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Archishman Chakraborty
Bilge Yilmaz

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The Wharton School
University of Pennsylvania

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Archishman Chakraborty† Bilge Yılmaz‡

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Abstract

Asymmetric information regarding project prospects causes dilution, leading to adverse selection and inefficiencies in the market for new investments. However, if the market obtains information about the firm over time, issuing callable convertible securities with restrictive call provisions is optimal. Even when the market's information is noisy, such securities can be designed to make the payoff to new claimholders independent of the private information of the manager. The restrictive call provision serves as a commitment device, enabling the manager to call only when the stock price rises in the future. This solves the dilution and adverse selection problem costlessly. The same first–best efficient outcome can also be implemented by issuing floating price and mandatory convertibles.

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†Department of Economics and Finance, Baruch College, CUNY; arch_chakraborty@baruch.cuny.edu.

‡Finance Department, The Wharton School, University of Pennsylvania, 2300 Steinberg-Dietrich Hall, Philadelphia, PA 19104. Email: yilmaz@wharton.upenn.edu. Phone: 215 898-1163. Corresponding author.

1 Introduction

We investigate the classic problem of inefficient under–investment when a manager has superior information about the firm's prospects relative to the market, as in Myers and Majluf (1984). Due to the asymmetry of information, any security issued by the firm is priced in competitive markets at its expected value. This leads to dilution in the claims of the existing owners of the firm, when the manager's information is better than average. Such dilution may lead the manager, acting in the interest of the existing owners, to take the socially inefficient decision of not investing in positive net present value projects.

In this paper we start from the premise that the initial asymmetry of information about the firm's assets in place and investment opportunities is likely to be resolved over time, even though at each date the manager's information is superior to that held in the market. Analyst announcements, future earnings, R&D outcomes, M&A announcements or decisions by regulators are few of the events that may reveal valuable information to the public over time. Our main goal is to use the future imperfect resolution of the initial asymmetry of information and design a security whose value is *independent of the initial private information* of the manager. In equilibrium, the price obtained for such a security in competitive markets will be a 'fair' price from the perspective of the manager, regardless of his private information. As a result, the symmetric information outcome of no dissipation or dilution will be implemented, solving the under-investment problem costlessly.

We show that suitably designed convertible securities can perform such a role, thereby providing a rationale for their common features and practices. In a simple binary state model, we find a callable convertible debt (or preferred stock) contract, with fixed conversion prices and restrictive call provisions, that mitigates adverse selection completely. A convertible can be thought of as equity plus a put option to convert to safer debt (equivalently, debt plus a call option to convert to equity that has greater upside potential). The convertibility feature thus allows investors to choose the kind of security they would like to hold ex-post — the senior debt claim or the junior common stock claim. The callability feature allows the manager to extinguish the put option by forcing early conversion into common stock following good news. Convertibility combined with callability ensures that different types of securities are held, depending on the nature of information that is publicly disclosed.[1]

Since the put option is long–lived and therefore valuable, the manager seeks to extinguish it and force early conversion whenever he is able to. In order to keep the manager honest, the security also has a restrictive call provision that does not allow the manager to call and force conversion unless good information has been revealed to the market and the share price is high enough. This restriction acts

[1] In order to focus on inefficiencies arising out of asymmetric information we abstract away from considerations of tax or clientele effects as well as bankruptcy and financial distress costs. As a result, debt is equivalent to preferred stock in the context of our model. For simplicity we will refer to the senior claim as debt.

as a commitment device, raising the value of the security for new claim-holders, ultimately benefitting the firm and existing claim-holders.

The better the initial information of the manager the higher is the chance that good information will eventually reach the market, raising the stock price and enabling the manager to force conversion. Since the likelihood of being able to force conversion is positively correlated with the manager's initial information, he can choose the conversion ratio and face value such that the expected value of the claims sold is independent of his private information. In short, if the manager thinks that his equity/debt is undervalued by any given amount in the market, he must also think that the option (adjusted for the probability of a conversion forcing call) is overvalued by the identical amount. The ability to extinguish the convertibility option via a conversion forcing call can be thought of as a 'bet' the manager lays with the market that good news will arrive in the future. The market overestimates its expected payoff from this bet whenever it underestimates the expected payoff from the other claims to cash flows sold by the manager.

The symmetric information outcome can also be implemented with floating price convertibles, i.e., convertibles with conversion ratios that depend on publicly observed market values, including mandatory convertibles that are automatically converted into equity. We show this in the context of a general model with an arbitrary number of states where, in addition, the public disclosure of information is endogenous and provided by a self-motivated analyst. In either model, the optimal security has the property that, in equilibrium, the market value of the claims sold is lower when more favorable is public information is later revealed to the market. The better the initial information of the manager the more likely it is that good information will later be revealed to the market, in effect keeping the initial expected value independent of the private information of the manager. Such a security exists as long as the resolution of the initial asymmetry of information occurs with enough fidelity, enabling the manager to costlessly solve the underinvestment problem.

The seminal work of Myers and Majluf (1984) has been followed by a large literature attempting to identify securities that mitigate the dilution and associated underinvestment problem. The paper by Brennan (1986) is the closest in spirit to our work. Brennan points out that a floating-priced convertible security can avoid the adverse selection problem if the conversion price depends on the market price. Such a security is automatically converted into $1/p$ shares, where p is the market price at the time of conversion. Thus, it pays a fixed dollar amount independent of the market price. If the private information of the manager is perfectly reflected in the market price at the time of conversion, then the adverse selection problem can be costlessly solved with such a security. When the manager's private information is imperfectly incorporated into the market price however, issuing such a security leads to dilution and may cause underinvestment. In contrast, we show that first–best efficiency can be achieved with commonly used securities such as a callable convertible bond with a fixed conversion ratio and restrictive call provisions, even when the manager's private information is never perfectly known by the market. We show also that this can be done via floating–price convertibles but provided the market value of the security is decreasing in the share price.

A significant portion of the literature following Myers and Majluf focusses on modes of financing that allow the management to separate by signaling its type and thus solve the under-investment problem. Since separation by signaling quality is typically costly, it creates another source of inefficiency and dissipation in value that might even exceed the dissipation in value caused by dilution.[2] In fact, Nachman and Noe (1994) show that non-dissipative signaling is not possible if the firm is limited to issuing securities with payoffs that are weakly increasing in the underlying cash flows.[3] Conversely, Gibson and Singh (2001) show that costless separation can be achieved when the firm is allowed to issue put warrants, whose payoffs are decreasing in cash flows. Our work shows that the first-best outcome can in fact be implemented in equilibrium, without any signaling or any dissipation in value, using securities with payoffs that are non-decreasing in cash flows. The difference with Nachman and Noe is that the manager is able to utilize the effect of the imperfect resolution of the current asymmetry of information on future market prices.

A number of papers restrict their attention to securities with non-decreasing payoffs and yet manage to attain separation without dissipation in value. Their results are obtained by using signaling devices that are costly to mimic for the bad type but not costly in equilibrium for the good type. Among these, Stein (1992) shows that callable convertible debt can be used by good firms in order to signal their types and separate from bad firms, in a model where the initial asymmetry of information is completely resolved by the time the security is called. The bad firm does not mimic the good firm provided the expected cost of financial distress from doing so is high enough to overcome the benefits of selling an overvalued claim. Since the initial information asymmetry is perfectly resolved, good firms are necessarily able to call the bonds and force conversion, thereby avoiding the same costs of financial distress. This ability to avoid costs of financial distress is the "backdoor equity" value of convertibles in Stein's setting. In contrast, we consider a more general environment in which the initial asymmetry of information is never perfectly resolved and where the value of the optimal security is independent of the private information of the manager and the beliefs of the market. As a result, there is no scope for mispricing whether or not the bad firm mimics the good firm, and even though the manager cannot guarantee that he will be able to force conversion in the future. In our setting, the back-door equity value of a convertible security arises simply from the fact that the manager may be able to exploit market reaction to 'good news' in the future and extinguish a valuable long-lived option to convert via a forcing call. The probability of being able to do so is correlated with the private information

[2]We will discuss only the most related papers here. The reader is referred to Harris and Raviv (1991) for a more thorough survey of the earlier signaling literature. In additon to costly signaling, there are papers analyzing how costly information acquisition might be used to mitigate adverse selection. See, e.g., Fulghieri and Lukin (2001).

[3]Innes (1990) points out that restricting attention to such non–decreasing securities prevents the creation of an agency problem whereby the manager temporarily inflates cash flows and so reduces the payout to investors.

of the manager. The manager can take advantage of this correlation by appropriately designing the face value and call provisions, in order to raise funds without dissipation or dilution at a fair price from investors. As we discuss later, there is empirical evidence that managers are not always able to force conversion. Therefore, if financial distress costs are a real concern, the manager should simply use convertible preferred stock or mandatorily convertible securities similar to those we analyze.

