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# Efficient Signalling with Dividends and Investments

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ABSTRACT

An efficient signalling equilibrium with dividends and investments or, equivalently, dividends and net new issues of stock is constructed, and its properties are identified. Because corporate insiders can exploit multiple signals, the efficient mix must minimize dissipative costs. In equilibrium, many firms both distribute dividends and deviate from first-best investment. Also, the impact of dividends on stock prices is positive. By contrast, the announcement effect of new stock is negative for firms with private information primarily about assets in place and positive for firms with inside information mainly about opportunities to invest.

FOR YEARS DIVIDENDS HAVE puzzled financial economists. Only recently have signalling models begun to yield results consistent with the extensive empirical evidence on dividends.[1] Although much work remains to be done, recent papers have provided partial answers to some perplexing questions. Why do corporate insiders distribute dividends rather than repurchase stock? Why do firms distribute dividends and sometimes almost simultaneously sell stock to finance new investment?[2] In other words, why do dividends persist despite their dissipative costs, including both adverse personal taxes and any investment foregone to finance dividends internally? Why do widows, retirees, and other investors with a demand for current cash purchase stocks paying dividends? Finally, why do announced increments in dividends increase stock prices?

Despite these recent results, many financial economists continue to view with caution predictions from models of signalling with dividends. Why, they ask, should corporate insiders signal with dividends when less costly mechanisms can convey credible private information to the market? True, dividends do maximize

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[1] Theoretical models include Bhattacharya [5, 6], Hakansson [17], John and Williams [24], and Miller and Rock [36]. Empirical evidence appears in Aharony and Swary [1], Asquith and Mullins [2], Charest [9], Fama and Babiak [15], Patell and Wolfson [43], Pettit [45], and other papers too numerous to cite.

[2] As documented in Kalay and Shimrat [27], unregulated firms sell stock only infrequently.

the wealth of current shareholders in signalling equilibria, but only when outside investors ignore other, pertinent information. For example, security analysts most likely can infer any private information implicit in dividends from either a firm's announced investment or its net new issues of securities. Moreover, these other sources of information may not impose on stockholders such large dissipative costs as the incremental personal taxes on dividends. In other words, dividends have not been shown to be an efficient signal competitive with other technologies for conveying credible private information to the market.[3]

Multiple signals have potentially important implications for the empirically most significant prediction of signalling models: announcement effects. Any model with a single costly signal must have a positive announcement effect; otherwise, insiders would never signal. Thus, the major empirical implication of any univariate model depends critically on the somewhat arbitrary initial selection of the signal. For example, adverse taxes produce for dividends a positive announcement effect if corporate insiders can signal solely with dividends. Similarly, foregone projects with positive net present value (NPV) produce for stock repurchases a positive announcement effect whenever dividends substitute perfectly for stock repurchases.[4] However, do these positive announcement effects persist when dividends and repurchases can serve simultaneously as separate signals? More generally, what are the announcement effects in more realistic problems with multiple signals, each subject to a different structure of dissipative costs?

A partial answer to these questions appears in this paper. Here, firms can signal simultaneously with dividends and investments or, equivalently, dividends and either sales or repurchases of stock. Because outside investors can infer all private information solely from net new issues of stock, corporate insiders need not signal with dividends. Assuming that insiders act to maximize their current stockholders' wealth, dividends can then exist in equilibrium only if dividends and new issues collectively communicate all private information at lower cost than new issues alone. In short, dividends must be efficient to survive in this signalling equilibrium. Nevertheless, as shown here, firms with valuable inside information distribute dividends in the efficient signalling equilibrium. Moreover, these firms minimize the dissipative costs of credible communication by modifying their investment and thereby their net new issues of stock. In turn, this can alter the announcement effects of new issues familiar from univariate models, but not the announcement effects of dividends.

This efficient signalling equilibrium has the following properties. In general, corporate insiders signal with both dividends and investment or, equivalently, dividends and net new issues. If asymmetric information arises primarily from

[3] Ofer and Thakor [42] study a similar problem of efficient signalling with dividends and repurchases, one time period, one private attribute, and two types of firms. However, their firms can invest at the margin only in financial assets with zero net present value, whereas, in this model, firms invest only in real assets. Given a single time period and a single private attribute, it is straightforward to show that, with marginal investments in both financial and real assets, firms optimally never hold financial assets. Vishwanathan [52] studies a somewhat different problem with multiple signals and a single attribute.

[4] These points appear, respectively, in John and Williams [24] and Miller and Rock [36].

assets in place, then insiders optimally reject projects with positive NPV. By contrast, if asymmetric information arises mainly from opportunities to invest, then insiders accept projects with negative NPV. Because the sources and uses of corporate funds must match, projects with positive (negative) NPV at the margin produce for net new issues negative (positive) costs at the margin. Consequently, the announcement effects of net new issues must be positive in the former case and negative in the latter. By contrast, dividends are always costly at the margin; hence, their announcement effects must always be positive. Thus, this paper generalizes recent results familiar from John and Williams [24], Miller and Rock [36], and Myers and Majluf [40].

This equilibrium can be interpreted roughly as follows. In John and Williams [24], a signalling equilibrium with dividends exists because the marginal benefit of reducing dilution differs across firms with different private values. By this argument, many signalling equilibria exist—in fact, one for each fixed level of corporate invesment. Among all such equilibria, the efficient signalling equilibrium can then be selected by endogenizing investment. This equilibrium entails either excessive or foregone investment, depending on the marginal cost of modifying investment as affected by the source of asymmetric information. If more valuable firms have lower marginal costs of reducing investment than less valuable firms, then the managers of the former firms optimally forego projects with positive NPV. However, if the more valuable firms have higher marginal costs, then their insiders optimally invest in projects with negative NPV. In either case, insiders in the more valuable firms reduce their signalling costs and thereby raise their stockholders' wealth. In this manner, the efficient signalling equilibrium produces for stockholders the maximum wealth among all possible separating equilibria.

The paper is organized as follows. In the model presented in Section I, insiders choose their corporate dividend, investment, and new issue of stock to maximize their current stockholders' wealth. Firms sell no bonds, pay no taxes, and incur no transaction costs. Investors, by contrast, pay taxes on dividends at a single, constant marginal rate, but no transaction costs when trading securities. Also, outsiders observe all components of firms' sources and uses of funds but not their complete production technologies. Instead, this latter information can be communicated credibly to outsiders only through a firm's aggregate dividend, investment, or new issues of stock. In this context, both signalling equilibria and the efficient signalling equilibrium are defined.

Next, the efficient signalling equilibrium is analyzed by transforming the signalling problem into an equivalent nonmimicry problem. In this equivalent problem, insiders in more valuable firms choose their corporate dividends and investment to maximize their current stockholders' wealth, subject to a nonmimicry constraint. This constraint stipulates that insiders in less valuable firms have no incentive to mimic the dividend and investment of the more valuable firms and thereby realize in the market their higher stock prices. The nonmimicry problem with two types of firms is studied in Section II. Empirical implications are discussed in Section III, and theoretical extensions are sketched in Section IV. In the Appendix, the nonmimicry problem is first derived from the original signalling problem, and its solution is then characterized. This derivation covers a much more general problem with a finite number of signals and a single attribute.

## I. The Model

For simplicity, the representative firm is financed exclusively with equity.[5] At the start of the model's single time period, corporate insiders—senior management and the board of directors—choose an aggregate dividend $D$ and investment $I$. Conditional on its current cash $C$, the firm finances this dividend and investment by selling (buying) in the capital market $N$ shares of stock at the ex-dividend price per share $p_e$. Collectively, the firm's sources and uses of funds must satisfy the constraint:

$$D + I = C + S, \tag{1}$$

where $S \equiv p_e N$ represents the total market price of new stock (repurchases if negative). Because the market determines the ex-dividend price per share $p_e$, conditional on corporate actions, while the firm's actions must satisfy constraint (1), insiders can control directly only the incremental stock $S$ and not the net new shares $N$.

