

TOBIAS BERG  
EVA SCHLIEPHAKE

# Market-Triggered Contingent Capital with Incomplete Information

We analyze the equilibria of market-triggered contingent capital if a bank's asset value is *not* common knowledge. Using a global game setup with private signals, we characterize the unique equilibrium for the conversion of the market-triggered contingent capital. The conversion likelihood increases with higher bank leverage, a higher face value of contingent capital, and a greater dilution for incumbent shareholders. We further show that the existence of both a private and a public signal constrains the optimal design of contingent capital for which a unique equilibrium exists.

G20, G21, G28

Keywords: contingent capital, banking regulation, risk-taking incentives, global games

## 1. INTRODUCTION

THE USE OF CONTINGENT CAPITAL—debt securities that convert into equity in times of distress—has received considerable interest in the debate on bank regulation. Contingent capital (or CoCo bonds) was originally proposed by Flannery (2005) as an instrument for bank stability. Properly designed, contingent

We would like to thank Toni Ahnert, Andreas Barth, Philipp König, George Pennacchi, Paul Schempp, Günter Strobl, Javier Suarez, Lucy White, and conference participants at the Baffi Carefin 2016 conference at Bocconi University and two anonymous referees for valuable comments and suggestions that helped to improve the quality of this paper. Eva Schliephake acknowledges financial support from FCT - Portuguese Foundation of Science and Technology for the project PTDC/EGE-ECO/6041/2020. All remaining errors are our own.

TOBIAS BERG is a Professor of Finance at Goethe University Frankfurt (E-mail: berg@econ.uni-frankfurt.de). EVA SCHLIEPHAKE is an Assistant Professor of Finance at Universidade Católica Portuguesa, Católica Lisbon School of Business & Economics, Portugal (E-mail: schliephake@ucp.pt).

Received April 22, 2020; and accepted in revised form May 15, 2024.

*Journal of Money, Credit and Banking*, Vol. 0, No. 0 (June 2024)

© 2024 The Author(s). *Journal of Money, Credit and Banking* published by Wiley Periodicals LLC on behalf of Ohio State University.

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

capital strengthens a bank's financial stability, as it absorbs losses and fosters incentives to promptly replace lost capital (Calomiris and Herring 2013). Contingent capital has been controversial, in part, because of the possibility of equilibrium multiplicity (Sundaresan and Wang 2015, Glasserman and Nouri 2016, Pennacchi and Tchisty 2018). In this paper, we use the global games approach of Morris and Shin (2003) to address equilibrium multiplicity in contingent capital.

Equilibrium uniqueness is important for (at least) two reasons. First, equilibrium multiplicity introduces the potential for price uncertainty and market manipulation, thus severely limiting the appeal to investors and issuers (see Sundaresan and Wang 2015). Such detrimental effects of equilibrium multiplicity have been shown not only in theory but also in an experimental setting (Davis, Korenok, and Prescott 2014). Second, the possibility of influencing banks' behavior by appropriately designed contingent capital has been at the center of various academic writings on this topic (Koziol and Lawrenz 2012, Calomiris and Herring 2013, Albul, Jaffee, and Tchisty 2016, Hilscher and Raviv 2014), Himmelberg and Tsyplakov 2012, Berg and Kaserer 2015, Pennacchi, Vermaelen, and Wolff 2014, Eufinger and Gill 2016). Flannery (2016) notes that market-triggered contingent capital may reduce incentives for excessive risk-taking and can overcome the supervisory reluctance to recognize and acknowledge the nonviability of a financial institution. However, multiple equilibria may preclude a design that properly influences a bank's incentives because conversion effectively depends on sunspot realizations. The potential for multiple equilibria has therefore been key for policymakers' assessment of the usefulness of contingent capital for banking regulation.<sup>1</sup>

Prior literature has assumed that bank asset value is public information.<sup>2</sup> Exceptions include Berg and Kaserer (2015) and Derksen, Spreij, and van Wijnbergen (2018), who analyze contingent capital that is triggered based on accounting ratios using the incomplete accounting information framework of Duffie and Lando (2001). With accounting-based triggers, a unique equilibrium always prevails, regardless of whether the asset value is common knowledge. The incomplete accounting information framework thus primarily helps to understand the pricing of contingent capital. The model of Pennacchi, Vermaelen, and Wolff (2014) encompasses mean-reverting deviations of market prices from fundamentals. Again, the model is set up such that a unique equilibrium exists if asset values are fully observable.

In this paper, we relax the assumption found in the prior literature. We assume that bank asset values are *not* common knowledge. We show that a unique equilibrium exists if investors receive relatively precise private information on the bank's risky assets. The unique equilibrium takes the form of an endogenous threshold asset value

1. See the review in Section 4.2 of Flannery (2016) for more details about the impact of equilibrium multiplicity on the design and use of contingent capital.

2. See the reviews by Flannery, Kwan, and Nimalendran (2013) and Flannery (2016) as well as Koziol and Lawrenz (2012), Calomiris and Herring (2013), Albul, Jaffee, and Tchisty (2016), Hilscher and Raviv (2014), Himmelberg and Tsyplakov (2012), and Eufinger and Gill (2016).

below which conversion always occurs and above which conversion never occurs. We also show that the conversion triggering asset value is greater than that defined by the trigger value because of strategic complementarity among traders.

Our paper contributes to the literature on potential harms and benefits from contingent capital in three ways. First, we show that contingent capital obtains a unique conversion equilibrium even when trading is intermittent. We show that asset value uncertainty is another model ingredient that can lead to equilibrium uniqueness. We analyze the market characteristics under which the benefits of contingent capital can be fully exploited without introducing the price uncertainty and market inefficiency caused by multiple price equilibria.