Constantinides and Grundy (1989) show that securities similar to (noncallable) convertible bonds can costlessly solve the adverse selection problem by signaling information, provided the firm is also allowed to buy back shares. In the absence of the possibility to buy back shares, there is no fully revealing equilibrium involving securities whose value is increasing in cash flows. On the other hand, Brennan and Kraus (1987) show that the good type may separate from the bad type by retiring existing debt, which is too costly for the bad type to mimic. We also allow the manager to buy back previously issued securities in our model, but such strategies are not utilized in equilibrium.

Nyborg (1995) considers the optimality of convertibles in a model where new private information arrives at each date to a risk averse manager. In his model there is information content not only in the type of security initially issued but also in the decision to call a previously issued convertible. He shows that risk-averse managers signal their quality by not calling immediately, whereas bad managers whose equity is expected to decline in the near future are forced to call.[4] Therefore, he concludes that voluntary and forced conversions should be accompanied by different price reactions. In our model, although there is asymmetric information at the time of call, the manager would like to force conversion whenever he is able to and thereby extinguish a valuable long–lived option. So, the decision to call is not informative in equilibrium. For the same reason, even though voluntary conversion is a feasible action for investors, they never choose to exercise it early. The manager is able to force conversion only after good news comes to the market and he meets the soft call restrictions.

Other explanations have been offered for the use of convertible securities. While in our model the asymmetric information is ordered in the sense of first order stochastic dominance, Brennan and Schwartz (1987) show that convertible bonds can be designed to be independent of asymmetric information about volatility, and not the mean, of cash flows. This provides insight on the possible role of convertibles in mitigating the asset substitution and other incentive problems caused by conflicts of interest among senior and junior claim holders (see Jensen and Meckling, 1976). Green (1984) shows that such incentive problem can be mitigated by convertible debt rather than straight debt. Cornelli and Yosha (2003) analyze a problem in which a manager can manipulate the interim signal about the quality of a project. If the investment occurs in multiple stages, this possibility of "window dressing" results in a conflict of interest and thus inefficient investment. Convertible debt can be used to solve this problem. A growing literature is also providing explanations for the use of convertible securities solving moral hazard problem within staged venture capital financing (see, e.g., Repullo and Suarez

[4] This is similar to Harris and Raviv (1985), except that in Nyborg the decision to issue a convertible is also endogenous.

(1998)) while a large and earlier literature provides insights on the pricing of convertible securities, the optimal exercise of call options, and on stock returns at the announcement of convertible debt calls (e.g., Ingersoll (1977a and 1977b) and Brennan and Schwartz (1977, 1980)).

The considerable attention that convertibles have received in the literature reflects the importance of the convertibles market. The value of the global convertible market crossed $600 billion in the early 2000s and has been growing since. In 2001, for example, there were around 400 new issues in the U.S. convertible market that raised a total of $106.8 billion.[5] About 95% of convertible securities are callable (see, e.g., Lewis, Rogalski and Seward, 1998) and the available evidence suggests that an overwhelming majority of these have restrictive call provisions similar to those we specify (i.e., the convertible can be called early only if the stock price exceeds a pre–specified trigger price).[6] To take one recent case, on December 8, 1999, Human Genome Science (HGS) raised $200 million by issuing subordinated convertible notes that were due in 2006. Under the terms of the issue, HGS could not call the bond before December 2002 unless the stock price crossed a trigger price (equal to $107.44, or 150% of the conversion price) and stayed there for 20 out of 30 consecutive trading days prior to the call date. In retrospect, HGS could not have chosen a better time for the issue, as the market was energized by prospects of genomics led medical discovery. The genomics/biotech sector turned out to be the best performing equity sector for that period, gaining 60% during the first three months of 2000. As a result, HGS was able to satisfy its call restrictions and call the bonds to force conversion on March 2, 2000, just 85 days after the original issue, its own stock having gained 96.1% in the meantime. Buoyed by the enthusiastic response of the market to genomics research, HGS undertook a second convertible issue on March 6, 2000. The bonds in the issue were due in 2007, and they also had a three year restrictive call provision with a trigger price set at $164.25 (again, equal to 150% of the conversion price). The issue is still outstanding. The market has treated HGS somewhat less favorably than originally anticipated, with its stock price currently around $15 and a triple–C rating on the bond.

Our results cast light on other commonly observed features of callable convertible securities. They imply that the manager should call whenever he is able to, at least in the absence of secondary effects arising out of tax shields or short–term movements in the stock price during the call notice period. This is in contrast with results obtained by Ingersoll (1977b) and the literature on call delay that followed. Ingersoll draws his conclusion from observing a large call premium (i.e., the conversion value exceeding the call price by an average of 44%), a fact suggesting that the callability option was in the money

[5]Source: Securities Data Company, Inc.. See also www.convertbond.com, a division of Morgan Stanley Dean Witter, and Francis, Toy and Whittaker (2000). Other details of the discussion in the rest of this paragraph are available from the same sources.

[6]For example, 44 out of the 49 securities in the sample analyzed in the Morgan Stanley Dean Witter U.S. Convertible Research Report (Iyer et al., 2000), covering the period April 1999 to March 2000, have such call restrictions, referred to usually as 'soft' or 'provisional' call restrictions in the industry.

for quite a while before the actual call decision. However, Asquith (1995) and Asquith and Mullins (1991) show that, after accounting for tax shield effects, a large portion of the observed call delay can be explained once 'hard' call restrictions are taken into account. Such 'hard' call restrictions take the form of call protection periods (typically one to three years). To the best of our knowledge, there has been no documentation of the role of 'soft' call provisions such as those we formalize, preventing calls unless there is a significant premium over the conversion price, in explaining call premiums. Our results also suggest that it may be possible empirically distinguish between early conversion forcing calls, and call and conversion decisions that occur later in the bond's life once hard and soft call restrictions have expired.

We also obtain cross–sectional implications on conversion ratios and option values. Other things equal, when the noise in the information revealed to the market is high (e.g., the firm or industry is young or difficult to value, or there is a low level of analyst following), the ability of the manager to force conversion is not necessarily a very strong signal of high future cash flows. In order to compensate the investors for this, the manager should raise the face value (i.e. lower the conversion ratio), thereby giving investors a more valuable protective put option. When the noise in the information revealed to the market is lower, the convertible should be more 'middle of the road', with the option values of both the opportunity to participate in the up–side as well that of downside protection quite significant.

The main focus of the existing empirical literature has been on the announcement effect of convertible debt issues as well as that of calls of these securities. Mikkelson (1981) pointed out that announcement of convertible debt calls is followed by a decline in the stock price. The subsequent empirical literature (Mazzeo and Moore (1992), Byrd and Moore (1996), Ederington and Goh (2001)) finds out that such a decline is typically short–lived and is more likely to be related to liquidity effects arising out of an increase in the number of available shares rather than due to asymmetric information effects. We abstract away from considerations of liquidity and our results do not predict any significant decline or increase in the stock price after the call announcement. However, we show that calling firms should experience high earnings or some other good news prior to call announcements, in line with the empirical evidence (see, e.g., Campbell, Ederington and Vankudre (1991)). The empirical evidence on the announcement effect of the issue of convertible securities suggests that there is a negative effect on the stock price (e.g., Dann and Mikkelson (1984), Field and Mais (1991)). In the pooling equilibrium that we focus on there should not be any significant announcement effect of the issue. Therefore, our analysis suggests that the negative announcement effect must be due to reasons other than adverse selection.[7]

Using future public information to alleviate a current adverse selection problem has applications

[7] It is well documented that hedge funds buy significant portions of convertible securities and simultaneously hedge their positions, mostly by short selling the underlying stock at the time of the convertible issue, thus creating a negative pressure on stock prices at announcement. See, e.g., L'habitant (2002).

beyond project financing. In the durable good context, Grossman (1981) investigates the role of warranties in solving the lemons problem of Akerlof (1970). He shows that pooling with an optimally designed warranty contract is optimal, in a setting where the future performance of the good is public information that perfectly reveals its value. In this context, Lutz (1989) argues that such warranty contracts may not be seen in practice, since buyers of the good may have an incentive to undetectably damage the good in order to obtain a large warranty payment. In the project financing context, such manipulation of the public signal by the buyers of the convertible security (and the associated moral hazard problem) is less likely to be an issue since the buyers do not actually own the assets being traded but only claims written on those assets.[8]

The rest of the paper is organized as follows. In Section 2, we set up our basic model. In Section 3, we first consider the benchmark case where the asymmetry of information is perfectly resolved over time and then the case where the asymmetry of information is never fully resolved. In Section 4, we present our general model while Section 5 concludes. The Appendix contains most of the proofs.

2 The Basic Model

The basic structure of our model is essentially identical to that of Myers and Majluf (1984). We consider a firm that has both assets in place and a new investment opportunity. The values of both the new investment opportunity and assets in place are uncertain. The uncertainty is captured by the "type" of the firm θ_1 or θ_2 with probabilities λ_1 or λ_2.[9] The manager privately knows his type and both the assets in place of the firm and the cash flows from the new investment opportunity depend on the type. Initially the firm is all equity with the number of shares outstanding given by $M = 1$.[10] The firm does not have sufficient internal funds to invest in the new project and has to raise capital by selling additional securities. The manager makes his decisions to maximize the welfare of the existing shareholders, the riskless rate is normalized to 0, and all agents are risk–neutral.