Information about the firm's future cash inflow is asymmetric. To specify this asymmetry as simply as possible, suppose that each firm can be one of two types. Denote by $j$, with $j \in \{1, 2\}$, the value of a single state variable affecting the firm's present value. For example, $j$ may measure its insiders' forecasted return on either assets in place or, alternatively, opportunities to invest. The firm's attribute $j$ is private information; it is known to insiders but not observed directly by outsiders. In particular, insiders observe the private attribute $j$ before picking both their corporate dividend $D$ and investment $I$, whereas outsiders must attempt to infer $j$ from the firm's sources and uses of funds. By contrast, all other aspects of the subsequent problem are common knowledge. Most notably, the current cash $C$ is fully revealed to outsiders through costless corporate audits.

After one period, the representative firm realizes its final cash inflow. Insiders then liquidate the firm and distribute all proceeds pro rata to its stockholders. Assuming that stockholders pay no personal taxes on liquidating dividends, the firm has a terminal value equal to its final cash inflow.[6] Denote by $F_j(I)$ the present value of this future cash inflow, as calculated by insiders conditional on their corporate investment $I$ and private information $j$. For most of the paper, this present value has the expositionally convenient form $F_j(I) = a_j + b_j G(I)$, with the positive constants $a_j$ and $b_j$. Given this simple technology, the firm's private attribute $j$ affects only its present value of assets in place $a_j$ and the coefficient $b_j$ in its present value of opportunities to invest. By construction of the private attribute $j$, more valuable firms have higher present values: $a_1 \leq a_2$ and $b_1 \leq b_2$, with at least one strict inequality. Finally, for all feasible investments $I \geq 0$, the function $G$ is continuously differentiable, strictly increasing, and

[5] For the relationship between debt and dividends, see, for example, John and Kalay [22, 23] and the references cited therein.

[6] Under the Internal Revenue Code, Section 331, liquidating dividends commonly generate only capital gains or losses for the recipient.

strictly concave, with the corner conditions $G(0) = 0$ and $G'(0) = \infty$. Although unessential for the subsequent results, the present value $F_j(I)$ can be interpreted as insiders' conditional expectation of their firm's future cash inflow, computed with respect to a state-price density function. This density function uniquely prices stocks in a complete market without taxes on capital gains.[7]

Dividends can be costly. When stockholders receive dividends, they must immediately pay personal taxes on their dividends at a constant marginal rate $t$, satisfying $0 \leq t < 1$. Because, by assumption, investors in a homogeneous clientele hold the representative firm's stock, its aggregate dividend $D$ then produces the total dissipative cost $tD$. Alternatively, $tD$ can be interpreted as the clientele's cost of avoiding taxes on dividends through a trading scheme, as in Miller and Scholes [37].[8] Finally, to highlight the costs of signalling with dividends, stockholders are presumed to pay no taxes on capital gains. Similarly, firms pay no taxes on corporate income, capital gains, or undistributed profits.[9]

To preclude arbitrage around the ex-dividend date, stock prices, cum- and ex-dividend, must be related. For analytical simplicity, suppose that a dividend's announcement date, ex-date, and payment date occur simultaneously at the beginning of the model's single time period.[10] In this case, if the representative firm has outstanding $Q$ shares immediately before the new issue of $N$ shares, then its cum-dividend price per share $p$ must equal its ex-dividend price per share $p_e$ plus the after-tax dividend per share $(1 - t)D/Q$:

$$p = p_e + (1 - t)D/Q. \tag{2}$$

Here, this simple specification is possible because all investors are taxed at the same marginal rate $t$.[11]

Conditional on the firm's sources and uses of funds, current stockholders solve their personal portfolio problems and thereby determine, in part, their demand for the firm's stock. In turn, this demand determines stockholders' aggregate net sales of the firm's shares or, equivalently, their demand for liquidity $L$. Generally, the demand $L$ depends on personal utilities for consumption, attitudes toward risk, and opportunities to invest. Rather than deriving this demand under specific, restrictive assumptions, the demand $L$ is specified simply as a differential function of the firm's total dividend $D$ and aggregate cum-dividend market price $P \equiv pQ$, which is decreasing in the dividend $D$: $L_D < 0$. Here, the subscript $D$ denotes a partial derivative. Also, to preclude problems of unanimity, all stockholders are presumed to have identical demands for liquidity $L$. In other words, the firm's

[7] See Ross [48].

[8] Bhattacharya [5] focuses on transaction costs. Miller and Rock [36] study the costs of foregone corporate investment. Direct empirical evidence of taxes on dividends appears in Peterson, Peterson, and Ang [44]. Indirect, conflicting empirical evidence appears in Black and Scholes [7], Elton and Gruber [14], Hess [20], Kalay [26], Litzenberger and Ramaswamy [28, 29], Miller and Scholes [38], and Poterba and Summers [46].

[9] In practice, the Accumulated Earnings Tax, Internal Revenue Code, Sections 531–37, is rarely applied to large corporations. See, for example, Miller and Scholes [37, pp. 333–35].

[10] In practice, the announcement date precedes by about one week the ex-dividend date, which precedes by about one month the payment date.

[11] In this model, the single tax rate $t$ on dividends precludes the problems discussed in Kalay [26] and evident empirically in Eades, Hess, and Kim [13].

homogeneous clientele of investors first observes the sources and uses of funds (1), correctly calculates the resulting market price $P$, and then rebalances its portfolios conditional on both the dividend $D$ and price $P$.[12] Moreover, when rebalancing their portfolios, these investors pay at least part of their personal taxes on dividends from sources of cash other than sales of the firm's stock.

To interpret this simple specification of stockholders' demand for liquidity, consider some special cases. If investors rebalance their portfolios when stock prices change, then the demand for liquidity $L$ increases in the market price $P$. Alternatively, if stockholders minimize their tax liabilities by realizing capital losses and deferring capital gains, then the demand $L$ decreases in the price $P$. Next, fix the market price $P$ and focus on the dividend $D$. If investors wish to maintain balanced portfolios, then their investments in the firm and thereby their total cash flow from the firm $L + tD$, measured before taxes, cannot depend on the dividend $D$. In this case, stockholders' demand for liquidity $L$ must decrease in the dividend $D$: $L_D < 0$. However, even if the demand $L$ does not decrease in the dividend $D$, the subsequent signalling equilibrium still exists, albeit with different properties, as discussed in the next section.

After solving their personal portfolio problems and determining their demand for liquidity, current stockholders buy or sell shares. In general, stockholders can trade the firm's shares either cum- or ex-dividend. However, with the single tax rate on dividends $t$ and the resulting no-arbitrage condition (2), all stockholders are indifferent between trading shares cum- or ex-dividend. Hence, for analytical simplicity, suppose that stockholders first receive the dividend $D$, pay their personal taxes $tD$, and then sell on personal account $M$ shares (negative with purchases) at the ex-dividend price per share $p_e$. To meet their demand for liquidity $L(D, P)$, current stockholders must sell (buy) the number of shares $M$ that satisfies

$$L(D, P) = (1 - t)D + p_e M. \tag{3}$$

Finally, to simplify the subsequent analysis, suppose that current stockholders retain at least some shares: $M < Q$.

