opportunity, for which it will have the sole access (hence the associated valuation v_i). The firm is also not threatened by a possible investment of the first firm to repurchase (the leader), as the latter has already depleted its cash balance. Consequently, the follower trades off the benefit of delaying the repurchase program associated with its ability to undertake investment with the cost of maintaining a relatively high cash balance. Given that the leader has already distributed cash through its own repurchase program, the position of the follower is therefore analogous to the one of a single firm in a non-strategic setting. The value of Firm i as the follower, $V_i^F(C_i)$, where

$$V_i^F(C_i) = \begin{cases} V_i^{F(1)}(C_i) & C_i \in [0, I_i) \\ V_i^{F(2)}(C_i) & C \in [I_i, \overline{C_i}] \end{cases} \tag{16}$$

satisfies therefore the following ODE

$$rV_i^F(C_i) = \mu_i \frac{\partial V_i^F(C_i)}{\partial C_i} + \frac{1}{2}\sigma_i^2 \frac{\partial^2 V_i^F(C_i)}{\partial C_i^2} + \mathbf{1}_{C_i > I_i} \lambda \left[v_i + V_i(C_i) - V_i^F(C_i) \right], \tag{17}$$

subject to the following boundary conditions:

$$
\begin{aligned}
V_i^{F(1)}(0) &= W_i(C_i^*) - C_i^* - \phi_i, && (18) \\
V_i^{F(2)}(\overline{C}_i) &= W_i(C_i^*) + \overline{C}_i^F - C_i^* - \psi_i, && (19) \\
\lim_{C_i \to I_i} V_i^{F(1)}(C_i) &= V_i^{F(2)}(I_i), && (20) \\
\lim_{C_i \to I_i} \frac{\partial V_i^{F(1)}}{\partial C_i} &= \left. \frac{\partial V_i^{F(2)}}{\partial C_i} \right|_{C_i = I_i}, && (21) \\
\left. \frac{\partial V_i^{F(2)}}{\partial C_i} \right|_{C_i = \overline{C}_i^F} &= 1. && (22)
\end{aligned}
$$

All five boundary conditions correspond to the conditions of the non-strategic case analyzed in Section 2.1.2. What needs emphasizing at this point is that the follower's optimal repurchase trigger $\overline{C}_i^F$ does not depend on the leader's (lower) threshold $\overline{C}_j^L$. This implies that the followers's reaction function is, in the relevant interval, flat.

2.2.2 The leader

We can now derive the value and the optimal timing of initiating a share repurchase program of the firm that engages in the program first (the leader). Given that its competitor still holds a sufficiently high cash balance, Firm i as the leader does not benefit fully from a potentially arriving investment opportunity as its net payoff from investment can only be $(1 - \kappa)(v_i - I_i)$. In addition, when deciding to disburse cash through the stock repurchase program, it also takes into account the possibility of acquiring an investment project in its aftermath by the industry peer, which would be associated with the negative payoff κp_i. Therefore, its value, $V_i^L(C_i)$, where

$$
V_i^F(C_i) = \begin{cases} V_i^{L(1)}(C_i) & C_i \in [0, I_i) \\ V_i^{L(2)}(C_i) & C \in [I_i, \overline{C_i}] \end{cases} \qquad (23)
$$

satisfies the following ODE:

$$rV_i^L(C_i) = \mu_i \frac{\partial V_i^L(C_i)}{\partial C_i} + \frac{1}{2}\sigma_i^2 \frac{\partial^2 V_i^L(C_i)}{\partial C_i^2} + \mathbf{1}_{C_i > I_i} \lambda \left[(1-\kappa) v_i + V_i(C) - V_i^L(C_i) \right], \tag{24}$$

subject to the following boundary conditions:

$$\begin{aligned}
V_i^{L(1)}(0) &= W_i(C_i^*) - C_i^* - \phi_i, && (25)\\
V_i^{L(2)}(\overline{C}_i) &= W_i(C_i^*) + \overline{C}_i^L - C_i^* - \psi_i - \underbrace{\kappa p_i \Gamma\left(\overline{C}_i^L; I_j, \overline{C}_j^F\right)}_{\text{PV effect of competitor's project}}, && (26)\\
\lim_{C_i \to I_i} V_i^{L(1)}(C_i) &= V_i^{L(2)}(I_i), && (27)\\
\lim_{C_i \to I_i} \frac{\partial V_i^{L(1)}}{\partial C_i} &= \left.\frac{\partial V_i^{L(2)}}{\partial C_i}\right|_{C_i = I_i}, && (28)\\
\left.\frac{\partial V_i^{L(2)}}{\partial C_i}\right|_{C_i = \overline{C}_i^L} &= 1 - \kappa p_i \left.\frac{\partial \Gamma}{\partial C_i}\right|_{C_i = \overline{C}_i^L}. && (29)
\end{aligned}$$

where $\Gamma(C_i; \underline{C}_j, \overline{C}_j)$ is given by (B.8).

The value-matching condition (25) as well as conditions (27) and (28) ensuring the continuity and differentiability of the value function at a reversible threshold I_i correspond to the respective conditions in Section 2.2.1. Value matching condition (26) reflects the additional, strategic cost borne by the leader upon initiating its repurchase program. The last component of (26) is the expected reduction in the firm value resulting from a potential investment by the follower after the leader's cash reserves become depleted upon the initiation of the program. It is a product of the degree of erosion of the firm's value conditional on the follower's investment, κp_i, and the probability-weighted discount factor Γ reflecting the present value of \$1 received upon the arrival of the follower's investment opportunity $\frac{\lambda}{r+\lambda}$ multiplied by the annuity-like correction factor capturing both the timing of the follower's own payout or need to refinance (which ends the competitive threat) and the possibility of it having insufficient cash reserves (i.e., $C_j < I_j$) when the opportunity arrives. Condition (26) also implies that the leaders's reaction function is upward sloping, that is, the repurchase thresholds in the relevant region are strategic complements. Finally, optimality condition (29) requires that the strategic benefit of delaying repurchase program should be taken into account, which results in the marginal value of cash at the repurchase threshold being greater than 1.

[...]

2.3 Equilibrium strategies

Having derived optimal policies for both firms as functions of their opponent's strategy (reaction functions) in Sections 2.2.2 and 2.2.1, we are in position to derive the endogenous firm roles and equilibrium values of $\overline{C}_1^*$ and $\overline{C}_2^*$, that is those that are best responses to the peer's optimal strategy (i.e., $\overline{C}_1(\overline{C}_2)$ and $\overline{C}_2(\overline{C}_1)$). It can be shown (see the discussion below) that the firm with a lower non-strategic (i.e., the follower's) stock repurchase trigger becomes the leader. The equilibrium values are obtained from the intersection of reaction functions $\overline{C}_1(C_2)$ and $\overline{C}_2(C_1)$.[11] Figure 4 depicts firm's reaction functions in a scenario where firm's differ with respect to the value of the project v_i (with $v_2 > v_1$).

It can be seen from Figure 4 that reaction functions of both firms intersect above the 45-degree line (which corresponds to Firm 1 becoming the leader) if and only if Firm's 1 non-strategic repurchase trigger $\overline{C}_1^F$ reaches the 45-degree line for a lower value of C than $\overline{C}_2^F$ (recall that $C_2 = sC_1$). Therefore, a straightforward comparison of non-strategic (i.e., follower) triggers allows to determine (endogenous) firm roles in the equilibrium.

[Please insert Figure 4 about here]

[...]

[11](*** We will have to say something more on equilibrium selection/robustness.***)

3 Comparative statics

[...]