Second, we analyze how the particular design of the contingent capital contract and the issuer's characteristics affect the *ex ante* probability of conversion. In particular, we show that conversion becomes more likely when more contingent capital is issued by an institution, when the contracted conversion trigger is higher, and when more outstanding shares are owned by contingent capital holders after conversion (i.e., the likelihood of conversion increases with the level of dilution implied by the contingent capital).

Third, we show that the existence of a unique equilibrium depends on the prevailing market microstructure, the precision of private and public information, and the proportion of noise traders in the market. Following the distinction of Challe and Chrétien (2018), we first focus on pure market order markets in our basic model setup and analyze the implications for full demand schedule markets in the extended model in Section 4. We show that in a pure market order market, equilibrium uniqueness can be preserved, given the precision of signals, if the number of shares promised to contingent capital owners after conversion is not too high given the contracted trigger value. In markets where full demand schedules prevail, price uniqueness requires that the effect of the coordinated behavior of strategic traders on the asset value is not too high compared to the noise in the market clearing.

The main policy implication of our analysis therefore is that highly dilutive contingent capital—often advocated on the grounds of reducing agency problems<sup>3</sup>—might not be optimal for the issuing bank (or for welfare in general) if triggering contingent capital has associated costs or because multiple conversion equilibria might be undesirable.

Our assumption on the absence of common knowledge of bank asset value is crucial for understanding contingent capital for two reasons. First, empirical work supports the notion that bank asset values are not common knowledge (Morgan 2002). Asymmetric information about bank asset values can be elevated during crisis episodes (Flannery, Kwan, and Nimalendran 2013), that is, when contingent capital is likely to be the most important.

3. See, for example, Flannery, Kwan, and Nimalendran (2013), Himmelberg and Tsyplakov (2012), Berg and Kaserer (2015), and Flannery (2016).

Second, the literature on global games has established that incomplete information can have strikingly different implications for the uniqueness of equilibria compared to common knowledge games (Carlsson and van Damme 1993, Morris and Shin 2003). In finance, global games are often used to assess the likelihood of self-fulfilling crises and to evaluate the impact of policies on the financial stability of institutions and contracts (Morris and Shin 1998, Morris and Shin 2004, Goldstein and Pauzner 2005, Allen et al. 2017, Leonello 2018). Bond and Goldstein (2015) present a global game in which traders affect their expected payoff by actively trading against each other. Our model applies the same logic, but the outcomes are driven by the inherent design of the contingent capital contract. Challe and Chrétien (2018) study the role played by the microstructure of the asset market in the emergence of information aggregation-driven multiple equilibria. They prove that high private signal precision leads to unique equilibria in pure market order markets, but in demand schedule markets, unique equilibria only exist if noise trading prevents the revelation of the precise private information. We follow their distinction and focus on pure market order markets in our basic model setup. In Section 4, we extend our results to a demand schedule market. In contrast to their focus on asset market outcomes, our model features the feedback effect of contingent capital conversion on the final payoffs of traders. This feedback effect is explicitly discussed by Ozdenoren and Yuan (2008) who develop a global game with a demand schedule micromarket structure that allows for feedback effects and strategic complementarity between informed traders. We adapt their model to market-triggered contingent capital and describe in detail the conditions for a unique pricing equilibrium.

Chan and Van Wijnbergen (2015) study the impact of a contingent capital conversion triggered by a regulator. Their study focuses on the *ex post* impact of conversion on the bank's fragility to bank runs and on systemic risk with different institutional setups. The question of when and why the conversion is triggered is not addressed in their paper. In contrast, we are interested in how the actions of investors in the asset market determine the conversion of market-triggered contingent capital. We use the global game setup to analyze the *ex ante* conversion probability of market-triggered contingent capital and how this probability is affected by the design of the contingent capital contract.

Davis, Korenok, and Prescott (2014) perform an experimental study to compare the price informativeness and efficiency of different contingent capital triggers. In the experiment, the fundamental asset value is common knowledge but there is uncertainty regarding the private valuation of the asset. The results of the experiment show that the markets are less informative for assets funded with market-triggered contingent capital, but market-triggered regimes considerably narrow the range of fundamental realizations where conversion errors occur. We argue that, if investors obtain a private signal that is noisy but relatively precise in relation to the public signal, the conversion error disappears because a unique equilibrium exists.

Glasserman and Nouri (2016) and Pennacchi and Tchistyi (2018) analyze sequential complete information setups that allow traders to learn from stock price

movements that aggregate information. Glasserman and Nouri (2016) show that a static setup can give rise to multiple equilibria while continuous trading admits just one equilibrium. With illiquid intermittent trading (e.g., the suspension of stocks from trading or a full market closure during market turmoil), the multiple equilibrium result from Sundaresan and Wang (2015) is confirmed. Pennacchi and Tchisty (2018) argue that the problem of multiple equilibria vanishes for market-triggered contingent capital with perpetual maturity. Moreover, Pennacchi and Tchisty (2019) explain a mistake in the proof of the main result in Sundaresan and Wang (2015) that resulted in an incorrect claim about the multiplicity of equilibria in a dynamic setup under the assumption of complete information. Glasserman and Nouri (2016) and Pennacchi and Tchisty (2018) show that multiple equilibria do not exist in markets with complete information and continuous trading, where all traders perfectly anticipate and observe the true fundamental value of the bank's assets.