By assumption, corporate insiders always act to maximize their current stockholders' wealth. They accomplish this by maximizing their stockholders' cash inflow $(1 - t)D + p_e M$, computed net of personal taxes on dividends, plus the present value of their remaining equity in the firm. After sales (purchases) of $M$ outstanding shares on personal account and $N$ new shares on corporate account, initial stockholders retain in the firm the fractional ownership $(Q - M)/(Q + N)$. Consequently, conditional on their corporate cash $C$ and private information $j$, insiders then select the dividend $D$, investment $I$, and new stock

[12] Here, the demand function for liquidity $L$ is imposed exogenously because stockholders' optimal response to observed corporate actions is not modeled explicitly. Nevertheless, the demand for liquidity $L$ can be interpreted as stockholders' reaction function in a Stackelberg game. In this game, insiders would rationally anticipate outsiders' reaction function $L$ when selecting their optimal dividend and investment. Next, outsiders would observe insiders' actions, rebalance their portfolios, and thereby buy or sell securities. Outsiders' resulting sales (purchases) of the firm's shares would then satisfy (3) with the demand for liquidity $L[D, P(D, I)]$.

$S$ to solve the problem:[13]

$$\max_{D,I,S} \left\{(1 - t)D + p_e M + \frac{Q - M}{Q + N} F_j(I)\right\}, \tag{4}$$

subject to the financial constraints (1) through (3) and the inequalities $D$, $I$, $S \geq 0$. Denote by $D_j$, $I_j$, and $S_j$ the optimal dividend, investment, and new stock from (4).

In this problem, corporate insiders maximize their stockholders' wealth. Specifically, they select the dividend $D$, investment $I$, and new stock $S$ to maximize the firm's present value to its current shareholders, conditional on the pricing function $P$. This has two implications. First, insiders have no intrinsic preference in (4) for revealing private information. Instead, truthful signals may or may not follow incidentally from a solution to (1) through (4), depending on the pricing function $P$. Second, with two corporate controls, $D$ and $I$, but only one private attribute $j$, the dividend $D$ need not reveal any information to outsiders. In fact, as subsequently shown, investment $I$ alone can credibly convey all private information to the market. Hence, if insiders optimally distribute a dividend, then this dividend must maximize their stockholders' wealth, despite its dissipative cost.

Problem (1) through (4) can be rewritten as follows. Again treat the net new stock $S$ as the slack variable in the firm's sources and uses of funds (1). Insert constraints (1) through (3) into the maximand (4), and delete the independent variable $S$. This produces the equivalent maximand:

$$U^j(D, I, P) \equiv L(D, P) + \frac{P - L(D, P)}{P + tD + I - C} F_j(I). \tag{5}$$

Also, with $S$ as the slack variable in (1), the firm's pricing function $P$ depends only on its dividend $D$ and investment $I$. In this case, the previous problem simplifies as follows: select the dividend $D_j$ and investment $I_j$ that solve

$$\max_{D,I\geq 0} U^j[D, I, P(D, I)]. \tag{6}$$

Given the solution to (6), the firm's optimal new stock $S_j$ then follows from its sources and uses of funds (1).

Insiders' maximand (5) measures the firm's true value to its current shareholders, conditional on an arbitrary pricing function $P$. In general, (5) holds under either symmetric or asymmetric information. Given symmetric information—that is, when both insiders and outsiders observe the private attribute $j$—this true value (5) simplifies as follows. Denote by $V^j(D, I)$ the firm's true

[13] For a discussion of this maximand (current stockholders' wealth), see Myers and Majluf [40]. This specification differs sharply from signalling models in which insiders maximize only market values, as in Bhattacharya [5], or managers' compensation, as in Harris and Raviv [18]. A special case of this maximand appears in John and Williams [24]. To compare the maximand (4) with the specification in Miller and Rock [36], insert (1) through (3) into the maximand (4) to produce the equivalent expression: $kP + (1 - k)F$ with $k \equiv (M + N)/(Q + N)$. Given (1) through (3), this requires a demand for liquidity satisfying $L = kP + (1 + k)(tD + I - C)$. In Miller and Rock [36], the weight $k$ is assumed to be constant.

value to its current shareholders under symmetric information. Were outsiders to observe the firm's private attribute $j$ and thereby its true value $V^j$, then competition in the capital market would produce a market price $P$ equal to $V^j$. Inserting the value $V^j$ into (5) yields the functional equation:

$$V^j(D, I) = U^j[D, I, V^j(D, I)]. \tag{7}$$

From the definition of $U^j$ in (5), this equation has at most two real roots: $V^j(D, I) = L[D, V^j(D, I)]$ and

$$V^j(D, I) = C + F_j(I) - I - tD. \tag{8}$$

If, as previously assumed, current stockholders retain some shares ($M < Q$), then the firm's true value $V^j$ to these stockholders must exceed their proceeds, net of personal taxes, from current sales of shares, $L$. In this case $V^j$ uniquely satisfies (8). In other words, the firm's true value to its current shareholders must equal its net present value $C + F_j(I) - I$ minus the dissipative cost of signalling with dividends, $tD$.

In this context, a signalling equilibrium is defined as follows. In a competitive capital market, both insiders and outsiders regard the pricing function $P$ as fixed by market forces. Conditional on the pricing function $P$, liquidation function $L$, and the private information $j$, insiders select their firm's optimal dividend $D_j$ and investment $I_j$ to maximize their stockholders' wealth in (6). In turn, outsiders both buy new shares and trade outstanding shares, believing correctly that the firms' total market price, measured cum-dividend, equals its true value in (7):[14]

$$P(D_j, I_j) = V^j(D_j, I_j). \tag{9}$$

In short, a signalling equilibrium $\{D_j, I_j, P(D_j, I_j)\}$ must satisfy both the incentive-compatibility condition (6) and the competitive-rationality condition (9). As in Riley [47], this informational equilibrium is an extension of the Walrasian model of price taking.

Many signalling equilibria may exist. Specifically, with the single private attribute $j$, many combinations of the two corporate controls, $D_j$ and $I_j$, may satisfy both (6) and (9). Accordingly, among all such combinations, each supported by a pricing function $P$, investors collectively pick the optimal pricing function. In practice, investors pick this function $P$ by establishing a procedure or mechanism for determining prices. Assuming that this mechanism must predate any private information, the optimal pricing function maximizes stockholders' ex ante wealth. Given the fractions of firms $\pi_j$ with attributes $j = 1, 2$, the optimal pricing function then solves the following problem:[15]

$$\max_{P \geq 0} \textstyle\sum_{j=1}^{2} \pi_j U^j[D_j, I_j, P(D_j, I_j)], \tag{10}$$

subject to (6) and (9). The resulting optimal schedule of dividends, investment, and prices $\{D_j^*, I_j^*, P(D_j^*, I_j^*)\}$ is called the efficient signalling equilibrium. In

[14] The competitive-rationality condition (9) can be generated from competitive bidding for the firm's stock by at least two outside investors. In this case, the pricing function $P$ is outsiders' reaction function to insiders' dividend $D$ and investment $I$.

[15] This concept of efficiency is especially appropriate if stockholders have diversified portfolios and no prior information. On the latter issue, see Holmström and Myerson [21].

other words, among all feasible signalling equilibria, defined by (6) and (9), the efficient equilibrium must maximize stockholders' ex ante wealth or welfare. Here, this interpretation holds because market mechanisms typically evolve sufficiently slowly so that the pricing function becomes institutionalized long before corporate insiders can collect private information about any particular firm.