We provide comparative statics results for the stock repurchase thresholds ($\overline{C}_1$ and $\overline{C}_2$), the expected time until the follower's payout (which is proportional to $\overline{C}_2/s - \overline{C}_1$), the strength of the peer effect ($\overline{C}_1 s/\overline{C}_2$), as well as the amounts of cash distributed by both firms through their repurchase programs ($\overline{C_{11}} - C_1^*$ and $\overline{C_{22}} - C_2^*$. The strength of the peer effect, $\overline{C}_1 s/\overline{C}_2$, is measured as the ratio of the repurchase threshold of the leader to that of the follower. It ranges from 0 to 1, with its value of 0 implying that the follower firm does never repurchase and $\overline{C}_2^F \to \infty$), and 1 meaning that the leader's repurchase decision is instantaneously followed by that of the follower.

The effect of a change of parameter θ on the strength of the peer effect measured as the gap R between the repurchase thresholds of the leader and the follower can be decomposed as follows:

$$\begin{aligned} \frac{dR}{d\theta} &= \underbrace{\frac{\partial \overline{C}_2}{\partial \theta}}_{\substack{\text{Direct effect of}\\ \text{follower}}} - \left[\underbrace{\frac{d\overline{C}_1}{d\overline{C}_2} \frac{\partial \overline{C}_2}{\partial \theta}}_{\text{Strategic effect}} + \underbrace{\frac{\partial \overline{C}_1}{\partial \theta}}_{\substack{\text{Direct effect}\\ \text{of leader}}} \right] \\ &= \frac{\partial \overline{C}_2}{\partial \theta} \left[1 - \frac{d\overline{C}_1}{d\overline{C}_2} \right] - \frac{\partial \overline{C}_1}{\partial \theta}. \end{aligned} \tag{30}$$

Eq. (30) indicates that the sign of the relationship between model parameter θ and the strength of the peer effect R may differ from that of its effect on a non-strategic threshold $\overline{C}_2$ for two reasons. First, a parameter change also affects directly the leader threshold $\overline{C}_1$. Second, any change to follower trigger $\overline{C}_2$ resulting from the parameter change affects trigger $\overline{C}_1$ and, hence, the strength of the peer effect R. As long as the repurchase thresholds are strategic complements (and we demonstrate that they are for a given order of repurchase initiations) and the parameter change affect both triggers (weakly) in the same direction, the peer effect is either more muted or has the opposite sign from the effect of the parameter change on the non-strategic repurchase threshold.

[...]

3.1 Empirical predictions

Based on the extensive numerical simulations, we are able to make the following empirical predictions:

- $\partial R/\partial \kappa < 0$, that is, the peer effect is weakened by the degree of product market competition. This outcome is driven by the fact that the profitability of the leader's project decreases with the degree of competition, whereas the follower's optimal response is unaffected by it. As a result, the entire peer effect comes from a lower repurchase threshold of the leader.
- $\partial R/\partial \phi_2 < 0$, that is, the peer effect is weakened by the firm's own financial constraints.
- $\partial R/\partial \psi_2 < 0$, that is, the peer effect is weakened by the firm's stock illiquidity.

  [...]

[...]

Tables [...] also provide the results for the expected time until the peer's payout and the size of repurchase program. [...]

4 Empirical evidence

[...]

5 Conclusions

We develop a liquidity management-based model of strategic stock repurchases by two firms anticipating the arrival of an investment opportunity and facing product market competition. We derive equilibrium stock repurchase policies of both firms and demonstrate that repurchase timings, once the roles of firms are determined, are generally strategic complements, that is, a later initiation of a competitor's repurchase program generally delays the firm's own repurchase decision.

Furthermore, we show that the distance between the repurchase triggers (or, the strength of the peer effect) is a combination of the firm's non-strategic policies and also a function of the strategic effect of the follower's threshold on the leader's repurchase trigger.

A number of the model's empirical predictions have been supported with a regression analysis based on a large sample of Compustat firms. Competition, financing constraints and stock illiquidity weaken the peer effect, whereas (industry) profitability strengthens it. The effect of competition is shown to be mitigated by greater financing constraints but is generally exacerbated by higher growth opportunities, profitability and volatility.