Have these papers "solved" the multiple equilibrium problem of market-triggered contingent capital? Yes and no. They have solved it for settings with continuous trading, perpetual maturity, and complete information. Although this is a significant achievement, not all contingent capital instruments have perpetual maturity, and trading is typically not continuous. This is particularly true in times of crisis when contingent capital arguably matters most. Our paper "solves" the multiple equilibrium problem in a model with one investment period, one return period, and an interim period for information under the assumption that asset values are not perfectly observable. Our results are thus complementary because we relax the strong assumption of perfect information by assuming that banks' assets are not common knowledge and that traders receive only noisy signals of their true asset value. Given that the absence of common knowledge of a bank's asset value motivates the existence of banks and that intermittent trading is of particular importance in times of crisis, we think that it is of first-order importance to understand the implications of the no-common-knowledge assumption for contingent capital design.

We proceed as follows. Section 2 introduces the basic model setup and derives the unique equilibrium under the assumption that traders use market orders and receive only private signals. Section 3 extends the model to allow traders to observe the historical share price as a public signal and derive the signal precision conditions for equilibrium uniqueness. Section 4 extends the model to a demand schedule market where the market clearing price provides an endogenous public signal. In addition to the informed strategic traders in our basic model setup, we add noise traders and liquidity traders that clear the market. We show that a unique price equilibrium also exists in markets in which demand schedules predominate if noise trading prevents the revelation of the private information. In Section 5, we summarize the implications of our analysis regarding the optimal design of contingent capital, and Section 6 concludes the paper.

## 2. MODEL SETUP

We consider an economy with three dates  $t \in \{0, 1, 2\}$ . At date  $t = 0$ , a bank invests in assets.<sup>4</sup> Asset returns are paid out at date 2. They are initially unknown, but at date 1, traders receive noisy and unbiased signals about them. After observing their signals, traders submit market orders for shares of the bank.<sup>5</sup> They do so simultaneously and independently, taking account of the signals they have received. The market orders are specified as fixed quantities. Traders are not allowed to condition these orders on the prevailing price. In other words, traders decide to buy or sell a fixed quantity of the share unconditionally on the execution price. We show that, with incomplete information, a unique equilibrium exists in such a static game. A static setup reflects illiquid intermittent trading—such as the suspension of stocks from trading or full market closure—which is more likely to occur in times of market turmoil. Therefore, our model precisely captures those situations where contingent capital is likely to be important for financial stability.

Consider a bank with assets of uncertain value  $A$ , funded by senior debt with face value  $B$ , contingent capital with face value  $C$ , and equity capital that—for notional convenience and without loss of generality—we assume to consist of a single share outstanding. Conversion of contingent capital is triggered by a low asset value realization that would result in a market value below exogenously given threshold  $L$ . Upon conversion, contingent capital holders receive  $m$  newly issued shares, so equity holders own a fraction of  $1/(1 + m)$  of the shares outstanding after conversion.

Following Sundaresan and Wang (2015), we introduce two hypothetical equity values. The first is the value of equity (per share) if conversion never occurs ( $S_H$ ). The second is the value of equity (per share) if conversion always occurs ( $S_L$ ). These two values can be derived as follows:

$$S_H(A) = \max(A - B - C, 0), \quad (1)$$

$$S_L(A) = \max(A - B, 0) \cdot \frac{1}{1 + m}. \quad (2)$$

The bank's share value is equal to  $S_H$  when conversion does not occur, and  $S_L$  when conversion occurs.

Multiple equilibria exist if  $L > C/m$ . As an example, assume that  $B = 80$ ,  $C = 10$ ,  $m = 3$ , and the conversion trigger is set to  $L = 5$ . In this case, the equity value can admit multiple equilibria. For an asset value of  $A = 99$ , no conversion results

4. Any firm could, in principle, issue market-triggered contingent capital, but, in practice, only banks do so. Therefore, we consistently refer to the issuer as a "bank."

5. The assumption of a pure market order market allows us to simplify the model and focus on how the design of contingent capital affects the likelihood of conversion. We extend our model in Section 4 to a full demand schedule market structure with noise traders.

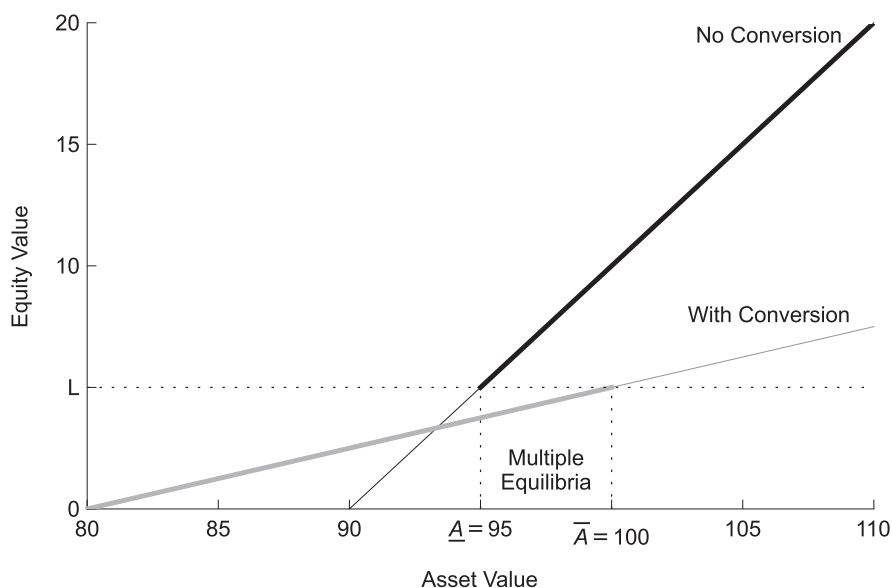


Fig 1. Multiple Equilibria in the Presence of Contingent Capital.