## II. Efficient Signalling Equilibrium

The previous signalling problem can be analyzed by transforming it into an equivalent problem, labeled the nonmimicry problem. In this latter problem, insiders in each firm choose their corporate dividend and investment to maximize their stockholders' wealth, subject to a nonmimicry constraint. When this constraint holds, insiders in the next, less valuable firm have no incentive to mimic the more valuable firm, match its dividend and investment, and thereby mislead outside investors. In this section, the nonmimicry problem is presented and its solution characterized.[16] In the Appendix, the nonmimicry problem is derived from the original signalling problem, (6), (9), and (10), for the general use of $N$ signals and one attribute, and its properties are characterized.

The derivation of the nonmimicry problem can be sketched as follows. From the Revelation Principle, the incentive-compatibility condition (6) for credible signals can be replaced by an equivalent truth-telling condition. The latter constraint requires that insiders prefer to report their corporate attribute $j$ directly and truthfully to outsiders, who correctly price the firm in (9), and then confirm their report with a vector of signals selected by firms with the reported attribute. Thus, insiders in the more valuable firms 2 must select a vector of signals that induces insiders in the less valuable firms 1 not to mimic the more valuable firms by reporting the attribute 2 and then matching their signals. By contrast, insiders in the more valuable firms have no incentive to mimic the less valuable firms. Consequently, the weighted average of corporate values attains its maximum value in (10) when insiders in each type of firm select the signals that maximize their true corporate value subject to the nonmimicry constraint on each firm 2.

Accordingly, focus first on the nonmimicry problem facing insiders in the more valuable firms. Because, by previous assumption, the private attribute $j$ orders the present value functions of the two types of firms, it also orders the true value functions: $V^1 < V^2$. If outside investors are to pay the higher, correct price for firm 2, then they must be able to distinguish between the two firms. For this to be possible, insiders in firm 2 must select some dividend $D_2$ and investment $I_2$ that insiders in firm 1 have no incentive to mimic. Thus, insiders in firm 2 must pick some pair $D_2$ and $I_2$ satisfying the nonmimicry constraint:

$$U^1[D_2, I_2, V^2(D_2, I_2)] \leq U^1[D_1^*, I_1^*, V^1(D_1^*, I_1^*)] = V^1(D_1^*, I_1^*) \equiv v_1^*, \quad (11)$$

where the equality follows from (7). Were insiders in firm 1 to mimic firm 2,

[16] Milgrom and Roberts [35] study a similar problem with two firms and two signals: advertising and price. Besanko and Thakor [4] solve a signalling problem with two subsequent states of the world, three signals, and a continuum of borrowers, each characterized by a single private attribute.

match both its dividend $D_2$ and investment $I_2$, and thereby realize in the market a price equal to the higher value $V^2(D_2, I_2)$ correct for firm 2, then the stock of firm 1 would have the true value to its current shareholders indicated on the left side of (11). By contrast, if insiders in firm 1 do not mimic firm 2 but choose their distinct, optimal dividend $D_1^*$ and investment $I_1^*$, then outsiders correctly identify the firm. In this case, competition in the capital market produces for firm 1 a price equal to its correct value $v_1^*$ on the right side of (11). Whenever inequality (11) holds, insiders in firm 1, who act in the interest of their current shareholders, have no incentive to mimic firm 2. This optimal dividend $D_1^*$ and investment $I_1^*$ are characterized in more detail below.

When the nonmimicry constraint holds, insiders in each type of firm face a relatively simple problem. Given (11), outside investors can identify correctly each firm and price each appropriately in (8). In this case, insiders in each firm $j$ choose the dividend $D_j^*$ and investment $I_j^*$ that maximize the firm's true value (8) to its current shareholders. Specifically, insiders in firm $j$ solve the problem:

$$\max_{D_j, I_j \geq 0} \{C + F_j(I_j) - I_j - tD_j\}. \tag{12}$$

For the more valuable firms $j = 2$, this maximization is constrained by inequality (11). For the less valuable firms $j = 1$, there is no nonmimicry constraint.

In part, each firm's optimal dividend and investment can be characterized by contrasting it with the corresponding solution under symmetric information. Were information symmetric, then outsiders could always observe each firm's private attribute and thereby its true value. In this case, competition in the capital market would produce for each firm $j$ a market price $P(D, I)$, conditional on its dividend $D$ and investment $I$, equal to its true value $V^j(D, I)$ in (8). Anticipating this, insiders in firm $j$ would choose their corporate dividend and investment to maximize their firm's true value (8). In other words, insiders would solve problem (12) without the nonmimicry constraint (11). Denote by $D_j^o$ and $I_j^o$ the resulting optimal dividend and investment for firm $j$. From (12), the firm optimally pays no dividend under symmetric information: $D_j^o = 0$. Also, from the previously assumed properties of the function $G$, the optimal investment under symmetric information $I_j^o$ uniquely satisfies the familiar first-order condition:

$$1 = F_j'(I_j^o). \tag{13}$$

Given the strict concavity of $F_j$, this first-order condition holds if and only if insiders in firm $j$ invest in all projects with non-negative NPV.

The solution to the nonmimicry problem has the following properties. Because insiders in the less valuable firms need not worry about mimicry, they solve (12) without constraint (11). For firm 1, insiders then choose the dividend and investment optimal under symmetric information:

$$D_1^* = 0, \qquad I_1^* = I_1^o. \tag{14}$$

In other words, each less valuable firm distributes no dividend and invests in all projects with non-negative NPV. This combination of dividends and investment both maximizes current stockholders' wealth and reveals to outsiders the firm's true identity.

For the more valuable firms, the optimal solution may or may not entail signalling costs. If for firm 2 the optimum under symmetric information satisfies the nonmimicry constraint (11), then its insiders also maximize their corporate value (12) by paying no dividend and investing in all projects with non-negative NPV: $D_2^* = 0$ and $I_2^* = I_2^o$. This solution holds if the two firms have sufficiently different optimal investments $I_j^o$ that yield sufficiently close corporate values $V^j(0, I_j^o)$. In this case, the efficient signalling equilibrium is costless.

In other cases, the efficient signals are costly. If the symmetric optimum for firm 2 violates the nonmimicry constraint (11), then the optimal dividend $D_2^*$ and investment $I_2^*$ maximize the corporate value (12) subject to a binding nonmimicry constraint (11). Assuming that the set of non-negative dividends and investments satisfying the nonmimicry constraint has a nonempty interior, then the corner condition $G'(0) = \infty$ always induces some investment: $I_2^* > 0$. As a result, insiders in firm 2 either pay no dividends, $D_2^* = 0$, and signal solely with investment, $I_2^* \neq I_2^o$, or signal with dividends, $D_2^* > 0$, and possibly also with investment. In the latter case, the first-order conditions from (11) and (12) imply that

$$-L_D(F_2 - F_1)(F_2' - 1) = t(V^2 - L)\left(\frac{a_2}{a_1} - \frac{b_2}{b_1}\right)\frac{a_1 b_1 G'}{F_2} \tag{15}$$

for the separable technology, $F_j = a_j + b_j G$, $j = 1, 2$. Both cases are considered below.

Focus first on the interior solution. Given the previously assumed liquidation function $L$ with $L_D < 0$, the inequality $F_1 < F_2$, and the strict concavity of $F_2$, the necessary condition (15) implies that the optimal investment $I_2^*$ and the symmetric optimum $I_2^o$ satisfy

$$I_2^* < I_2^o \quad \text{if and only if} \quad \frac{a_2}{a_1} > \frac{b_2}{b_1}. \tag{16}$$

Relative to the optimal corporate investment under symmetric information $I_2^o$, insiders in firm 2 invest either less or more, depending primarily on the source of asymmetric information. When $a_2/a_1 > b_2/b_1$, the private attribute has a greater relative impact on the present value of assets in place than the present value of opportunities to invest. Because the asymmetry of information arises primarily from assets in place, insiders optimally reduce their corporate investment relative to the symmetric optimum and thereby forego projects with positive NPV. By contrast, when the reverse, strict inequality holds, the asymmetry of information arises mainly from opportunities to invest. In this second case, insiders optimally invest more than their symmetric optimum and select projects with negative NPV.