Let A_i stand for the expected value of the cash flows from the assets in place given type θ_i. The manager has to raise an amount $C = \$1$ from outside investors in order to invest in a project. The new investment and assets in place *combined* produce a random cash flow of X, taking values in some set $\mathbf{X}$, a subset of the non–negative real numbers. Let $G(x|\,\theta_i)$ denote the cumulative distribution function of X given θ_i. We assume that project cash flows for type θ_2 first order stochastically dominate those for type θ_1:

$$\text{For all } x \in \mathbf{X},\ G(x|\theta_2) \leq G(x|\theta_1). \tag{1}$$

[8]Similarly, a warranty policy with a large variance may be unpleasant for risk–averse buyers. In our context, the availability of well–developed markets for hedging instruments makes such an objection less problematic.

[9]In Section 4 we consider the N type case for $N > 2$. The restriction to finite types is for convenience only.

[10]The restriction to an all–equity firm simplifies the exposition. All results extend in a straightforward manner to the case where the firm has existing senior debt outstanding, provided we interpret all cash flows as net of prior obligations.

Define the expected value of the total cash flows for type θ_i of the firm, given that it invests, to be $V_i = E[X|\theta_i]$. Let $\overline{V}$ denote the ex–ante expected value of V_i. From (1), V_i must be non–decreasing in i. To focus on non–trivial cases, we assume henceforth that $V_2 > V_1$.

Furthermore, in line with Myers and Majluf (1984), we assume that projects have positive NPV regardless of the manager's type, i.e.,

$$V_i - A_i > 1 \tag{2}$$

for all $i = 1, 2$. With symmetric information, and in competitive markets, all types of the manager will undertake the socially efficient outcome of investing in the project. The expected payoff of the existing shareholders from doing so will equal $V_i - 1$, the net present value of the firm of type θ_i. In the presence of informational asymmetries between the manager and the market however, the manager might inefficiently under-invest and forego a positive NPV project (as in Myers and Majluf, 1984).

If the cash flows from the project together with the assets in place of the firm are greater than or equal to the cost of the project with probability one, then the firm can always issue riskless secured debt at zero cost and the problem would be uninteresting. To rule out the possibility of riskless debt we assume that, when the type of the manager is θ_1, with strictly positive probability the total cash flows X will fail to cover the required outlay of \$1, i.e.,

$$G(1|\theta_1) > 0. \tag{3}$$

Let $S(x)$ be the payoff from a security S when realized cash flows are x. We will restrict attention to securities with payoffs $S(x)$ that are non–decreasing in x and that satisfy limited liability, i.e.,

$$0 \leq S(x) \leq x \text{ for all } x. \tag{4}$$

Let $\mathbf{S}$ be the set of admissible securities. Note from (1) that for any admissible security $S \in \mathbf{S}$, $S_i \equiv E[S(X)|\theta_i]$ is non–decreasing in the type of the manager.

Equity, debt and convertible debt are all admissible securities. An equity share will be denoted by $\alpha \in (0, 1)$, with the expected value of the cash flows from a share α, given θ_i, equal to αV_i. For any bond with a face value of F, let $D_i(F) = E[\min(X, F)|\theta_i]$ be its expected value given θ_i. For any convertible bond with a face value of F that is convertible into α shares, let $C_i(\alpha, F)$ be the expected value of the cash flows from the convertible given θ_i:

$$C_i(F) = E[\max(\alpha X, \min(X, F)) \,|\, \theta_i]. \tag{5}$$

$C_i(\alpha, F)$ and $D_i(F)$ are continuous in F and non–decreasing in i.

Our model has two (groups of) players, the manager (who maximizes the welfare of old shareholders) and the potential investors, and three dates 0, 1 and 2. The manager knows θ when he makes his investment and financing decisions. In contrast, initially the investors are uninformed about

θ, though later they will obtain information about the firm type. Furthermore, these investors are competitive and efficient, so that at each date they value all securities at their expected value given publicly available information. We will refer to the set of potential investors collectively as the market.

At date 0, given his private information, the manager decides whether or not to invest and what securities to issue to finance the investment. The market is uninformed about the manager's type at date 0 and competitively values the securities issued by the manager. The manager invests at date 0 if the issue succeeds, while at date 2 the total cash flows are realized and distributed.[11] At the intermediate date 1, some of the asymmetric information present at date 0 is resolved. Specifically, the market publicly observes a signal $m \in \{m_1, m_2\}$ of the type of the manager. We assume that the probability with which a signal m_i is observed, given the manager is of the type θ_i, is equal to $\beta \in (\frac{1}{2}, 1]$. The parameter β is a proxy for the degree to which the initial asymmetry of information between the manager and the market is resolved between the time the investment is undertaken but before cash flows are realized. The case $\beta = 1$ corresponds to the case of perfect resolution. On the other hand, the case $\beta = \frac{1}{2}$ corresponds to the case where none of the asymmetry is ever resolved before cash flows are realized. In general, given β, date 1 can be thought of as the time necessary for information of quality measured by β to be disclosed to the market.

Though our results do not depend on a specific interpretation of the signal m, it might help the reader to think of it as an analyst announcement or the outcome of a patent application which may or may not be approved by the government. For the present moment we will assume that the signal m is exogenous. In Section 4 we provide a simple story to endogenize the signal so that its distribution (i.e. β) will depend on the date 0 financing strategy of the manager. The information and timing structure above implicitly defines a dynamic game of incomplete information between the manager and the market. Our notion of equilibrium will correspond to the perfect Bayesian equilibria of this game.

We end this section with a few further remarks with respect to the model and the timing structure. First, we allow the manager to issue securities at date 0 whose payoffs depend on the endogenous date 1 *response* of the market (e.g., the market value of equity or the stock price) to the realized public signal m. For example, the manager is allowed to issue a callable convertible bond that can be called only if the stock price exceeds a threshold value (or a floating price convertible whose conversion rate depends on the stock price). If such a security is used in equilibrium, the threshold value may be such that the bond can be called only when the public signal is equals m_2 and the ensuing stock price is higher than the threshold. Although it will not matter for our results, we do not allow the manager to set a call restriction or a conversion provision *directly* in terms of the public signal m. This is desirable

[11] Though this possibility never arises in equilibrium, we assume that if the manager fails to raise the required outlay for the project at date 0, he invests the amount raised in a riskless asset. On the other hand if he raises more than the required outlay he immediately distributes the excess as dividends.

as, in practice, securities whose payoffs depend on the endogenous stock price in some manner are quite common, whereas securities whose payoffs depend directly on some public signal such as an analyst announcement or an earnings announcement are not so, presumably because such public signals are frequently quite amorphous and contracts directly contingent on them are not enforceable in a court.

Second, since the dilution costs of adverse selection arise via transfers from the old claim–holders to the new claim–holders, it is necessary for our results that the manager attach a 'welfare' weight to old claimholders that is strictly greater than what he attaches to the new group. For simplicity, we assume that the manager cares only about the old shareholders. Such an assumption is common in the literature and may be innocuous in our context, since in practice younger firms (that are more susceptible to adverse selection in the first place) do seem to display a higher degree of managerial ownership, presumably aligning managerial interests with those of the existing claimholders.[12] Finally, we implicitly assume that the manager cannot postpone his investment decision to a later date, possibly because actions from competitors will erode the value of the project if he does so. Similarly, it is also not possible for the manager to anticipate a future need for cash and raise the required cash early, at a date before date 0, under conditions of symmetric information.[13]

3 The Optimality of Callable Convertible Securities

To gain intuition we start by analyzing the benchmark case where the date 0 asymmetry of information is perfectly resolved at date 1. This corresponds to the case where $\beta = 1$. In Subsection 3.2, we will consider the case where $\beta < 1$, so that the date 0 asymmetry of information is never perfectly resolved.

3.1 Perfect Resolution of Asymmetric Information

Under perfect resolution of the asymmetry of information, a callable convertible security can be summarized by the collection $(F, \alpha, k, T_{call}, T_{conv})$, where F denotes the face value of the bond, α is the share of the firm the bondholders will have if they decide to convert into common stock, k is the call price which the bondholders will receive if the bond is called and they decide to surrender the bond, T_{call} is the maturity date of the call provision and T_{conv} is the maturity date of the convertibility

[12] See, e.g., Graham and Harvey (2001). It is not clear however that this is an optimal provision of managerial incentives from the perspective of the shareholders. Ex–ante, uninformed shareholders may prefer that the manager maximize the total value of the firm and so not under–invest. See Dybvig and Zender (1991) for a similar point. However, such a contract may not be renegotiation proof at the interim stage. A complete characterization of the optimal provision of managerial incentives is beyond the scope of this paper.