NOTES: This figure is based on the assumptions made in Sundaresan and Wang (2015) who assume that bank asset values are perfectly observable by all market participants. Parameters used are  $B = 80$ ,  $C = 10$ ,  $m = 3$ , and  $L = 5$ .

in an equity value of  $S_H(A) = \max(99 - 80 - 10, 0) = 9 > L$ , which is above the conversion trigger. Furthermore, the conversion to a resulting equity value of  $S_L(A) = \max(99 - 80, 0) \cdot 1/4 = 4.75 \leq L$  constitutes an equilibrium outcome.

We depict the asset value region for which multiple equilibria exist in Figure 1. Equilibrium values are highlighted in bold: the no-conversion line is an equilibrium outcome whenever  $S_H(A) > L$ . The with-conversion line is an equilibrium outcome whenever  $S_L(A) \leq L$ . The critical asset values are implicitly defined by  $S_H(\underline{A}) = L$ , that is,  $\underline{A} = L + B + C$  and  $S_L(\bar{A}) = L$ , that is,  $\bar{A} = (1 + m)L + B$ . It is straightforward to show that the multiple equilibria region is nonempty, that is,  $\underline{A} < \bar{A}$  iff  $L > \frac{C}{m}$ .

Whenever the fundamental value falls in multiple equilibria region  $A \in [\underline{A}, \bar{A}]$ , both statements are true: If no conversion occurs, the asset value is above the conversion trigger value (thick black line). Therefore, no contingent capital conversion is an equilibrium outcome. However, it is also true that if a conversion occurs, the asset value drops below the trigger value (bold red line), such that conversion is also an equilibrium.

The existence of multiple equilibria, however, crucially depends on the assumption that the bank's asset value is perfectly observable by all market participants. If the private information is noisy but informative, the game has a unique equilibrium even though the corresponding common information game results in multiple equilibria.

**Assumption 1.** Incomplete information about the bank's asset value

Traders cannot directly observe asset value  $A$  but instead receive a noisy and unbiased signal about the true asset value:

$$x_i = A + \sigma \epsilon_i, \quad (3)$$

where subindex  $i$  denotes the  $i$ th trader and  $\sigma > 0$  is a measure of the signal precision. Conditional on the true asset value, the signals of all traders are independent and identically distributed. We assume that noise term  $\epsilon_i$  has zero mean and is distributed with cumulative probability function  $F$  for which density  $f$  exists.

Furthermore, we assume that traders have an uninformative prior on true asset value  $A$ .<sup>6</sup>

Assumption 1 is the key assumption that distinguishes our analysis from the prior literature on contingent capital.

**Assumption 2.** Dilutive contingent capital

To focus on situations in which multiple equilibria exist, we assume that the conversion of the contingent bond into capital is highly dilutive, which implies that it is disadvantageous to shareholders. Contingent capital is dilutive if the trigger value ( $L$ ) is sufficiently high:

$$L > \frac{C}{m}. \quad (4)$$

This equation can be easily reformulated as

$$\frac{m}{m+1}(L+C) > C. \quad (5)$$

The left-hand side of this condition is akin to a postconversion value of the contingent capital (the percentage of shares held by contingent capital holders after conversion is multiplied by the sum of the trigger value and contingent capital notional), while the right-hand side is akin to a no-conversion value of the contingent capital. We make Assumption 2 for two reasons. First, in the literature that argues for contingent capital, a dilutive conversion ratio has been proposed to provide—in addition to a higher loss absorption capacity—disincentives for excessive risk-taking and incentives for an early recapitalization of banks. Second, this assumption implies the existence of multiple equilibria for stock prices when asset values are common knowledge.<sup>7</sup>

6. This assumption ensures that signal  $x_i$  captures all information available to traders about the true asset value. If each trader has a private prior about the true asset value, then this prior acts like a second signal, and traders' posteriors can be determined by appropriately averaging the prior and signal  $x_i$ . For a public prior or an additional public signal, see Section 3. We also extend our proof for a general prior in Section A.5 of our Online Appendix.

7. This is the most interesting case for our study. The opposite case of nondilutive contingent capital, for which the conversion of capital would increase the incumbent shareholder's value, is discussed in Section C of our Online Appendix. In this case, no market price equilibria exist for a certain range of asset values.



We now analyze the equilibrium in which information is incomplete and dispersed among all agents. Initially, homogeneous traders receive a private signal based on which they decide to buy or short-sell the stock of the bank that issued the contingent capital. Both actions generate an exogenous payoff that is profitable if successful, that is, if conversion is indeed triggered or prevented.<sup>8</sup> We relax this assumption in Section B of our Online Appendix.<sup>9</sup>

The trader's choice between the two actions creates a link between the realized share price and the actions of the trader: Given the fundamental value of the bank's assets, buy orders slightly above threshold value  $L$  drive the price beyond the threshold value, and therefore, prevent a conversion. In contrast, short-sale orders placed just below the threshold value push the share price below the threshold  $L$ , thereby triggering conversion. The critical mass condition for a regime switch (a conversion) necessitates that a greater number of traders short-sell the share compared to those offering to buy the share.

Formally, we assume that a continuum of risk-neutral traders,  $i \in [0, 1]$ , exists with endowment  $w \geq L$ . Each trader can choose from two actions  $a \in \{0, 1\}$ , where  $a=1$  denotes buying one share and  $a=0$  denotes (short-) selling one share of equity.<sup>10</sup>

In the following, we first establish that it is optimal for each trader to submit buy or sell orders "close to" the conversion threshold  $L$ , that is, either just below  $L$  (if a trader believes conversion will occur) or just above  $L$  (if a trader believes, no conversion will occur). Second, we derive the payoffs for each trader under the assumption that the submitted quotes are either slightly above or slightly below the conversion threshold.