This interior solution is illustrated in Figures 1 and 2. In Figure 1, the inequality $a_2/a_1 > b_2/b_1$ applies. Here, the lower, concave curve is a level curve from the maximand (12) of firm 2, while the upper curve is the locus of points along which the nonmimicry constraint (11) for firm 2 is binding. Points above the nonmimicry constraint are feasible; points below are not. As indicated in Figure 1, the

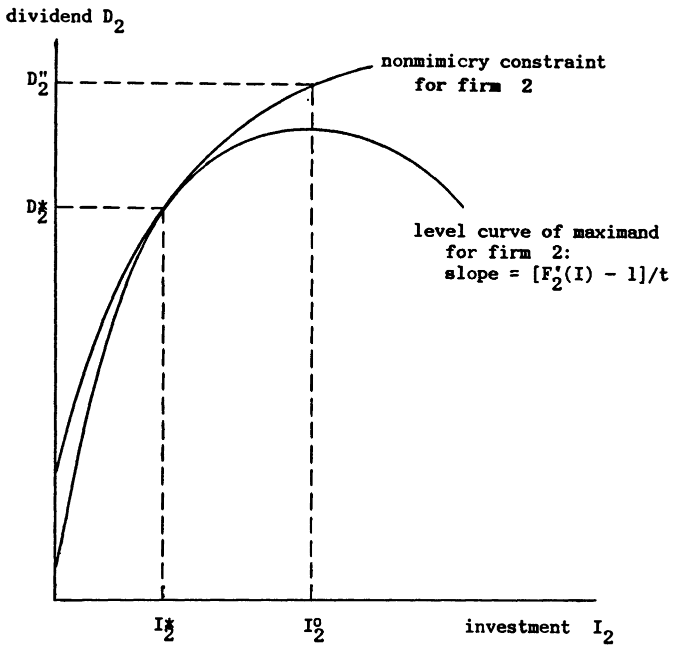


**Figure 1.** Optimal dividend and investment for firm 2 when $a_2/a_1 > b_2/b_1$. Stockholders in firm 2 are indifferent between any dividend $D_2$ and investment $I_2$ along the level curve $v_2 = V^2(D_2, I_2)$, with the slope $(F_2' - 1)/t$. The nonmimicry constraint for firm 2 is binding along the upper curve $v_1^* = U^1[D_2, I_2, V^2(D_2, I_2)]$. For firm 2, the optimal dividend and investment are $D_2^*$ and $I_2^*$. The corresponding optimum under symmetric information is 0 and $I_2^o$, with $F_2'(I_2^o) = 1$. Given $a_2/a_1 > b_2/b_1$ at $D_2 = D_2^*$ and $I_2 = I_2^*$, firm 2 invests less than its symmetric optimum: $I_2^* < I_2^o$.

two curves are tangent at the efficient signalling pair $(D_2^*, I_2^*)$, satisfying both the binding nonmimicry constraint (11) and the first-order condition (15). Consequently, insiders in firm 2 optimally forego projects with positive NPV: $I_2^* < I_2^o$.

Figure 1 has the following interpretation. If insiders in firm 2 signal solely with dividends and thereby invest at their symmetric optimum, $I_2^* = I_2^o$, then they must distribute the dividend $D_2''$ in Figure 1. Any smaller dividend induces mimicry; any larger dividend imposes superfluous costs on their stockholders. However, if insiders in firm 2 reduce their corporate investment from $I_2^o$ to $I_2^*$, then they can cut their dividend from $D_2''$ to $D_2^*$, increase their stockholders' wealth, and still preclude mimicry. Here, this modified signal is superior because the marginal cost of reducing investment is less for firm 2 than firm 1 whenever $a_2/a_1 > b_2/b_1$. In other words, signalling solely with the dividend $D_2''$ is feasible but inefficient. Instead, firm 2 optimally foregoes some projects with positive NPV and signals with both dividends and investment: $0 < D_2^* < D_2''$ and $0 < I_2^* < I_2^o$.

For the reverse inequality, the solution is illustrated in Figure 2. In this second case, the inequality $a_2/a_1 < b_2/b_1$ holds. Again, insiders in firm 2 can signal solely with the dividend $D_2''$ and then invest at their symmetric optimum $I_2^o$. As before, this signalling equilibrium is feasible but inefficient. For firm 2, the marginal cost of increasing its investment is less than the corresponding cost for firm 1. Thus, insiders in firm 2 can increase their corporate investment from $I_2^o$ to $I_2^*$ and cut their dividend from $D_2''$ to $D_2^*$. This both increases their stockholders' wealth and precludes mimicry by insiders in firm 1. In this second case, firm 2 optimally adopts projects with negative NPV and signals with both dividends and investment: $0 < D_2^* < D_2''$ and $0 < I_2^o < I_2^*$.

Finally, insiders in the more valuable firm may signal solely with either dividends or investment. Specifically, insiders signal solely with dividends, $D_2^* > 0$, and invest to maximize NPV, $I_2^* = I_2^o$, whenever $a_1 b_2 = a_2 b_1$. Alternatively, if the level curve of the maximand has a slope that, as illustrated in Figure 3, everywhere exceeds the slope of the nonmimicry constraint, then insiders optimally pay no dividend: $D_2^* = 0$. Without a dividend, $D_2^* = 0$, the firm's optimal investment $I_2^*$ is then determined by the binding nonmimicry constraint (11). Depending on the two firms' technologies $F_1$ and $F_2$, this investment $I_2^*$ can either exceed or not exceed the symmetric optimum $I_2^o$. For the case illustrated in Figure 3, the optimal solution satisfies $I_2^* > I_2^o$. These results are summarized in the following proposition.

PROPOSITION 1: *For firm* 1, *the optimal dividend* $D_1^*$ *and investment* $I_1^*$ *satisfy* (14). *For firm* 2, *the optimal dividend* $D_2^*$ *and investment* $I_2^*$ *satisfy the nonmimicry*

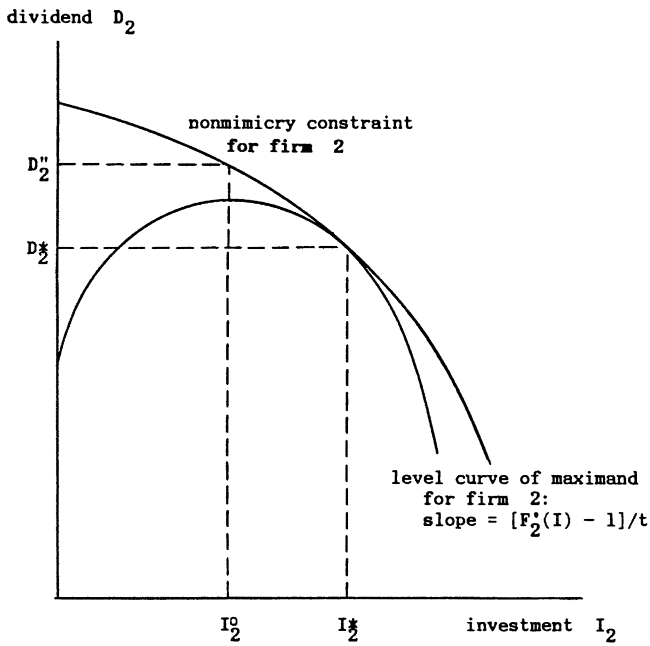


**Figure 2.** Optimal dividend and investment for firm 2 when $a_2/a_1 < b_2/b_1$. Stockholders in firm 2 are indifferent between any dividend $D_2$ and investment $I_2$ along the level curve $v_2 = V^2(D_2, I_2)$, with the slope $(F_2' - 1)/t$. The nonmimicry constraint for firm 2 is binding along the upper curve $v_1^* = U^1[D_2, I_2, V^2(D_2, I_2)]$. For firm 2, the optimal dividend and investment are $D_2^*$ and $I_2^*$. The corresponding optimum under symmetric information is 0 and $I_2^o$ with $F_2'(I_2^o) = 1$. Given $a_2/a_1 < b_2/b_1$ at $D_2^*$ and $I_2^*$, firm 2 invests more than its symmetric optimum: $I_2^* > I_2^o$.