[13] Perhaps because there is no such date— the firm may be 'born' under conditions of asymmetric information. Note in this respect that we allow the expected value of the assets in place A_i to depend on the manager's type. A strategy of raising a lot of cash early may also create agency problems between the manager and shareholders, arising out of inefficient use of 'free' cash, and so may be prevented by the latter group.

option. In line with common practice, we assume that if the firm calls the convertible security then the holders still retain the right to convert into equity and do not have to surrender the security as long as they convert. It will become clear later that nothing can be gained by calling the bond before date 1 (i.e., the first best cannot be achieved). Accordingly, we assume henceforth that the callability option cannot be exercised before date 1. In practice, convertibles frequently have call protection periods that prevent calls within a minimum initial period. As mentioned earlier, in the context of the model date 1 can be thought of as the time required for information of quality β to be disclosed to the market.

We show in what follows that a callable convertible security $(F^*, \alpha^*, k^*, T^*_{call}, T^*_{conv})$ exists with the property that all types of the manager can raise the required outlay by issuing such a security. The way to achieve this is to design the security in a way that ensures that a bad signal in the future allows investors to hold a convertible whereas a good signal allows the manager to extinguish the protective put option, leaving investors with straight equity. For any given type of the manager, a convertible is more valuable than just the equity part of the security. A properly designed callable convertible security ensures that the value of the convertible when prospects are not so good equals the value of the straight equity part when firm prospects look better. Consequently, the fair date 0 value of the security is equal to the required outlay of \$1 regardless of the manager's information at that date.

More formally, suppose that $T^*_{call} = 1$, so that the call provision expires on date 1 while $T^*_{conv} = 2$, so that the convertibility option is long-lived and expires on date 2.[14] Let the equity share α^* be a 'fair' share of the cash flows given that the manager's type is θ_2. That is, α^* satisfies

$$\alpha^* V_2 = 1. \tag{6}$$

Next, suppose that the face value F^* is such that, the value of the pure convertible is equal to the outlay of \$1, given that the manager has bad news, i.e., his type is θ_1,

$$C_1(\alpha^*, F^*) = 1. \tag{7}$$

Using (5) it is easily seen that such an F^* can always be found. For at $F^* = 0$, the expression in (7) is equal to $\alpha^* V_1 < 1$, by construction of α^*, while if F^* becomes large the expression in (7) approaches $V_1 > 1$. By continuity there exists an intermediate value of F^* such that (7) holds. We show now that the call price k^* can be chosen suitably to finance the project regardless of θ, at zero cost (i.e., with no dilution) for the existing shareholders. To do this we proceed backwards in time and analyze the optimality of the manager's decision to call the bonds and the optimality of the investors' decisions to convert.

[14] One could equally assume that both options are long–lived (i.e. have the same maturity as the bond). We also assume that the debt part of the security is a zero–coupon bond. These assumptions keep the analysis as simple as possible and do not affect any qualitative results.

Suppose that we are in date 1 and $m = m_2$, so that it is common knowledge that $\theta = \theta_2$. We want the call value k^* to be such that the manager wants to call the bonds in this case. The optimality of the call decision depends in turn on the optimal conversion decision of the bondholders, both in the case where the bonds are called and in the case where the bonds are not. If the bonds are not called, the bondholders will not want to convert as the convertibility option is more valuable alive than dead, i.e., since their payoff from not converting is at least as high as their payoff from converting:

$$C_2(\alpha^*, F^*) \geq C_1(\alpha^*, F^*) = 1 = \alpha^* V_2. \tag{8}$$

If the bond is called, then the bondholders will want to convert if their payoff from converting is at least as high as the payoff from holding the bond, i.e., if

$$k^* \leq \alpha^* V_2 = 1. \tag{9}$$

Suppose that k^* is such that (9) holds. Then, when $\theta = \theta_2$, the manager will want to call the bonds and force conversion, as the payoff of the old shareholders from doing so, $(1-\alpha^*)V_2$, is at least as high as $V_2 - C_2(\alpha, F^*)$, the payoff from not forcing conversion.

Suppose next that we are in date 1 and $m = m_1$ so that it is common knowledge that $\theta = \theta_1$. We want the call value k^* to be such that the manager does not want to call the bonds and the bondholders do not want to convert the bonds if they are not called. If the bonds are not called, the bondholders do not want to convert as

$$\alpha^* V_1 < \alpha^* V_2 = 1 = C_1(\alpha^*, F^*). \tag{10}$$

Therefore the manager will not want to call the bonds if

$$k^* \geq C_1(\alpha^*, F^*) = 1. \tag{11}$$

From (9) and (11), if

$$k^* = 1 \tag{12}$$

then the manager will call the bond to force conversion if $\theta = \theta_2$ and will not call the bond if $\theta = \theta_1$. In the latter case, bondholders will not convert. For such a bond and sequentially optimal call and conversion decisions, the payoff to the bondholders will be equal to 1 regardless of the private information of the manager, from (7) and (6). As a result, when the bond is issued at date 0, investors will not face any adverse selection and will be willing to provide \$1, the expected value of the issue. Furthermore, the expected payoff for the old shareholders in type θ_i of the firm at date 0 will equal $V_i - 1$, the first best value of the firm given θ_i. As a result, the manager will always invest. Finally, we have to specify beliefs off the equilibrium path at date 0 to complete the characterization of this perfect Bayesian equilibrium. We suppose that the uniformed investors believe that $\theta = \theta_1$ whenever the manager issues any other security at date 0. Thus, neither type of the manager has an incentive to deviate.

Proposition 1 *Suppose $\beta = 1$. Then it is an equilibrium for both types of the manager to invest by issuing the callable convertible security $(F^*, \alpha^*, k^*, T^*_{call}, T^*_{conv})$ characterized by (6), (7) and (12) and with $T_{call} = 1$ and $T_{conv} = 2$. The manager will call to force conversion only when m_2 is observed. The security will not be called or converted when m_1 is observed. In this equilibrium, the expected value of the claims sold to the new claim holders will equal 1 regardless of θ, and the expected payoff to old shareholders of type θ_i of the firm will equal $V_i - 1$, the first best value of the firm given θ_i, for all $i = 1, 2$.*

Proof. Follows from the discussion above. □

The value of the optimal security that we characterize above is independent of the private information of the manager. Thus, the security is correctly valued even though the bad type mimics the good type. This property of the optimal security will be seen to carry over to the case where the resolution of the asymmetry of information is imperfect. Notice in this respect that we did not specify any soft call restrictions on our security. In the next section, we will see that such restrictions are needed only when financial market are noisy, i.e., $\beta < 1$.

Note that first–best efficiency can also be achieved simply by using short–term debt maturing in period 1 and then refinancing when there is no asymmetry of information. Specifically, at date 0, the manager can issue short–term risk–free debt, issuing any other security to retire the debt at zero cost in the symmetric information environment of date 1. Similarly, the efficient outcome could also be implemented by floating price convertibles of the sort considered by Brennan (1986). This equivalence breaks down when the date 0 asymmetry of information is never perfectly resolved. In such cases, convertibles of the type we characterize strictly dominate the short term debt–and–refinancing strategy, as well as Brennan-type securities. The simple scenario of this section nevertheless serves to bring out the intuition why callable convertible securities mitigate adverse selection problems.

3.2 Imperfect Resolution of Asymmetric Information

We now turn to the case where the date 0 asymmetry of information is only imperfectly resolved at date 1, i.e., $\beta \in (\frac{1}{2}, 1)$. As we show below, as long as β is high enough, there exists a callable convertible security such that if the manager finances the investment by issuing this security then the first best outcome will still be implemented in equilibrium. The structure of the efficient equilibrium as well as the optimal security will be very similar to that characterized in the previous section. In particular, the manager will call to force conversion into equity only when good news is disclosed at date 1 and the security will not be called or converted when bad news is disclosed. The important difference from the previous case is that in the case of bad news, the manager will be prevented by a restriction on the call provision from calling the bond and forcing conversion. This restriction on the call provision will take the form that the security can be called only when the share price of the firm exceeds a certain threshold or trigger value. By specifying this restriction at date 0, the manager will be able to commit to not calling the bond and using his privileged information in the future at the expense of the new investors, ultimately benefitting the existing claim holders.

Formally, a callable convertible security with a restrictive call provision consists of a tuple $(F, \alpha, k, p, T_{call}, T_{conv})$ where the only difference from the security of the previous section is that the bond can be called only if the share price at date 1 exceeds a trigger price p. For brevity, we will refer to this trigger price as the call restriction. We first characterize the optimal such security keeping in mind the properties it must have in order to implement the efficient outcome in equilibrium. Then we show that it is an equilibrium for the manager to issue such a security regardless of his private information.