All in all, product market considerations and ability to respond to competitors' capital investment are first-order determinants of the observed inter-firm dynamics of corporate stock repurchase decisions.

A Discount factors and annuity formulae

First, we observe that the present value of \$1 received upon hitting the share repurchase trigger $\overline{C}$ before exhausting the cash balance for a current level of cash equal to C is given by (cf. Dixit (1993)):

$$\overline{\Lambda}(\overline{C},0;C) \equiv E\left[e^{-rT_{\overline{C}}}\mathbf{1}_{\{T_{\overline{C}}<T_0\}}|C\right] = e^{\left(\overline{C}-C\right)\left(\frac{\mu}{\sigma^2}+a\right)}\frac{e^{2aC}-1}{e^{2a\overline{C}}-1}, \tag{A.1}$$

where T_y is the stopping time at realization y of process (1) and

$$a \equiv \sqrt{\left(\frac{\mu}{\sigma^2}\right)^2+\frac{2r}{\sigma^2}}. \tag{A.2}$$

Similarly, we define the present value of \$1 received upon when cash balance is exhausted before $\overline{C}$ is hit as

$$\underline{\Lambda}(\overline{C},0;C) \equiv E\left[e^{-rT_0}\mathbf{1}_{\{T_{\overline{C}}>T_0\}}|C\right] = e^{-C\left(\frac{\mu}{\sigma^2}+a\right)}\frac{e^{2a\left(C-\overline{C}\right)}-1}{e^{-2a\overline{C}}-1}. \tag{A.3}$$

Now, we can write (for simplicity, we drop the parameters of $\overline{\Lambda}(.)$ and $\underline{\Lambda}(.)$)

$$V(C) = \overline{\Lambda}(C)\left[\frac{(\overline{C}-C^*)r}{r}-\psi\right]-\underline{\Lambda}(C)\left[\frac{C^*r}{r}+\phi\right]+\left[\overline{\Lambda}(C)+\underline{\Lambda}(C)\right]V(C^*), \tag{A.4}$$

where $V(C^*)$ is simply obtained by substituting C^* for C in (A.4). Consequently, $V(C)$ can be expressed as

$$\begin{aligned} V(C) &= \overline{\Lambda}(C)\left[\frac{(\overline{C}-C^*)r}{r}-\psi\right]-\underline{\Lambda}(C)\left[\frac{C^*r}{r}+\phi\right] \\ &+ \left[\overline{\Lambda}(C)+\underline{\Lambda}(C)\right]\frac{\overline{\Lambda}(C^*)\left[\frac{(\overline{C}-C^*)r}{r}-\psi\right]-\underline{\Lambda}(C^*)\left[\frac{C^*r}{r}+\phi\right]}{1-\overline{\Lambda}(C^*)-\underline{\Lambda}(C^*)}, \end{aligned} \tag{A.5}$$

which is equivalent to (8) with

$$\overline{\Theta}(0,\overline{C};C) \equiv \frac{\overline{\Lambda}(C)\left[1-\underline{\Lambda}(C^*)\right]+\overline{\Lambda}(C^*)\underline{\Lambda}(C)}{1-\overline{\Lambda}(C^*)-\underline{\Lambda}(C^*)}, \text{ and} \tag{A.6}$$

$$\underline{\Theta}(0,\overline{C};C) \equiv \frac{\underline{\Lambda}(C)\left[1-\overline{\Lambda}(C^*)\right]+\overline{\Lambda}(C)\underline{\Lambda}(C^*)}{1-\overline{\Lambda}(C^*)-\underline{\Lambda}(C^*)}. \tag{A.7}$$

B Present value factor associated with competitive threat

The present value $\Gamma(\overline{C},\underline{C};C)$ of \$1 received upon Poisson arrival with rate λ conditional on it occurring before hitting either the upper trigger $\overline{C}$ or 0 as well as C lying outside interval