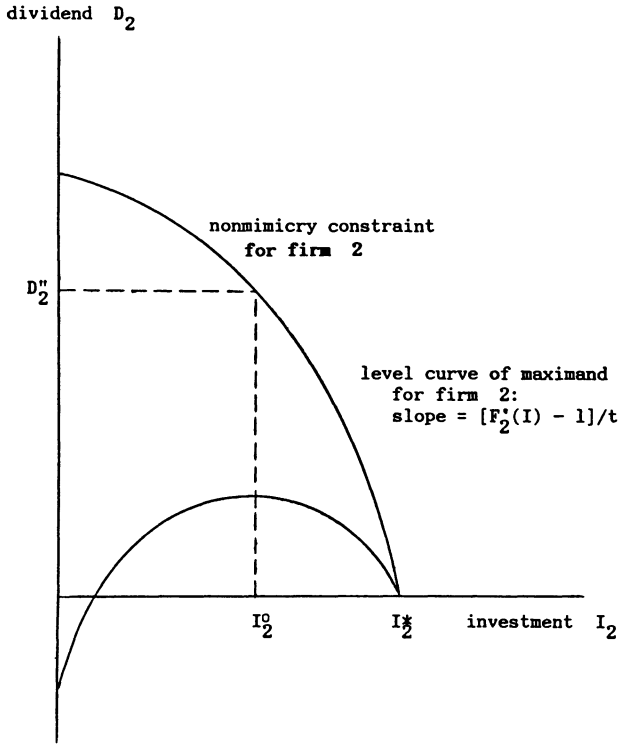


**Figure 3.** Optimal dividend and investment for firm 2 when $D_2^* = 0$. Stockholders in firm 2 are indifferent between any dividend $D_2$ and investment $I_2$ along the level curve $v_2 = V^2(D_2, I_2)$, with the slope $(F_2' - 1)/t$. The nonmimicry constraint for firm 2 is binding along the upper curve $v_1^* = U^1[D_2, I_2, V^2(D_2, I_2)]$. For firm 2, the optimal dividend and investment are 0 and $I_2^*$, respectively. The corresponding optimum under symmetric information is 0 and $I_2^o$ with $F_2'(I_2^o) = 1$. In this case, firm 2 invests more than its symmetric optimum: $I_2^* > I_2^o$.

*constraint* (11) *with equality and either* $D_2^* = 0$ *or the first-order condition* (15). *In the latter case, firm* 2 *invests less than its symmetric optimum* $I_2^o$ *if* $a_2/a_1 > b_2/b_1$ *and more if* $a_2/a_1 < b_2/b_1$.

In fact, these results are more general than previously indicated. To see this, recall the assumption from Section I that stockholders' demand for liquidity $L$ decreases in the aggregate dividend $D$: $L_D < 0$. If, instead, this inequality is reversed, $L_D > 0$, then the inequality in (16) is also reversed, while all other results are unchanged. Alternatively, if $L_D = 0$, then insiders in firm optimally pay no dividend and, instead, signal solely with investment, again as illustrated in Figure 3. Finally, without the separable technology, $F_j = a_j + b_j G$, the previous results again apply with the sign of the elasticity $d\log(F_2/F_1)/dI$, evaluated at $I_2^*$, substituting for the sign of the difference $a_1 b_2 - a_2 b_1$.

The above analysis focuses on the efficient signalling equilibrium and ignores possible pooling equilibria. This focus is motivated as follows. First, pooling equilibria are unstable. By a minor modification of Theorem 5 in Riley [47], any uninformed investor can make offers to buy the stock of initially indistinguishable firms, conditional on both dividends and investment, that induce only insiders in the more valuable firms to accept. These investors then make profits, impose losses on other investors, and thereby unravel any pooling equilibrium. Also, when at least one signal is productive, pooling equilibria can be Pareto inferior to signalling equilibrium, despite the dissipative costs. In the efficient signalling equilibrium, the revelation of inside information improves the initial allocation of capital across firms relative to a pooling equilibrium. On average, this increases the firms' initial market values and improves the welfare of well-diversified investors.

## III. Empirical Implications

The efficient signalling equilibrium of this paper has several empirical implications. Some implications are familiar from previous, more restrictive models; others are new. Among the novel results, some help to explain existing empirical evidence, while still others offer opportunities for future work.[17]

All cross-sectional announcement effects are easily calculated for the efficient signalling equilibrium. In this equilibrium, the pricing function $P$ is uniquely determined only at two points: $(D_j^*, I_j^*)$, $j = 1, 2$. Accordingly, from among the many pricing functions that can support the equilibrium, choose a differentiable function $P$. Next, compute the necessary conditions from the original signalling problem (6) and rearrange the results. This produces the second proposition.

PROPOSITION 2: *For firm* 2, *the announcement effects for dividends and investment are*

$$P_D = t\,\frac{P - L}{tD + I + L - C}, \tag{17}$$

*whenever* $D_2^* > 0$, and

$$P_I = (1 - F_2')\,\frac{P - L}{tD + I + L - C}, \tag{18}$$

*evaluated at the optimal signals* $D_2^*$ *and* $I_2^*$.

To interpret these announcement effects, focus first on dividends. By previous assumption, current stockholders retain some shares, so that $L < V^2 = P$ in equilibrium. Also, suppose that stockholders prefer higher stock prices $P$, other things equal: $U_P > 0$ in (5). In this case, the denominator in (17) is positive, so that the announcement effect for dividends (17) is positive. In other words, announced increases (decreases) in dividends increase (decrease) stock prices, measured cum-dividend. Were (17) nonpositive, then corporate insiders could increase their stockholders' wealth by eliminating all dividends, much as in Bhattacharya [5], John and Williams [24], and Miller and Rock [36]. Here,

[17] Many empirical studies document dividend announcement effects. A partial list includes Aharony and Swary [1], Asquith and Mullins [2], Charest [9], Patell and Wolfson [43], and Pettit [45].

however, unlike previous papers, the positive announcement effect persists despite the redundancy of dividends. That is, dividends need not convey any inside information not revealed by investment. Instead, to survive in the efficient signalling equilibrium, only the optimal combination of dividends and investment must convey inside information to the market and do so at minimum cost.

The announcement effect for incremental investment (18) is only slightly more complicated. From the strict concavity of the function $G$, the announcement effect (18) is negative if $a_2/a_1 > b_2/b_1$, positive if $a_2/a_1 < b_2/b_1$, and zero otherwise. In the first case, the negative announcement effect, $P_I < 0$, induces optimal underinvestment, $I_2^* < I_2^o$, which minimizes signalling costs in the efficient signalling equilibrium. Similarly, whenever $a_2/a_1 < b_2/b_1$, the positive announcement effect induces the optimal overinvestment, which again minimizes signalling costs in the efficient signalling equilibrium. Without this announcement effect, insiders would be induced to pick all projects with non-negative NPV, $I_2^* = I_2^o$, and to signal solely with dividends.