Let the maturity date for the call provision T_{call} on our optimal callable convertible security be set for date 1 and the maturity date of the convertibility option T_{conv} be set for date 2, as before. Suppose that both types of the manager issue the security at date 0 and expect the security to be converted (due to a forcing call) to equity at date 1, but if and only if good news is disclosed (i.e., $m = m_2$) at that date. Suppose further that, given this expectation, each type $\theta \in \{\theta_1, \theta_2\}$ of the manager estimates that the expected value of the claims sold equals \$1, the cost of the project. Since $\Pr[m_i|\theta_i] = \beta$, F and α must then satisfy the following two equations:

$$\beta C_1(\alpha, F) + (1 - \beta)\alpha V_1 = 1, \tag{13}$$

$$(1 - \beta)C_2(\alpha, F) + \beta\alpha V_2 = 1. \tag{14}$$

The first equation states that the required outlay of 1 dollar is equal to the expected value of the security, conditional on θ_1 *and* conditional on the fact that the security will be converted to equity when $m = m_2$ but not when $m = m_1$. The second equation has the same interpretation, but for θ_2. We show in the Appendix that (13) and (14) possess a solution $\alpha \in (0, 1)$ and $F > 0$ when β is high enough. For now assume that such a solution exists. If the market conjectures at date 0 that the security will be converted to equity at date 1 when $m = m_2$ and good news about the firm is disclosed, but not when $m = m_1$, it follows from (13) and (14) that the expected value of the security will be equal to \$1 at date 0. In competitive markets, such a security will trade at that price at date 0.

We show next that if the security is converted at date 1, it must be the outcome of a conversion forcing call. This is immediately seen from the fact that a convertibility option is worth more alive than dead and from (13) and (14) that their average value equals the required outlay of \$1:

$$\alpha V_i < 1 < C_i(\alpha, F) \text{ for } i = 1, 2. \tag{15}$$

This is the "back–door equity" value of the convertible security in the context of our model — when converted, the equity share of the new claim-holders will be lower than what they would obtain under symmetric information. To compensate the new claim-holders, the value of the debt part of the claim is "sweetened" and the convertible value is higher than what they would obtain under symmetric information. Since the convertibility option is worth more alive than dead regardless of the manager's private information, the same relationship must hold given the market's information. This implies that the new claimholders will not convert unless forced to do so. It also implies that the manager would like to force conversion whenever he is able to. However, if the manager always forces conversion, the expected value of the security to the new claim-holders will fall below $1 and they will be unwilling to provide the funds for the project, hurting the existing claim-holders. Consequently, a restriction on the call provision is necessary as it enables the manager to commit to not calling the bond unless good news is disclosed. In turn this will make the investors willing to pay $1 for the issue at date 0. We now determine the call price and the trigger price that are needed for this to hold.

Let $\mu_i(m)$ be the posterior probability at date 1 attached by the market to the event that $\theta = \theta_i$ after observing m. Note that since $\beta > \frac{1}{2}$ we must have $\mu_2(m_2) > \mu_2(m_1)$. Choose any call price k that is less than the expected value of the equity claim given $m = m_2$,

$$k < \sum_{i=1}^{2} \mu_i(m_2)\alpha V_i. \tag{16}$$

In equilibrium, when $m = m_2$, the right–hand side of (16) will be the date 1 market value of equity part of the security. As a result, the bondholders will convert when it is called.[15] Choose the trigger price p (that defines the restrictive call provision) to be in between the market value of old shareholders' claims when $m = m_1$ and when $m = m_2$, i.e.,

$$\sum_{i=1}^{2} \mu_i(m_1)[V_i - C_i(\alpha, F)] < p < \sum_{i=1}^{2} \mu_i(m_2)(1-\alpha)V_i. \tag{17}$$

Such an interval for p exists from (15). In equilibrium, the date 1 stock price will equal the right–hand side of (17) when $m = m_2$ so that the manager will be able to force conversion by calling; while when $m = m_1$, the stock price will equal the left–hand side of (17), so that the bond cannot be called and will not be converted.

This completes our characterization of the optimal security. In the Appendix, we show that it is an equilibrium for all types of the manager to issue this security at date 0 and that in this equilibrium there will be no dilution. Even though the asymmetry of information is never exactly resolved, the adverse selection problem is exactly solved when β is high enough.

Proposition 2 *There exists $\beta^* \in (\frac{1}{2}, 1)$ such that for $\beta > \beta^*$, it is an equilibrium for the manager to invest by issuing a callable convertible security $(F, \alpha, k, p, T_{call}, T_{conv})$ with F and α satisfying (13) and (14), k and p satisfying (16) and (17) and with $T_{call} = 1$ and $T_{conv} = 2$, regardless of his private*

[15] For the sake of completeness, we suppose that the manager raises the required money by issuing equity, in the off–the–path of play event that bondholders surrender the bond upon a call.

information θ. In this pooling equilibrium, the manager calls to force conversion only when $m = m_2$ is observed, regardless of θ. The security cannot be called and is not converted when $m = m_1$ is observed. The date 0 expected value of the claims sold to the new claim holders equals 1 and that for the old shareholders of type θ_i of the firm equals $V_i - 1$, the first best value of the firm. Furthermore, the optimal equity share α is increasing in β while the face value F is decreasing in β: $\frac{\partial \alpha}{\partial \beta} > 0 > \frac{\partial F}{\partial \beta}$.

Proof. In the Appendix. ■

The convertible bond characterized above has payoffs that are non–decreasing in underlying cash flows. Nevertheless, the call provision and attached restrictions make the expected value of the security independent of the private information of the manager. The manager will call the bond to force conversion to equity when good information is disclosed and the restrictions on the call provision are met. The better is the initial information of the manager the higher is the chance that this occurs. However, the manager may not always be able to call and force conversion. The worse the initial information of the manager the greater is the chance that he will be unable to force conversion, so that the new claimholders will be left holding the more valuable convertible debt. For the optimal security, these two effects exactly offset each other so that the date 0 expected value of the claims for the new claimholders is independent of the private information of the manager.

Recall that for $\beta = 1$, financing with short term debt and refinancing at date 1 also implements the same outcome as the optimal callable convertible security. However, this is no longer true when $\beta < 1$. If the manager issues short-term debt at date 0 that matures in date 1, then he has to raise cash to honor his debt obligations at that date by issuing some admissible security like equity or debt. Since there is still residual asymmetric information at date 1, the high type of the manager will still suffer from dilution at that date, regardless of whether $m = m_1$ or m_2. The date 0 expected value of this date 1 dilution will be positive for the high type and may even make him unwilling to invest in the project in the first place. A similar point applies to Brennan–type floating price convertibles that pay \$1 at date 1 regardless of the information revealed to the market.

In Proposition 2 we provide an example of one security and one equilibrium that implements the symmetric information outcome. There exist other equilibria, involving similar securities, that also achieve the same outcome. For example, there exists a separating equilibrium where the high type issues a callable, convertible security similar to the one characterized above (differing only in the call provisions k and p), and the low type issues any other security, say equity. In such a separating equilibrium, given that the convertible has been issued at date 0, the future signal m does not convey any information about the expected value of total cash flows to the market, which is known to be equal to V_2. Nevertheless, if the market conjectures that the bond will be called in order to force conversion when $m = m_2$, then the share price will equal $(1 - \alpha)V_2$ at that date and state. On the other hand, if the market conjectures that the bond cannot be called or converted when $m = m_1$, then the share price will equal $V_2 - C_2(\alpha, F)$. From (15), we see that $(1 - \alpha)V_2$ is greater than $V_2 - C_2(\alpha, F)$. As a result, if the manager sets a call price $k < \alpha V_2$ and a trigger price p satisfying $p < (1-\alpha)V_2$ but $p > V_2 - C_2(\alpha, F)$, type θ_2 of the manager will be able to force conversion when $m = m_2$ but not when $m = m_1$, thereby implementing the symmetric information outcome. Type θ_1 of the manager will be indifferent between mimicking the high type or issuing fairly priced equity given his information and so, in the candidate equilibrium, will not mimic. In reality, the efficient pooling outcome characterized in Proposition 2 may be more robust than the efficient separating one if the (low type) of the manager has some interest in maintaining a high date 0 stock price. Without going into issues of refining the set of equilibria, in this paper we simply make the point that even when the initial asymmetry of information is never perfectly resolved, there exists at least one efficient equilibrium that exactly achieves the symmetric information outcome.[16]

Proposition 2 also shows that as β falls, α also falls while F rises. We discuss the intuition underlying this result in the context of the following example.

Example

Suppose that $\lambda_1 = \lambda_2 = \frac{1}{2}$ and that cash flows follow the (negative) exponential distribution for each type, i.e.

$$G(x|\theta_i) = 1 - \exp\left[-\frac{x}{\theta_i}\right]$$

with $\theta_1 = 9$ and $\theta_2 = 10$. Then $V_i = E[X|\theta_i] = \theta_i$. In such a case, computations indicate that the optimal security of Proposition 2 exists as long as $\beta > \beta^* \simeq 0.503$. As $V_2 - V_1$ rises, the threshold value β^* rises.