If the fundamental asset value falls in the multiple equilibria region  $A \in [\underline{A}, \bar{A}]$ , there is a potential gain from conversion from which an outside trader can benefit, that is, he or she can short-sell the stock at price  $p_{S,i} \leq L - \mu$ , where  $\mu$  is arbitrarily close to zero. In such a quote-driven market, conversion occurs when the market clearing price is smaller than  $L$ .<sup>11</sup> If the conversion occurs, the *ex post* value of the stock equals  $S_L(A) \leq L$  and the trader makes a net profit of  $(p_{S,i} - S_L(A))$ . If the conversion does

8. The simplifying assumption of exogenous payoffs is very common in applications of global games in financial economics (e.g., Morris and Shin (2003), Dasgupta (2007), Plantin, Sapra, and Shin (2008), Ahnert and Kakhbod (2017)).

9. In Section B of our Online Appendix, we provide an extension in which payoffs are endogenously determined by the market clearing condition. When the expected payoff of traders considers the probability of selling orders being executed, the expected payoffs are strategic complements close to the conversion mass, but further away, they become strategic substitutes. Intuitively, each trader wants to be on the winning side, but their payoff is the highest when they are merely the pivotal trader. We also show that in settings with endogenous payoff probabilities, a unique switching equilibrium exists.

10. The quantity restriction replaces the usual risk aversion assumption of CARA utility as, for example, in Bond and Goldstein (2015) and allows us to explicitly determine closed-form solutions. The introduction of risk-averse traders who optimally allocate their endowment between a safe investment and a risky share investment would not change our qualitative results.

11. This setup reflects a simplified demand schedule model with fixed quantities. In Section B of our Online Appendix, we extend the setup to endogenously determine the probabilities of buy orders being executed.

not occur, the value of the stock turns out to be  $S_H(A) \geq L$ , and the trader incurs a net loss of  $-(S_H(A) - p_{S,i})$ .

Alternatively, a trader can buy the asset at price  $p_{B,i} \geq L + \mu$  where  $\mu \rightarrow 0$ . If conversion does not occur, the *ex post* share value is  $S_H(A)$ , and the trader makes a profit of  $S_H(A) - p_{B,i}$ . However, if conversion occurs despite the placed buy offer, the trader incurs a loss of  $-(p_{B,i} - S_L(A))$ .

We now derive conditions for the optimality of placing either a buy or a sell order. Assume that a trader decides to place a buy order. This trader faces the following individual maximization problem when choosing the price at which to place the buy order:

$$\max_{p_{B,i} \in (L, \infty)} E[-(p_{B,i} - S_L(A))|x_i] + E[S_H(A) - p_{B,i}|x_i]. \quad (6)$$

A trader deciding to place a sell order encounters the corresponding individual maximization problem:

$$\max_{p_{S,i} \in (0, L)} E[p_{S,i} - S_L(A)|x_i] + E[-(S_H(A) - p_{S,i})|x_i]. \quad (7)$$

Short-selling at a price lower than  $L$  would not increase the likelihood of conversion but would decrease the short-sellers' total profit (and vice versa). If short-sellers submitting the lowest prices have a higher likelihood of trade execution, traders with particularly negative signals about the fundamentals might prefer to submit short-sell orders at an even lower price. However, our primary interest lies in the aggregate outcomes rather than distributional effects among various traders. Therefore, we assume uniform pricing among all traders rather than discriminatory pricing. It is straightforward to see that  $p_{B,i} = p_B = L + \mu$  and  $p_{S,i} = p_S = L - \mu$  such that  $\lim_{\mu \rightarrow 0} p_B = p_S = L$ .

After all submitted offers are integrated into the trading book, excess demand for the stock results in no conversion, leading to a share value of  $S_H(A)$  in  $t = 2$ . In contrast, an excess supply of the stock triggers the conversion of the contingent capital and results in an *ex post* share value of  $S_L(A)$ .<sup>12</sup> While  $\lambda$  is fixed, conversion is triggered by the endogenous decision of agents to either buy or sell the stock. As traders take either a short or a long position after receiving their private signal, the critical mass condition that triggers conversion is that there are more investors short-selling the stock than there are traders willing to buy the stock.

This situation results in the payoff matrix provided in Figure 2.

12. The most sensible assumption is that conversion will occur if more traders short-sell than buy the stock, that is, the critical mass of buyers needed to prevent conversion is  $\lambda = 0.5$ . However, our results hold for any arbitrary  $\lambda \in [0, 1]$ . If agents were only allowed to buy the asset at the current stock price (unknown to agents at that moment), the critical mass would be  $\lambda = \frac{L}{S_H(A)}$ .

		Other traders	
		Conversion $\ell \leq \lambda$	No Conversion $\ell > \lambda$
Trader	Buy	$-(L - S_L(A))$	$(S_H(A) - L)$
	Sell	$(L - S_L(A))$	$-(S_H(A) - L)$

Fig 2. The Action Related Payoff Conditional on Other Traders' Actions.

The resulting trader's net utility from buying the stock (action  $a = 1$ ) is:

$$\pi(\ell, A) = \begin{cases} -2(L - S_L(A)) & \text{if } \ell \leq \lambda \\ 2(S_H(A) - L) & \text{if } \ell > \lambda. \end{cases} \quad (8)$$

The net utility of action  $a = 1$  is increasing in the asset value realization and proportion  $\ell$  of traders that choose to buy the stock.

Traders can neither observe the true value of  $A$  nor the signals that other traders receive. They base their decisions to buy or sell entirely on their observations of noisy signal  $x_i$ . The signal, however, not only conveys information about the true asset value but also about the beliefs of other traders, their beliefs about other traders' beliefs (higher order beliefs), and the corresponding actions of those traders. Based on those higher order beliefs, there exists a unique equilibrium that we summarize in the following proposition.