The above announcement effects apply to dividends and investment, each with the other held constant. However, for empirical work, the analogous results with dividends $D$ and new stock $S \equiv p_e N$ may be more appropriate. For these results, insert the firm's sources and uses of funds (1) into its maximand (5), eliminate investment $I$, and then compute from (6) the first-order conditions for dividends $D$ and new stock $S$. Finally, rearrange terms, producing for firm 2 the two announcement effects:

$$P_D = (t + F_2' - 1)\frac{P - L}{tD + I + L - C}, \tag{19}$$

whenever $D_2^* > 0$, and

$$P_S = (1 - F_2')\frac{P - L}{tD + I + L - C}, \tag{20}$$

evaluated at the optimal dividend $D_2^*$ and net new stock $S_2^*$. Again, the announcement effect of dividends (19) is positive; otherwise, $D_2^*$ could not be positive. Also, net new stock (20) has the same impact as incremental investment (18).

The announcement effects for incremental investment (18) and new stock (20) have signs that depend on the parameters in the firms' present value functions. Whenever $a_2/a_1 > b_2/b_1$, the announcement effects are negative; otherwise, both are non-negative. To interpret these inequalities, recall that the intercept $a_j$ represents the present value of assets in place, while the coefficient $b_j$ reflects the rate of return on opportunities to invest. With this interpretation, the ratio of intercepts $a_2/a_1$ exceeds the ratio of coefficients $b_2/b_1$ if the asymmetric information arises mainly from assets in place rather than opportunities to invest; otherwise, the reverse inequality holds. Consequently, with asymmetric information produced primarily by assets in place, the announcement effects (18) and (20) are negative; otherwise, both are non-negative.

What are the empirical implications of these announcement effects? Collectively, the comparative statics (17) through (20) characterize the optimal pricing function $P$, evaluated at the optimal dividend $D_2^*$ and investment $I_2^*$ of the more valuable firm 2. If these properties are to hold for all possible values of the private attributes of the two firms 1 and 2, then (17) through (20) must hold for all possible prices $P$. In this case, the above comparative statics have immediate implications for intertemporal announcement effects. Outsiders cannot distinguish between firms before observing their sources and uses of funds; hence, competition forces investors to price identically their stock. From (17) and (19), announced increases in dividends must then increase stock prices. Also, from (18) and (20), the intertemporal announcement effects of investment and net new issues must reflect firms' source of asymmetric information.

How might this dependence of intertemporal announcement effects on the source of asymmetric information be reflected in the data? Because inside information is not directly observable, an additional hypothesis is required. Accordingly, construct two samples of stock prices: one from large, mature firms and the other from small, rapidly growing firms. If the former firms have valuable assets in place and limited opportunities to invest, then their inside information should arise mainly from existing assets. Also, if the latter firms have few assets in place and valuable opportunities to invest, then their private information should come primarily from current opportunities. In other words, the sample of mature firms should on average satisfy the inequality $a_2/a_1 > b_2/b_1$, whereas the sample of growth firms should on average satisfy the reverse inequality. Therefore, if the hypothesis about mature versus growth firms is correct, then the comparative statics (18) and (20) and thereby the intertemporal announcement effects for investment and net new issues should be negative for the former sample and positive for the latter.

For large, established firms, the announcement effect of new stock has been documented in detail. Specifically, for stocks listed on the New York and American Stock Exchanges (that is, seasoned stocks of mainly large, mature firms), new issues almost always reduce market prices, sometimes dramatically so. Recent empirical evidence includes Asquith and Mullins [3], Dann and Mikkelson [11], Masulis and Korwar [32], Schipper and Smith [50], and others. Similarly, repurchases raise stock prices, as documented in Dann [10], Masulis [31], and Vermaelen [51]. These announcement effects are consistent with the comparative statics (20). For smaller, more rapidly growing firms, indirect evidence consistent with (20) appears in Schipper and Smith [50]. Specifically, new stock issued by subsidiaries, classified by the authors as growth firms, increases the market price of the parent firm. However, no specific model of the announcement effect, such as (20), has been tested empirically for any group of firms.[18]

Other empirical implications here are familiar from previous, more restrictive models. As in John and Williams [24], many firms distribute dividends, while others do not. Also, of those firms distributing dividends, some simultaneously sell new shares. Finally, new stocks paying dividends are purchased in equilibrium, other things equal, by clienteles with a demand for current cash—for

[18] Announcement effects of investment are documented in McConnell and Muscarella [33] and Mishra [39]. Indirect empirical evidence appears in Brittain [8, p. 113], Darling [12], Michaelsen [34], and Rozeff [49]. Also, the distinction between mature and growth firms appears in the traditional literature—e.g., Graham and Dodd [16].

example, widows, senior citizens, and financial institutions. These phenomena, puzzling under symmetric information with taxes, have been discussed extensively in the nonacademic literature.[19]

Similar results appear in other recent papers. Most notably, Miller and Rock [36] introduce investment as their sole signal, fix exogenously external financing, and then determine dividends residually through firms' sources and uses of funds. By assumption, each firm's current cash is inside information, while its production technology and thereby its distribution of future cash inflows are common knowledge. Also, without taxes, dividends substitute perfectly for stock repurchases. In the resulting signalling equilibrium, almost every firm invests less than its optimum under symmetric information, distributes a larger residual dividend, and thereby reveals its current cash. Also, Myers and Majluf [40] show that insiders optimally forego projects with positive present value if their firms must sell risky securities to raise the required capital.

## IV. Conclusion

In this paper, an efficient signalling equilibrium with dividends, investment, and net new issues of stock is identified and its properties developed. By assumption, corporate insiders have superior information about a single, valuable attribute: their firm's future return on either assets in place or opportunities to invest. Insiders can convey this information to outsiders through many combinations of dividends and announced investment or, equivalently, dividends and new stock. Given a single private attribute and two independent signals, the efficient mix of dividends and investment must then minimize the dissipative cost of signalling.

In equilibrium, some firms signal with both dividends and investment. For firms paying dividends, the announcement effect of dividends is positive when investment is fixed. However, when dividends are fixed, the announcement effect of investment or, equivalently, net new stock is negative for firms with asymmetric information primarily from assets in place and positive for firms with asymmetric information mainly from opportunities to invest. Managers in the former firms optimally reject projects with positive NPV, while managers in the latter firms accept projects with negative NPV.

Many extensions of this model are possible. For example, dissipative signalling models can be driven by costs other than differential taxes and securities other than common stock. As in Bhattacharya [5], transaction costs incurred by firms when raising external capital can produce a signalling equilibrium. Also, to support sales of corporate bonds or preferred stocks, insiders may optimally distribute dividends, alter investment, thereby raise their firm's stock price, and reduce their stockholders' dilution. Still more realistic models might include clienteles of stockholders categorized by personal tax rates and distinct demands for liquidity. In equilibrium, different clienteles would presumably purchase stocks of identifiable firms, categorized by corporate risks, current cash inflows, and prospective returns on both assets in place and opportunities to invest.

[19] For example, the first phenomenon is discussed in Joy [25, p. 385].

Finally, in a repeated game with reputations, dividends might reveal corporate characteristics, with or without dissipative costs. In a sequential equilibrium, outsiders would recognize the relationship between current dividends and future returns, pay higher prices for stocks with historically higher dividends, other things equal, and thereby induce insiders to smooth dividends over time relative to corporate cash inflows.