With $\beta = 0.75$, computations indicate that the solution to (13) and (14) is $\alpha = 0.096$ and $F = 0.679$. To see that such a convertible implements the first–best, observe first that for type θ_2 of the manager the value of the equity claim is $\alpha V_2 = 0.96$ whereas, using (5), the value of the pure convertible is seen to be $C_2(\alpha, F) = 1.13$. Since type θ_2 of the manager expects to be able to force conversion at date 1 with probability $\beta = 0.75$, the date 0 expected value of the claims sold given the manager's information equals $0.75(0.96) + 0.25(1.13) = 1$, the cost of the project. Similarly, for type θ_1 of the manager, the value of the equity share is $\alpha V_1 = 0.86$, while the value of the pure convertible $C_1(\alpha, F) = 1.05$. Since such a manager expects to be able to force conversion at date 1 with probability $1 - \beta = 0.25$, the date 0 expected value of the claims sold given the manager's information equals $0.25(0.86) + 0.75(1.05) = 1$, the required outlay. Thus, all types of the manager will be willing to issue such a security and invest

[16] Similarly, there may also exist inefficient equilibria involving underinvestment similar to the one characterized by Myers and Majluf (1984). Furthermore, extensions of standard forward induction refinements such as the Intuitive Criterion of Cho and Kreps (1987), or Divinity (Banks and Sobel (1987)), will fail to refine the equilibrium set. However, suitable extensions of 'mistaken theory' refinements of the sort proposed by Van Damme (1989) and Hillas (1994) will imply that every equilibrium will implement the symmetric information outcome when β is high enough. On the other hand, if we allow securities whose payoffs are *directly* contingent on m, then every perfect Bayesian equilibrium must be efficient for β high enough. In this paper we do not allow such securities or consider refinements.

in the project at date 0.

It remains to specify the call restrictions on the bond. Since the firm initially has one share outstanding, the values obtained for α and F translate to a conversion price of $\frac{(1-\alpha)F}{\alpha} = 6.39$. The share price at issue is $\overline{V} - 1 = 8.5$. Using formula (17), one can verify that the share price at date 1 will equal 8.81 (i.e., 38% more than the conversion price) when the market receives good news m_2 at that date, and will equal 8.19 (i.e., 28% more than the conversion price) when the market receives bad news m_1. Thus, the trigger price p that defines the call restrictions should be between 8.19 and 8.81. Finally, using (16), one sees that the call price k must be less than 0.936.

Table 1 shows the date 0 market values of the different component securities for $\beta = 0.75$ and $\beta = 1$. The last column is the discount due to the callability feature.

Table 1	α	**F**	**Equity**	**Put**	**Debt**	**Call**	**Convertible**	**Call provision**
$\boldsymbol{\beta = 0.75}$	0.096	0.679	0.91	0.18	0.66	0.43	1.09	−0.09
$\boldsymbol{\beta = 1}$	0.1	0.493	0.95	0.10	0.48	0.57	1.05	−0.05

The intuition for these comparative static results is clear if one fixes as the benchmark the case of perfect resolution of information, $\beta = 1$. In comparison, when $\beta < 1$, there is some chance that even the low type of the manager will be able to force conversion, leaving the investors holding equity that is less valuable. To compensate the investors, the manager will raise F and sweeten the debt, thereby raising the value of the downside protection (i.e., the put option to convert to debt) for the shareholders. Equivalently, since for low β, even the high type of the manager may not be able to force conversion with a large probability, allowing the investors to hold a convertible that is more valuable, the manager can lower the equity share α (i.e., the value of the call option to convert to equity) and still be able to raise the required outlay of \$1 at date 0 from the investors. This implies that the conversion ratio should be increasing (equivalently, the conversion price be decreasing) in β. It also follows that the market value of the call option to convert the risky debt to equity is increasing in β and the value of the put option to convert the equity to risky debt is decreasing in β.

The example above as well as the experience of HGS discussed in the Introduction illustrates that issuing convertibles is not without its risks from the perspective of the manager— he may be unable force conversion and end up servicing a more valuable convertible. In this respect, the experience of MCI Communications Corporation was more successful, occurring as it did during a less "exuberant" period for the stock market, 1978–83. We conclude this section by briefly recalling its salient features (see Greenwald (1984) for details of this well–known case). In 1978, largely as a result of a lifting of a court order that previously restricted its operations, MCI started on a period of dramatic growth, with total assets growing from \$161 million in March 1978 to \$2.071 billion in March 1983. This growth needed frequent infusions of external capital and MCI often decided to use convertible securities in order to raise the funds. An issue of convertible preferred stock in December 1978 raised $28 million, followed by a second offering in September 1979 that raised $67.5 million and a third offering in October 1980 raising $49.5 million. All these securities were callable, with restrictive call provisions. The restriction allowed the firm to call provided that the market price of MCI stock exceeded the conversion price by a pre-specified margin of around 25% for 30 consecutive trading days around the call date. As events turned out, MCI's stock price rose enough for it to be able to force conversion on all three issues by November 1981. As MCI continued on its growth path, it raised $100 million in an August 1981 convertible debt issue and $250 million in a May 1982 issue. A rising stock price enabled MCI to force conversion on both these issues as well by February 1983. A sixth convertible debt issue raised $400 million in March 1983 while in July of that same year MCI raised $1 billion with a 'synthetic' convertible consisting of a package of bonds and detachable warrants. As luck would have it, MCI fared poorly in product market competition with AT&T and its stock price went into sharp decline at this time. The call restrictions made it impossible for MCI to force conversion on these last two issues and it was left with a heavy debt burden that it had difficulty servicing, although it managed to do so ultimately.

4 The General Case with an Endogenous Signal

We now extend the basic model in Section 2 by letting the manager's private information take more than two values. Accordingly, let θ take values in the set $\{\theta_1, ..., \theta_N\}$, $N \geq 2$, with $\Pr[\theta = \theta_i] = \lambda_i$. We assume that suitable generalizations of (1)—(3) hold for all θ.

When there are more than two types, one convertible bond with a fixed conversion ratio will not be able to implement the symmetric information outcome for all types. One solution is to allow the manager to issue multiple convertibles with differing face values, conversion ratios and call restrictions. For example, with $N = 3$, issuing two callable convertible securities with properties similar to those obtained above can be shown to be efficient. An alternative approach is to consider floating-price convertibles with conversion ratios that depend on date 1 endogenous variables like the market value of equity or the stock price, including mandatory convertibles that are automatically converted to equity.[17] We will take the latter approach in what follows, in order to demonstrate in closed form the existence of an equilibrium that implements the symmetric information outcome.

We will also extend the model by providing a simple story to endogenize the date 1 public signal m. Specifically, we suppose that at date 1, there is an analyst who is either an expert (i.e., informed) with probability γ, or a charlatan (i.e., uninformed) with probability $1 - \gamma$, with $\gamma \in (0, 1]$. The analyst's

[17] In 2001, such securities constituted around a quarter of the convertible market. See also Chemmanur, Nandy and Yan (2004) for a model justifying mandatory convertibles as a costly signal.

type is private information and he makes a public announcement $m \in \{m_1, ..., m_N\}$ given his type on date 1, after observing the date 0 decisions of the manager. The message m_i is to be interpreted as a statement by the analyst that the state of the world is θ_i. We assume that when the analyst is an expert he discloses the true state, i.e., sends message m_i when the state is θ_i. When the analyst is a charlatan, he tries to maintain his reputation for being an expert, i.e., chooses his disclosure strategy in order to maximize the market's posterior probability given the message that he is informed.[18]

As before, we will look for perfect Bayesian equilibria of this game. Let $\mu_i^0(S)$ denote the uninformed analyst's (as well as the market's) date 0 beliefs that the type of the manager is θ_i given that a security $S \in \mathbf{S}$ has been issued by the manager. Let $\sigma_i(S)$ be the probability with which the uninformed analyst sends message m_i at date 1 given that a security S has been issued at date 0. Let $\mu_i(m, S)$ denote the market's date 1 beliefs of the market that $\theta = \theta_i$ given a message m sent by the analyst and given S has been issued at date 0. Let $\nu(m, S)$ denote the date 1 beliefs of the market that the analyst is an expert given that the date 0 security is S and that he has sent a message m. Finally, let

$$\overline{V}(m, S) = E[X|m, S] = \sum_{i=1}^{N} \mu_i(m, S) V_i \tag{18}$$

be the date 1 market value of the expected cash flows of the firm given that the analyst's message is m and that the security issued is S.

We will look for a pooling equilibrium where each type of the manager issues the same floating price mandatory convertible bond at date 0. Such a security, denoted by $S^* = (\alpha^*, V^*)$, consists of a *vector* of equity shares $\alpha^* = (\alpha_1^*, ..., \alpha_N^*)$ together with a vector $V^* = (V_1^*, ..., V_N^*)$ of cut-off levels for the date 1 market value of the firm. The interpretation is that the security is converted to α_i^* shares when the date 1 market value of the firm is V_i^*.[19]

In order to state our result, it will be convenient to define

$$\widehat{V} = \left[\sum_{i=1}^{N} \lambda_i \frac{1}{V_i} \right]^{-1} \tag{19}$$

[18] Our results on the existence of an efficient equilibrium do not depend on the analyst being either perfectly informed or perfectly uninformed, or on the precise specification of the uninformed analyst's preferences, as long as γ is high enough.