**PROPOSITION 1.** *With exogenous payoffs, there exists a unique equilibrium. In this equilibrium, traders play a symmetric switching strategy with threshold  $\Lambda$ . In this equilibrium, contingent capital converts if and only if  $A \leq \Lambda$ .*

The detailed proof can be found in Section A.1 of our Online Appendix. We summarize the rationale for the proof in the following.

In deciding the optimal strategy, a trader forms expectations not only on the gain from buying the stock but also on the expected proportion of other traders who also buy. In contrast to a complete information game, in a game where the asset value is observed only with noise, agents form higher order beliefs on the signal distribution of the other traders and their corresponding actions.

Assume that all traders adopt a simple switching strategy, short-selling whenever they receive a signal below an arbitrary value  $k$  and buying otherwise. Consequently, when the value of the bank's assets is higher, fewer traders receive a low signal and short-sell.

Anticipating that all other traders play a switching strategy at  $k$ , each trader forms expectations on the proportion of other traders that receive a signal below the critical value (and therefore short-sell). Therefore, a higher  $k$  results in a higher percentage of others short-selling for a given realization of the asset value. The expected net utility of a buyer decreases in critical switching point  $k$  chosen by all traders.

The question is, does a  $k := \Lambda$  exist such that strategy profile  $a = 0$  if  $x_i < k$  and  $a = 1$  if  $x_i > k$  is the dominant strategy for all traders? If such a unique value exists that defines the optimal switching strategy, the trader that receives signal  $x_i = \Lambda$  must be indifferent between buying and selling.

Due to dominance region  $(A < \underline{A}, A > \bar{A})$  where conversion and nonconversion certainly occur, the trader that receives a very low signal infers that many other traders must obtain a low signal. Forming higher order beliefs on their beliefs and corresponding actions, he or she anticipates that many other traders will sell the asset because they believe that conversion will be triggered. As a result, conversion becomes very likely such that short-selling becomes the preferred option: the net expected utility from buying is negative. Similarly, for very high signals, the trader anticipates that many other traders receive a good signal such that, forming higher order beliefs on others' beliefs and corresponding actions, he or she infers that conversion is improbable; thus, he or she will buy the asset because the net expected utility is positive. Therefore, as the expected net utility from buying decreases in  $k$ , there must exist a unique  $\Lambda$  for which the net expected utility of a short-selling trader who receives signal  $x_i = \Lambda$  is zero such that he or she is indeed indifferent between buying and selling.<sup>13</sup>

As a corollary, it directly follows that:

**COROLLARY 1.** *The unique equilibrium implies that the ex post share values are unambiguously determined by the fundamental asset value, that is,*

$$S(A) = \begin{cases} S_L(A) & \text{if } A \leq \Lambda \\ S_H(A) & \text{if } A > \Lambda. \end{cases}$$

In the limit, where  $\sigma \rightarrow 0$ , we can explicitly solve for  $\Lambda$ . Without any public information, the trader's signal is the best estimate he or she has about the true asset value. If a trader receives signal  $x_i = \Lambda$ , his or her best estimate of other traders' information is that there are as many traders that receive a worse signal as there are traders that receive a better signal than his or her own signal. From the proof of Proposition 1 in Section A.1 of our Online Appendix, we know that the probability the indifferent trader assigns to a proportion less than  $\ell$  of the other traders observing a signal greater than  $\Lambda$  if the observed signal  $x_i = \Lambda$  is uniformly distributed (see Formula (27) in the Online Appendix). Thus, we can express the indifferent trader's net expected utility from buying as

$$\int_0^1 \pi(\ell, \Lambda) d\ell = \int_0^{\frac{1}{2}} -2(L - S_L(\Lambda))d\ell + \int_{\frac{1}{2}}^1 2(S_H(\Lambda) - L)d\ell = 0. \quad (9)$$

13. Our argument for uniqueness bears some relation to that in the continuous-time models with common knowledge by Pennacchi and Tchistyi (2019). In essence, both approaches establish a continuous structure on the price that market participants are willing to pay, either by using continuous trading or by using a continuum of traders with different private signals.

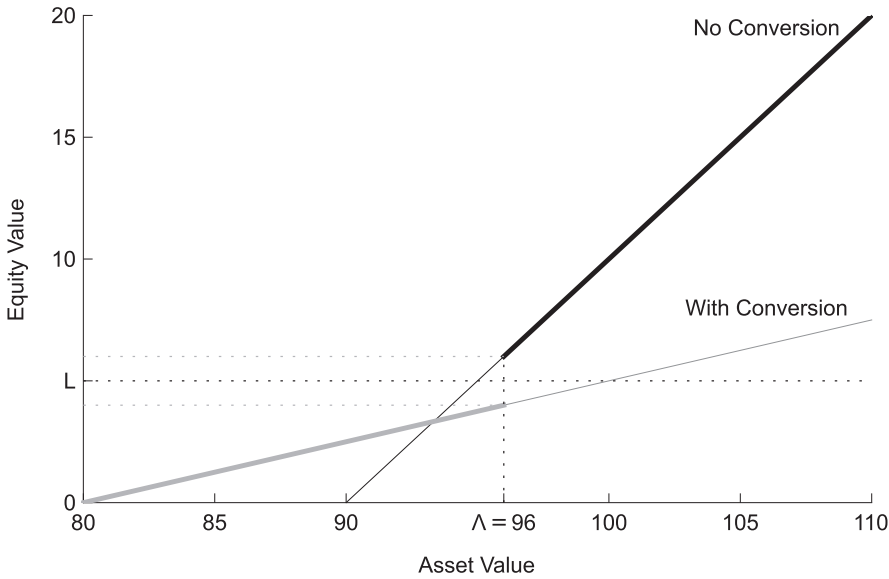


Fig 3. Unique Equilibrium in the Presence of Contingent Capital.