$(0, \underline{C})$ when the Poisson shock occurs, or

$$\Gamma(\overline{C}, \underline{C}; C) \equiv E\left[e^{-rT_\lambda}\mathbf{1}_{\{T_\lambda < \min\{T_{\overline{C}}, T_0\} \wedge C \geq \underline{C}\}} | C\right], \tag{B.1}$$

where T_λ ($T_{\overline{C}}$, T_0, respectively) denotes the time of the Poisson arrival (the first time process C hits the threshold $\overline{C}$ and 0, respectively), and where

$$\Gamma^(C) = \begin{cases} \Gamma^{(1)}(C) & C \in [0, \underline{C}) \\ \Gamma^{(2)}(C) & C \in [\underline{C}, \overline{C}] \end{cases} \tag{B.2}$$

solves the following ODE

$$r\Gamma(C) = \mu\Gamma'(C) + \frac{1}{2}\sigma^2\Gamma''(C) + \lambda\left[\mathbf{1}_{C \geq \underline{C}} - \Gamma(C)\right], \tag{B.3}$$

subject to

$$\Gamma^{(1)}(0) = 0, \tag{B.4}$$

$$\lim_{C \to \underline{C}} \Gamma^{(1)}(C) = \Gamma^{(2)}(\underline{C}), \tag{B.5}$$

$$\lim_{C \to \underline{C}} \Gamma^{(1)}_C(C) = \Gamma^{(2)}_C(\underline{C}), \tag{B.6}$$

$$\Gamma^{(2)}(\overline{C}) = 0. \tag{B.7}$$

$\Gamma(\overline{C}, \underline{C}; C)$ can be written explicitly as

$$\Gamma(C) = \begin{cases} \frac{\lambda}{r+\lambda} f_0(-f_1 + f_2 - f_3)\left(e^{\beta_1^\lambda C} - e^{\beta_2^\lambda C}\right) & C \in [0, \underline{C}) \\ \frac{\lambda}{r+\lambda}\left[1 - f_0\left((f_1 - f_2 + f_5)e^{\beta_1^\lambda C} + (-f_1 - f_3 + f_4)e^{\beta_2^\lambda C}\right)\right] & C \in [\underline{C}, \overline{C}] \end{cases} \tag{B.8}$$

where

$$f_0 = \frac{e^{-(\beta_1^\lambda + \beta_2^\lambda)\underline{C}}}{(\beta_1^\lambda - \beta_2^\lambda)\left[e^{(\beta_1^\lambda - \beta_2^\lambda)\overline{C}} - 1\right]e^{\beta_2^\lambda \overline{C}}}, \quad f_1 = (\beta_1^\lambda - \beta_2^\lambda)e^{(\beta_1^\lambda + \beta_2^\lambda)\underline{C}}, \quad f_2 = \beta_1^\lambda e^{\beta_1^\lambda \underline{C} + \beta_2^\lambda \overline{C}},$$

$$f_3 = \beta_2^\lambda e^{\beta_2^\lambda \underline{C} + \beta_1^\lambda \overline{C}}, \quad f_4 = \beta_1^\lambda e^{\beta_1^\lambda(\underline{C} + \overline{C})}, \quad f_5 = \beta_2^\lambda e^{\beta_2^\lambda(\underline{C} + \overline{C})}.$$

Parameters β_1^λ and β_1^λ are the positive and negative root, respectively, of the following equation:

$$r + \lambda - \mu x - \frac{1}{2}\sigma^2 x^2 = 0. \tag{B.9}$$

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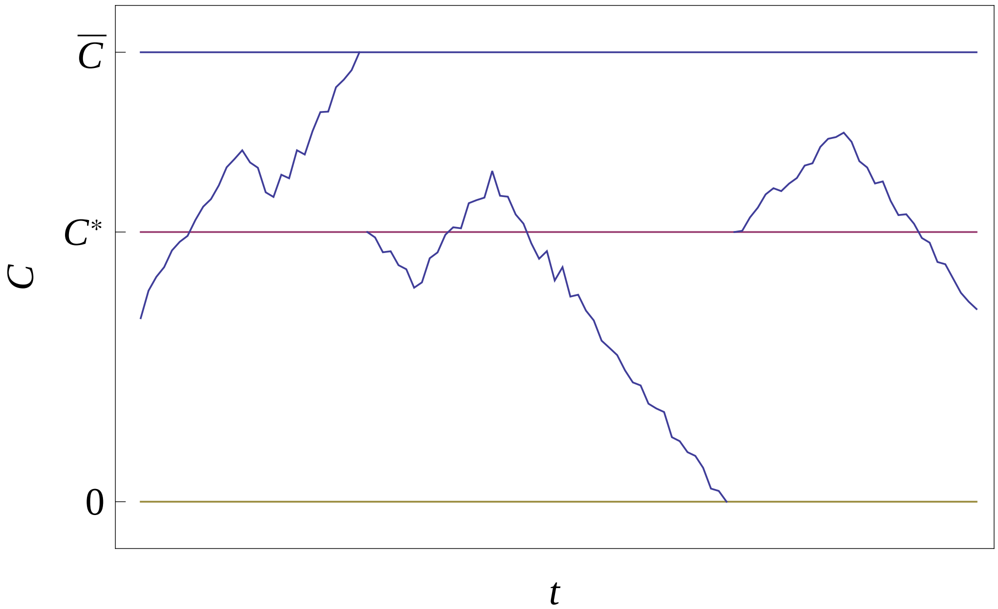

FIGURE 1
An illustration of the optimal share repurchase and refinancing policies. Barrier C^* corresponds to the target cash balance, whereas barrier $\overline{C}$ (zero) corresponds to the cash balance that triggers stock repurchase (equity issuance).

Firm 1 \ Firm 2	Sufficient liquidity	Liquidity too low
Sufficient liquidity	$(1-\kappa)(v_1 - I_1), (1-\kappa)(v_2 - I_2)$	$v_1 - I_1, -\kappa p_2$
Liquidity too low	$-\kappa p_1, v_2 - I_2$	$0, 0$

FIGURE 2
Payoffs associated with the arrival of investment opportunity as a function of the firm's own and its competitor's liquidity position.