[19] We can equally let the conversion ratios depend on the date 1 stock price of the firm, instead of the total market value, without affecting anything. Mandatory conversion allows us to ignore the debt part of the claim. All results will carry over if we instead use a non–mandatory floating–price convertible. Since the conversion ratio in such a security is floating with the stock price, we can choose a sufficiently low face value for the debt part of such a security, in order to guarantee voluntary conversion. This also allows us to eliminate the need for restrictive call provisions. Call provisions forcing conversion may still be attached however, in order to make sure that conversion happens.

$\widehat{V}$ is the inverse of the average equity shares sold in the symmetric information world. Let

$$\gamma^* = \max \left[1 - \frac{\widehat{V}}{V_N}, \frac{\widehat{V} - V_1}{V_1(\widehat{V} - 1)} \right]. \tag{20}$$

Proposition 3 *For all $\gamma > \gamma^*$ there exists a pooling equilibrium where all types of the manager issue the same mandatory convertible $S^* = (\alpha^*, V^*)$ satisfying*

$$V_i^* = \gamma V_i + (1 - \gamma)\overline{V}, \tag{21}$$

and

$$\alpha_i^* = \frac{1}{\gamma} \left[\frac{1}{V_i} - (1 - \gamma)\frac{1}{\widehat{V}} \right] \in (0, 1), \tag{22}$$

for all $i = 1, ..., N$. On the equilibrium path, $\sigma_i(S^*) = \lambda_i$ and $\overline{V}(m_i, S^*) = V_i^*$ for all i. The date 0 expected value of the claims sold to the new claim holders is equal to 1 and that for the old shareholders of type θ_i of the firm is equal to $V_i - 1$, the first best value of the firm.

Proof. In the Appendix. ■

In the pooling equilibrium neither the market nor the uninformed analyst will infer anything about θ from the date 0 choice of securities. Since the informed analyst always tells the truth, the uninformed analyst, in order to maximize the market's posterior probability of his expertise, announces m_i with probability $\sigma_i = \lambda_i$, the probability he attaches to the informed analyst sending message m_i. As a result, the market will attach probability γ to the analyst being informed after any message m_i and so the market value of the firm $\overline{V}(m_i, S^*)$ will be equal to V_i^* for each m_i. The new claimholders will obtain a share α_i^* when the date 1 market value of the firm equals V_i^*.

Given this equilibrium behavior, the conversion ratios α^* will be chosen in such a way that the expected value of the claims sold will equal \$1 regardless of the private information of the manager. Since the manager of type θ_i attaches probability $\gamma + (1 - \gamma)\lambda_i$ to the message m_i and a probability $(1 - \gamma)\lambda_j$ to a message $m_j \neq m_i$, we must have that α^* solves

$$[\gamma + (1 - \gamma)\lambda_i]\alpha_i^* V_i + (1 - \gamma) \sum_{j \neq i} \lambda_j \alpha_j^* V_i = 1,$$

or, equivalently,

$$\gamma \alpha_i^* + (1 - \gamma) \sum_{j=1}^{N} \lambda_j \alpha_j^* = \frac{1}{V_i} \tag{23}$$

for all $i = 1, ..., N$. Equation (23) has a simple interpretation—the expected equity share sold by type θ_i must equal the share $\frac{1}{V_i}$ that would be sold by this type in the first–best world. The solution to the system (23) is given by (22). When γ is greater than its threshold value γ^*, the solution is admissible, i.e., $\alpha_i^* \in (0, 1)$ for all i. To support the pooling equilibrium, we assume that if any other security is issued at date 0 everyone attaches probability 1 to type θ_1.

Note that

$$\alpha_i^* - \alpha_j^* = \frac{1}{\gamma}\left[\frac{1}{V_i} - \frac{1}{V_j}\right] \tag{24}$$

Thus, α_i^* is decreasing in i—the more optimistic is the market the lower is the share sold. Furthermore, it is easily checked that the market value $\alpha_i^* V_i^*$ of the claims sold when $m = m_i$ is also decreasing in i. Intuitively, the higher the type of the manager the greater is the chance that a favorable m will be disclosed in date 1. To keep the expected value of the claims sold constant across manager types, the market value of the claims sold must be decreasing in the date 1 market value of the company. This property of the floating price convertible is identical to the corresponding property of the callable convertible security characterized in Section 3.2.

Note moreover that for $i > j$ the difference $\alpha_i^* - \alpha_j^*$ (as well as $\alpha_i^* V_i^* - \alpha_j^* V_j^*$) is decreasing in γ. The less the probability that the analyst is informed, the more sensitive must be the date 1 market value of shares sold to the analyst's message, in order to keep the date 0 expected value independent of θ. Finally, since the firm initially has one share outstanding, after the conversion the share price p_i^* will be given by $(1 - \alpha_i^*)V_i^*$ which is increasing in i. The more optimistic is the market at date 1 the higher will be V_i^*, the total value of the firm. Furthermore, the lower will be α_i^* the number of shares sold and so the total number of shares outstanding. For both these reasons the stock price will be higher the more optimistic the market.

5 Conclusion

We show that when the asymmetry of information is imperfectly resolved over time, commonly used securities such as callable convertible preferred stock or debt can perfectly solve the adverse selection problem. By conditioning call and conversion decisions on the future public resolution of the manager's current private information such securities make the value of the claim insensitive to the private information of the manager. The manager prefers to force conversion whenever he is able to, but may not be able to force conversion due to the presence of call restrictions. Complete mitigation of adverse selection can also be achieved by a floating price and mandatory convertibles, and even when the future information disclosure is endogenous.

Regarding extensions, note that in our model the manager never obtains additional information over the course of time. Since manager's current estimate of the distribution of cash flows must equal the expected value of his future estimate, our results are robust to this possibility. A more interesting extension is to consider the case where the manager is able to influence the distribution of the future signal. The model of Section 4 allows for this in a limited form, where the manager can influence the announcement strategy of the uninformed analyst through his date 0 investment and financing choices. A fuller investigation of such 'signal jamming' possibilities, via earnings management for example, may be interesting.

6 Appendix

Proof of Proposition 2

1. Existence of a Solution to (13) **and** (14)

Define the function $\xi(\alpha, F; \beta)$, $\xi : [0,1] \times \mathbb{R}_+ \times (\frac{1}{2}, 1] \to \mathbb{R}^2$ as

$$\xi^1(\alpha, F; \beta) = \beta C_1(\alpha, F) + (1-\beta)\alpha V_1 - 1 \tag{25}$$

and

$$\xi^2(\alpha, F; \beta) = (1-\beta) C_2(\alpha, F) + \beta\alpha V_2 - 1 \tag{26}$$

Recall that $\xi(\alpha^*, F^*; 1) = 0$ where α^* and F^* solve (7) and (6) respectively. We wish to use the implicit function theorem to demonstrate the existence of an admissible solution to (25) and (26) when β is high enough. To do this we need to show that the Jacobian of ξ with respect to α and F when evaluated at $(\alpha^*, F^*; 1)$ is non–singular.

Denoting partial derivatives with subscripts:

$$\begin{aligned} \xi^1_\alpha(\alpha^*, F^*; 1) &= \frac{\partial C_1(\alpha^*, F^*)}{\partial \alpha} \\ \xi^1_F(\alpha^*, F^*; 1) &= \frac{\partial C_1(\alpha^*, F^*)}{\partial F} \\ \xi^2_\alpha(\alpha^*, F^*; 1) &= V_2 \\ \xi^2_F(\alpha^*, F^*; 1) &= 0 \end{aligned}$$

It follows that the relevant Jacobian is non–singular iff $\frac{\partial C_1(\alpha^*, F^*)}{\partial F} \neq 0$. But since

$$C_1(\alpha, F) = \int_0^F x dG(x|\theta_1) + F \int_F^{F/\alpha} dG(x|\theta_1) + \alpha \int_{F/\alpha}^{\infty} x dG(x|\theta_1),$$

we obtain

$$\frac{\partial C_1(\alpha^*, F^*)}{\partial F} = \left[G(\frac{F^*}{\alpha^*}|\theta_1) - G(F^*|\theta_1) \right] > 0$$

since $\alpha^* \in (0,1)$ and $F^* > 0$.

2. Existence of a pooling equilibrium

To show that pooling with such a security is indeed an equilibrium, we proceed backwards in time.