NOTES: The parameters used are  $B = 80$ ,  $C = 10$ ,  $m = 3$ , and  $L = 5$ .

In the limit, where  $\sigma \rightarrow 0$ , the critical asset value realization that defines the optimal switching strategy is therefore given by

$$\Lambda = B + \frac{(m+1)(C+2L)}{m+2}. \quad (10)$$

Using our numerical example, the critical asset value would be  $\Lambda = 96$  as illustrated in Figure 3.

Our explicit result allows us to perform comparative statics. Critical value  $\Lambda$  equalizes the gains from buying and selling, that is, the distance from trigger value  $L$  to the resulting stock price in cases of conversion and nonconversion. A higher critical asset value implies that conversion occurs for a broader range of true asset value realizations. Conversion becomes more likely for any distribution of the asset value.

**PROPOSITION 2.** *Higher bank leverage  $B$ , a higher face value  $C$ , a higher contracted trigger value  $L$ , and a higher contracted conversion share  $m$  increase the probability of contingent capital conversion, ceteris paribus.*

The conversion of the contingent capital becomes more likely for higher unique threshold values  $\Lambda$  given a certain distribution of the asset value. An increase in outstanding debt  $B$  increases critical asset value  $\Lambda$ . Formally,  $\frac{\partial \Lambda}{\partial B} = 1 > 0$ . A higher face value  $C$  of contingent capital also results in a higher probability of conversion. The marginal change in the threshold value is positive:  $\frac{\partial \Lambda}{\partial C} = \frac{(m+1)}{m+2} > 0$ . An increase in

$C$  shifts the red line down and leaves the black line unchanged, forcing, again, an increase in the critical asset value. A higher contracted trigger value  $L$  leads to the more likely conversion of contingent capital:  $\frac{\partial \Delta}{\partial L} = \frac{2(m+1)}{m+2} > 0$ . Figure 2

Finally, and most interesting, a higher contracted conversion share  $m$  makes conversion more likely:  $\frac{\partial \Delta}{\partial m} = \frac{(C+2L)}{(2+m)^2} > 0$ . A higher  $m$  implies higher dilution costs for equity holders, and thus, higher gains for traders that sell the asset and therefore benefit from conversion. Therefore, short-selling the contingent capital becomes more attractive, which makes conversion more likely to occur. Graphically, an increase in  $m$  decreases the slope of the red line, thereby reducing the distance to the trigger value, which implies a shift to the right in the critical asset value.

### 3. HISTORICAL ASSET VALUE AS EXOGENOUS PUBLIC SIGNAL

The results of the previous section apply to the situation in which traders observe only a private signal.<sup>14</sup> In this section, we extend our analysis to formally investigate the impact of a public signal on the equilibrium outcome. This extension is built upon the work of Morris and Shin (2003) and Hellwig (2002), demonstrating that a unique equilibrium always exists if the precision of the private relative to the public noise is sufficiently high.

As before, we assume that each investor receives a private, noisy signal.

$$x_i = A_1 + \sigma \epsilon_i, \quad (11)$$

where  $\sigma \epsilon_i$  is normally distributed with mean 0 and precision  $\beta$ .<sup>15</sup> The only difference with (3) in the private signal is subscript  $A_1$ . The subscript introduces the idea of a stylized intertemporal setup where past prices provide a natural public signal to investors on the prior distribution of  $A_1$ :

$$A_1 = A_0 + \eta \text{ with } \eta \sim \mathcal{N}(0, v^2). \quad (12)$$

In our static model context, this equation implies that all investors observe  $A_0$  at  $t = 0$  before making their investment decision at  $t = 1$ . Instead of having an improper prior, investors now know that the uncertain asset value  $A_1$  is normally distributed with mean  $A_0$  and precision  $\alpha = 1/v^2$ .

14. This situation was ensured by assuming that investors have an improper prior, for example, that any realization of  $A$  was equally likely. This ensured that the posterior beliefs were well behaved, exhibiting the convenient characteristic that the observed signal  $A_i$  served as the best estimate of the actual  $A$  for each investor.

15. We use the precision rather than the variance here to facilitate the notation of the posterior distribution.

**PROPOSITION 3.** *If investors observe a public signal with precision  $\alpha$  and a private signal with precision  $\beta$ , condition*

$$\frac{\alpha}{\beta} \sqrt{\alpha + \beta} \leq \sqrt{2\pi} \frac{(mL - C)^{-1}}{1 + m} \quad (13)$$

*is sufficient to secure a unique conversion equilibrium.*

The detailed derivation of the condition on the relative precision is presented in Section A.2 of our Online Appendix.

The left-hand side (LHS) of Condition (13) increases in  $\alpha$  and decreases in  $\beta$ . Since  $\alpha$  is a measure of public signal precision and  $\beta$  is a measure of the precision of the private signal, Condition (13) is satisfied whenever private signals are relatively precise compared to public signals. At the extreme, if the public signal is uninformative ( $\alpha = 0$ ), Condition (13) is always fulfilled, and we return to our basic model setup.