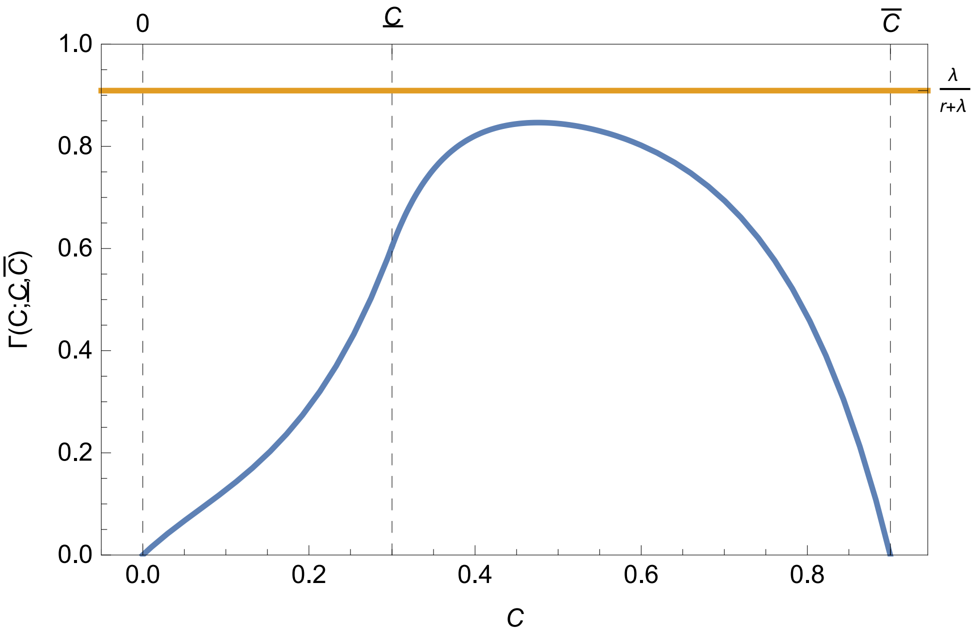

FIGURE 3
Discount factor $\Gamma\left(C;\underline{C},\overline{C}\right)$ (blue line) reflecting the present value of \$1 received upon Poisson arrival with rate λ conditional on it occurring before hitting either the upper trigger $\overline{C}$ or 0 as well as C lying outside interval $(0,\underline{C})$ when the Poisson shock occurs, for the set of parameter values: $r=0.05, \mu=0.04, \sigma=0.1, \lambda=0.5, \underline{C}=0.3$ and $\overline{C}=0.9$. As a benchmark, the unconstrained (i.e., standard) discount factor associated with a Poisson arrival $\lambda/(r+\lambda)$ is also plotted (orange line).

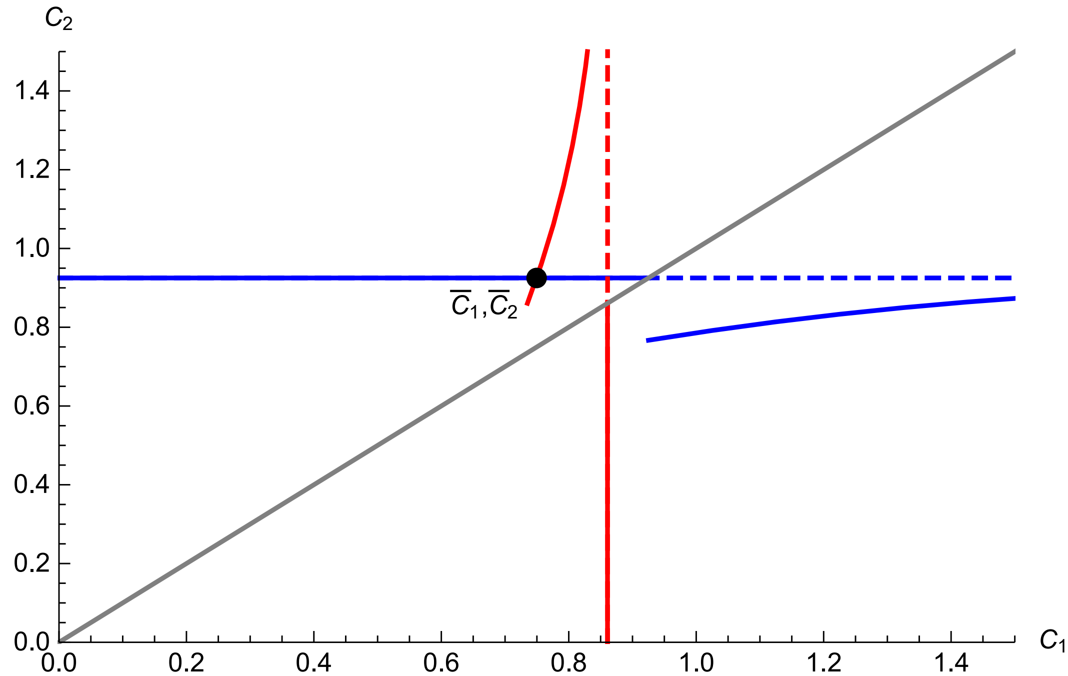

FIGURE 4
Reaction functions (red line for Firm 1 and blue for Firm 2) and the equilibrium share repurchase strategies $(\overline{C}_1, \overline{C}_2)$ for the set of parameter values: $r = 0.05, \mu = 0.04, \sigma = 0.1, \phi = 0.15, \psi = 0.05, \lambda = 0.1, v_1 = 0.1, l_1 = 0.1, v_2 = 0.12, l_2 = 0.12,$ and $\kappa = 0.75$.