Date 1, $m = m_1$

In this case if the market conjectures that the bond will not be converted, then the share price will be given by the left–hand side of (17). As a result the manager will not be able to call the bond and so, from (15) it follows that it will not be converted. We also allow the manager to buy back the security in the market by issuing some other security. For any security S that is issued to buy back the debt, we assume that the market puts probability 1 on the type for whom $C_i(\alpha, F) - S_i$ is the maximum, where $S_i \equiv E[S(X)|\theta_i]$. Given such beliefs, it is straightforward to check that both types of the manager will either not want to issue such a security to buy back the existing claims, or will not be able to do so.

Date 1, $m = m_2$

In this case if the market conjectures that the bond will be converted, then the share price will be given by the right–hand side of (17). From (15) and (16), the manager will call to force conversion regardless of his private information and investors will convert when the security is called. If instead the manager tries to buy back the security and issue other claims S then, as above, the market attaches beliefs putting probability 1 on the type θ_i for whom $\alpha V_i - S_i$ is the maximum. No type of the manager will find such a deviation profitable.

Date 0

Given the call and conversion decisions of date 1 above, from (13) and (14) it follows that the market value of the security at date 0 will equal 1 dollar, the required outlay for the project. As a result, the manager, regardless of his private information, will be able to raise the required funds. The date 0 expected payoff of the existing shareholders will thus be equal to $V_i - 1 > A_i$ for each θ_i. Consequently, the manager will find it profitable to invest. Finally, we suppose that at date 0, if any type of the manager deviates by issuing some other security then the market puts probability 1 on type $\theta = \theta_1$. As a result, no type of the manager will find such a deviation profitable.

3. Comparative Statics: $\frac{\partial \alpha}{\partial \beta} > 0 > \frac{\partial F}{\partial \beta}$.

Notice first that each of the two equations (13) and (14) describe a downward sloping locus in the space of (α, F). Let L_1 and L_2 be the two loci. It is easy to verify that their slopes are given by

$$\left.\frac{\partial \alpha}{\partial F}\right|_{L_1} = -\frac{\beta \frac{\partial C_1}{\partial F}}{(1-\beta)V_1 + \beta \frac{\partial C_1}{\partial \alpha}}$$

and

$$\left.\frac{\partial \alpha}{\partial F}\right|_{L_2} = -\frac{(1-\beta) \frac{\partial C_2}{\partial F}}{\beta V_2 + (1-\beta) \frac{\partial C_2}{\partial \alpha}}$$

Furthermore, since $\beta > \frac{1}{2}$ and since $\alpha V_i < C_i(\alpha, F)$ for all $i = 1, 2$, inspection of (13) and (14) yields that as β rises L_1 shifts in and L_2 shifts out. To prove the desired result it therefore suffices to show that

$$\left.\frac{\partial \alpha}{\partial F}\right|_{L_1} < \left.\frac{\partial \alpha}{\partial F}\right|_{L_2} \tag{27}$$

To this end notice that

$$\frac{\partial C_i(\alpha, F)}{\partial \alpha} = \int_{\frac{F}{\alpha}}^{\infty} x dG(x|\theta_i)dx$$

and

$$\frac{\partial C_i(\alpha, F)}{\partial F} = G(\frac{F}{\alpha}|\theta_i) - G(F|\theta_i)$$

Using this, some algebra yields the following equivalent condition to (27):

$$\frac{G(\frac{F}{\alpha}|\theta_1) - G(F|\theta_1)}{G(\frac{F}{\alpha}|\theta_2) - G(F|\theta_2)} > \frac{1-\beta}{\beta} \frac{V_1 - \beta \int_0^{\frac{F}{\alpha}} x dG(x|\theta_1)}{V_2 - (1-\beta) \int_0^{\frac{F}{\alpha}} x dG(x|\theta_2)}$$

Note that as β goes to 1, the left–hand side of the last inequality stays bounded away from zero, while the right becomes becomes arbitrarily small. It follows that for β large enough, (27) obtains.■

Proof of Proposition 3

We begin our construction of the pooling equilibrium by considering the strategy of the uninformed analyst at date 1, on the equilibrium path. Since all types of the manager pool by issuing the same convertible S^*, neither the analyst nor the market learns nothing about θ from the date 0 financing decision. As a result, $\mu_i^0(S^*) = \lambda_i$ for all i. Since the informed analyst discloses the truth, this implies that the posterior probability that the market attaches to the analyst being informed after a message m_i is

$$\nu(m_i, S^*) = \frac{\lambda_i \gamma}{\lambda_i \gamma + \sigma_i(S^*)(1-\gamma)} \tag{28}$$

Since the uninformed analyst wants to maximize the posterior probability that he is informed, it follows that

$$\sigma_i(S^*) = \lambda_i \text{ and } \nu(m_i, S^*) = \gamma \text{ for all } i = 1, ..., N, \tag{29}$$

in equilibrium. To see this, note first that $\nu(m_i, S^*)$ cannot vary across messages m_i— if there exist messages m_i and m_j such that $\nu(m_i, S^*) > \nu(m_j, S^*)$, the uninformed analyst will strictly prefer to send message m_i (i.e., $\sigma_i(S^*) = 1$) implying that $\nu(m_i, S^*) = \frac{\lambda_i \gamma}{\lambda_i \gamma + (1-\gamma)} < 1 = \nu(m_j, S^*)$, a contradiction. So, we must have $\nu(m_i, S^*) = \kappa$ for some constant $\kappa \in [0,1]$ for all $i = 1, ..., N$. From (28) we then obtain

$$\sigma_i(S^*)(1-\gamma)\kappa = \lambda_i \gamma (1-\kappa)$$

for all i. Since $\sum_i \sigma_i(S^*) = 1$, it follows that $\kappa = \gamma$ and $\sigma_i(S^*) = \lambda_i$ for all i.

Having established the equilibrium behavior of the uninformed analyst, we now turn to the date 1 market value of the firm $\overline{V}(m_i, S^*)$ after a message m_i. Note that

$$\mu_i(m, S^*) = \begin{cases} \gamma + (1-\gamma)\lambda_i & \text{if } m = m_i \\ (1-\gamma)\lambda_i & \text{otherwise} \end{cases} \tag{30}$$

Thus,

$$\overline{V}(m_i, S^*) = \gamma V_i + (1-\gamma)\overline{V} \tag{31}$$

Since $\overline{V}(m_i, S^*) = V_i^*$ for all i, the security S^* entitles the new shareholders to convert to α_i^* shares when the market value of the security is $\overline{V}(m_i, S^*)$.

Next, we turn to the choice of the equity shares α^*. Since $\sigma_i(S^*) = \lambda_i$ for all i, type θ_i of the manager knows that the analyst's message will be m_i with probability $\gamma + (1-\gamma)\lambda_i$ and will be equal to m_j with probability $(1-\gamma)\lambda_j$ for $j \neq i$. We want to choose α^* such that the expected value of the claims sold in equilibrium is equal to the outlay of 1, for each type of the manager. That is, α_i^* must solve:

$$[\gamma + (1-\gamma)\lambda_i]\alpha_i^* V_i + (1-\gamma)\sum_{j\neq i}\lambda_j \alpha_j^* V_i = 1,$$

for all $i = 1, ..., N$. Re–arranging we obtain,

$$\gamma\alpha_i^* + (1-\gamma)\sum_{j=1}^{N}\lambda_j\alpha_j^* = \frac{1}{V_i}, \tag{32}$$

for all $i = 1, ..., N$. Multiplying by λ_i and summing over i we obtain $\sum_{j=1}^{N}\lambda_j\alpha_j^* = \frac{1}{\widehat{V}}$. Using this in (32) we obtain (22). It is easy to check that if $\gamma > \max[1 - \frac{\widehat{V}}{V_N}, \frac{\widehat{V}-V_1}{V_1(\widehat{V}-1)}]$ then $\alpha_i^* \in (0,1)$ for all i.

Given the equilibrium behavior derived above, the date 0 expected value of the claims sold by type θ_i of the manager is seen to be equal to 1, by construction. Thus, the date 0 market value of the security will also equal 1 and the expected payoff to the old claimholders will equal $V_i - 1 > A_i$ for all $i = 1, ..., N$. This implies that no type of the manager will prefer to under–invest.

Note that the manager is allowed to buy back the security S^* in the market by issuing some other security after a message m_i. For any security S that is issued to buy back the convertible, we assume that the market puts probability 1 on the type θ_j for whom $\alpha_i^* V_j - S_j$ is the maximum. Given such beliefs, it is straightforward to check that all types of the manager will either not want to issue such a security to buy back the existing claims, or will not be able to do so.

It remains to check that no type of the manager will want to deviate at date 0 by issuing a different security S'. We suppose that if any such security S' is issued by any type of the manager then the market attaches probability 1 to type θ_1, i.e., $\mu_1^0(S') = 1$. It follows that $\mu_1(m, S') = 1$ for all m so that $\overline{V}(m, S') = V_1$ for all m. Given such beliefs, it is straightforward to verify that no type of the manager will find such a deviation profitable, and we omit the details. ■

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3254 Steinberg Hall-Dietrich Hall
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