## Appendix

In this Appendix, the efficient signalling problem with $N$ signals and a single attribute is solved in two steps. First, the efficient signalling problem is shown to be equivalent to another problem, labeled the nonmimicry problem. Second, the solution to the nonmimicry problem is characterized, a special case of which is identified in Section II.

*Efficient Signalling Problem*: Given the vector of signals $y \in R_+^N$, rewrite the efficient signalling problem, (6), (9), and (10), as follows:

$$\max_{P \geq 0} \sum_{j=1}^{2} \pi_j U^j[y_j, P(y_j)], \tag{A1}$$

subject to the constraints,

$$y_j = \operatorname*{argmax}_{y \geq 0} U^j[y, P(y)], \tag{A2}$$

$$P(y_j) = V^j(y_j), \tag{A3}$$

for both types of firms $j = 1, 2$. The utility function $U$: $R_+^{N+1} \rightarrow R_+$ is continuously differentiable in all arguments with $U_P^j > 0$.

Any feasible scheme $(Y, P)$, consisting of the signalling schedule $Y$: $R_+ \rightarrow R_+^N$ and the pricing function $P$: $R_+^N \rightarrow R_+$, must satisfy both the incentive-compatibility condition (A2) and the competitive-rationality condition (A3). All such feasible schemes $(Y, P)$ are called signalling equilibria, whereas a scheme solving the efficient signalling problem, (A1) through (A3), is called an efficient signalling equilibrium.

Under symmetric information, the competitive-rationality condition (A3) holds for all feasible signals $y \geq 0$. In this case, inserting (A3) into the incentive-compatibility condition (A2) produces the problem:

$$y_j^o \equiv \operatorname*{argmax}_{y \geq 0} U^j[y, V^j(y)], \tag{A4}$$

for firms $j = 1, 2$. Suppose that the solutions to (A4) satisfy $y_1^o \neq y_2^o$.

*Nonmimicry Problem*: From the Revelation Principle, each signalling scheme is equivalent to some direct and truthful scheme. Under these equivalent schemes, insiders report their firm's private attribute directly and truthfully to outsiders. See, for example, Harris and Townsend [19] or Myerson [41]. Because all feasible schemes are defined by the incentive-compatibility condition (A2) and the competitive-rationality condition (A3), an equivalent, direct, and truthful scheme can be constructed as follows. In a direct scheme, insiders in each firm $j \in \{1, 2\}$

report to the market some feasible corporate attribute $k$, $k \in \{1, 2\}$, without knowing the reports of other firms. Conditional on the report $k$ and a pricing function $P$ satisfying the competitive-rationality condition (A3), outsiders then compute the signal $y_k$ and pay for the firm the price $P(y_k) = V^k(y_k)$. For insiders in firm $j$, this direct scheme induces a truthful report $k = j$ if and only if

$$j = \underset{k\in\{1,2\}}{\operatorname{argmax}}\ U^j[y_k,\ V^k(y_k)]. \tag{A5}$$

In other words, truth telling must be incentive compatible.

Next, consider the problem:

$$\max_{y\geq 0} \textstyle\sum_{j=1}^{2} \pi_j U^j[y_j,\ V^j(y_j)], \tag{A6}$$

subject to

$$U^j[y_k,\ V^k(y_k)] \leq U^j[y_j,\ V^j(y_j)], \tag{A7}$$

for both firms $j$ and distinct reports $k \neq j$. The nonmimicry constraints (A7) are equivalent to the previous constraint (A5), which, by the Revelation Principle, is equivalent to the original constraint (A2), with the pricing function $P$ defined by (A3). Also, given the competitive-rationality condition (A3), the maximands (A1) and (A6) are equivalent. Thus, the efficient signalling problem, (A1) through (A3), is equivalent to problem (A6) and (A7). Finally, whenever $U^j[y_j,\ V^j(y_j)] = V^j(y_j)$ as in (7), then (A6) and (A7) simplify accordingly.

Problem (A6) and (A7) has two nonmimicry constraints. Deleting the constraint (A7) with $j = 2$ and $k = 1$ produces the following relaxed problem: solve (A6) subject to the constraint (A7) with $j = 1$ and $k = 2$. In turn, this relaxed problem can be solved recursively as follows: $y_1^* = y_1^o$ and

$$y_2^* \equiv \underset{y\geq 0}{\operatorname{argmax}}\ U^2[y,\ V^2(y)], \tag{A8}$$

subject to the nonmimicry constraint,

$$U^1[y,\ V^2(y)] \leq U^1[y_1^*,\ V^1(y_1^*)] \equiv u_1^*, \tag{A9}$$

for all feasible $j$. Henceforth, problem (A8) and (A9) is called the nonmimicry problem. The remaining nonmimicry condition (A7) with $j = 2$ and $k = 1$ cannot constrain the above solution because insiders in firm 2 prefer $y_2^o$ to $y_1^o$. Also, if firm 1 mimics $y_2^o$, then the resulting pooling equilibrium is unstable (Riley [47], Theorem 5).

*Solution to the Nonmimicry Problem:* The efficient signalling equilibrium can be nondissipative. If the solution $y_2^o$ in (A4) also satisfies constraint (A9), then it must solve the nonmimicry problem, (A8) and (A9). This is the simplest possible case.

Next, focus on the remaining, more complicated case. In this second situation, the solution with symmetric information $y_2^o$ does not satisfy the nonmimicry constraint (A9):

$$U^1[y_2^o,\ V^2(y_2^o)] > u_1^*. \tag{A10}$$

Now, consider the following Kuhn-Tucker problem: find the multipliers $\lambda$ and $\mu$

with $\mu = (\mu_1, \cdots, \mu_N) \geq 0$, such that $y_2^*$ satisfies the stationary conditions for the nonmimicry problem, (A8) and (A9):

$$0 = (U_y^2 + U_P^2 V_y^2) - \lambda(U_y^1 + U_P^1 V_y^2) + \mu, \tag{A11}$$

and

$$0 = \lambda\{U^1[y_2^*, V^2(y_2^*)] - u_1^*\}, \quad 0 = \mu_n y_n^*, \tag{A12}$$

$n = 1, \cdots, N$, as well as the nonmimicry constraint (A9) and the inequality $y_2^* \geq 0$. If $U^1[\cdot, V^2(\cdot)]$ is locally convex at $y_2^*$, then this Kuhn-Tucker problem is equivalent to the nonmimicry problem, (A8) and (A9). However, if $U^1[\cdot, V^2(\cdot)]$ is not convex at $y_2^*$, then a more elaborate argument is required.

In the latter case, suppose that $y_2^*$ satisfies

$$0 = U_y^1 + U_P^1 V_y^2, \tag{A13}$$

with $y_2^* \geq 0$. Were this true, then $y_2^*$ would also solve (A4), as can be seen by comparing the necessary and sufficient conditions for (A4) with (A11). However, this would violate (A10); hence, the nonmimicry solution $y_2^*$ cannot satisfy (A13). In this case, the signal $y_2^*$ satisfies the weak Arrow-Hurwitz-Uzawa constraint qualification. See, for example, Mangasarian [30, pp. 154–55]. As a result, the solution to the nonmimicry problem, (A8) and (A9), also solves the Kuhn-Tucker problem.

The multiplier associated with the nonmimicry constraint (A9) is non-negative. If $\lambda = 0$, then the unique solution to the constraint (A9) and the first-order condition (A11) guarantee that $y_2^* = y_2^o$, violating (A10). Given $\lambda > 0$ and the complementary slackness condition (A12), then the nonmimicry constraint (A9) must be binding.

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