The right-hand side (RHS) of the condition depends on the contract parameters of the contingent capital. In particular, the RHS decreases in contracted conversion share  $m$  and trigger value  $L$  but increases in face value  $C$ . Given precisions  $\alpha$  and  $\beta$ , the sufficient condition for a unique equilibrium therefore becomes stricter as  $mL - C$  increases, that is, as the set of asset values,  $[\underline{A}, \bar{A}]$ , increases for which multiple equilibria exist.<sup>16</sup>

If the precision of information is exogenous, the unique equilibrium condition can be interpreted as an upper limit on the conversion trigger,  $L < \bar{L}(m, C)$ , as a function of face value  $C$  and the contracted shares allocated to contingent capital holders after conversion,  $m$ . We obtain

$$\bar{L}(\alpha, \beta, m, C) = \frac{C}{m} + \frac{\sqrt{2\pi}}{\frac{\alpha}{\beta} \sqrt{\alpha + \beta}} \frac{m^{-1}}{(1 + m)}. \quad (14)$$

This upper limit consists of two terms. The first term captures Assumption 2, which states that conversion of contingent capital harms incumbent shareholders:  $L > C/m$ . The second term represents a measure of the precision of the private signal relative to the asset risk scaled by a shareholder dilution factor. The upper limit increases in the precision of the private signal. At the limit,  $\lim_{\beta \rightarrow \infty} \bar{L}(\alpha, \beta, m, C) = \frac{\infty}{m}$ . At the other extreme, when the private signal becomes uninformative or the public signal becomes extremely precise  $\lim_{\beta \rightarrow 0} \bar{L}(\alpha, \beta, m, C) = \lim_{\alpha \rightarrow \infty} \bar{L}(\alpha, \beta, m, C) = \frac{C}{m}$ , and no unique equilibrium exists.

Figure 4 depicts the constrained parameter space of trigger value  $L$  and conversion shares  $m$  given the precision of the private signal in relation to the asset risk. The exogenous precision of the private in relation to the public signal therefore

16. If  $mL < C$  the condition can never hold. This is because, for nondilutive contingent capital, no equilibrium exists even in the absence of private and public signals.

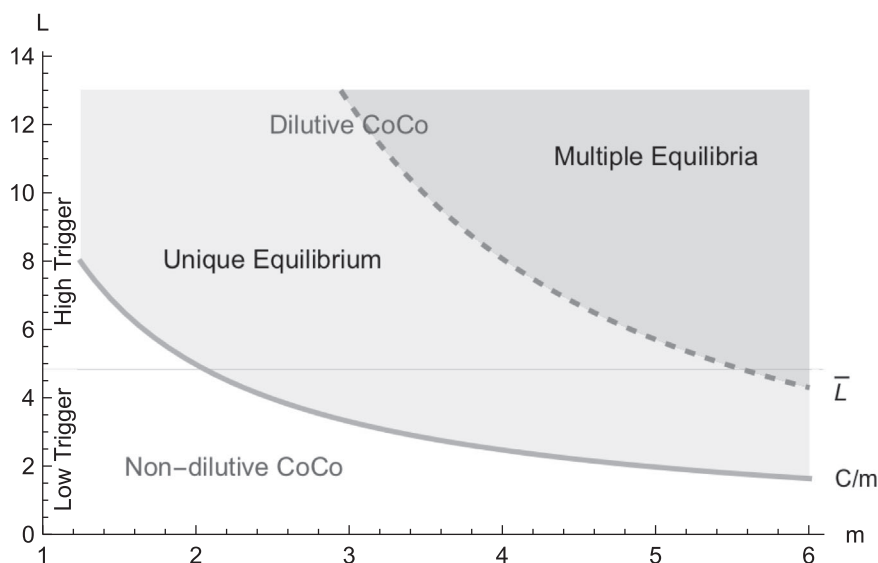


Fig 4. The Equilibrium Outcomes in the Presence of a Public Signal.

NOTES: The Parameters Used Are  $C = 10$ ,  $\alpha = 0.05$ , and  $\beta = 5$ .

constrains the optimal design of contingent capital. We discuss this point and its policy implications further in Section 5.

Assuming that the condition in Proposition 3 holds, we can now pursue comparative statics with respect to historical price  $A_0$ .

**PROPOSITION 4.** *The critical fundamental asset value,  $\Lambda$ , below which the contingent capital converts, decreases in the historical price, that is,  $\frac{d\Lambda}{dA_0} < 0$ , but increases in  $L$ ,  $B$ ,  $C$  and  $m$ .*

The detailed proof can be found in Section A.3 of our Online Appendix. A higher observed market price reduces the critical asset value that triggers conversion. The rationale is that, after observing a very high public signal, investors must receive an even lower private signal to counteract their prior. The critical asset value decreases with a higher precision of the public signal, that is, when investors place a greater weight on the historical value in their posterior. Provided that the relative precision of the private signal suffices, the comparative statics regarding exogenous parameters  $L$ ,  $B$ ,  $C$ , and  $m$  remain unchanged with the introduction of a public signal.

#### 4. PRICE AS ENDOGENOUS PUBLIC SIGNAL

In pure market order markets, the precision of the public signal is bounded from above, even as the underlying private signal becomes arbitrarily precise. As



a consequence, high levels of private information precision uniquely pin down a unique equilibrium. In contrast, in markets where demand schedules predominate, an infinitely precise private signal also leads to an infinitely precise public signal (Challe and Chrétien 2018). In such a market, unique equilibria exist only if noise trading prevents the revelation of precise private information as shown in Angeletos, Hellwig, and Pavan (2006). In contrast to Angeletos, Hellwig, and Pavan (2006) and Challe and Chrétien (2018), the market clearing asset price in our setting not only endogenously signals information but also triggers the conversion of contingent capital. This has a feedback effect on the trading decision of the traders. Therefore, we extend our model to analyze the two-way feedback effect of the full demand schedule market microstructure and the simultaneous decision of informed traders to trade on the conversion triggering, in a setup slightly modified from Ozdenoren and Yuan (2008). They develop a global games model with a demand schedule micro-market structure that permits feedback effects and strategic complementarity among informed traders. We apply their framework to market-triggered contingent capital, providing a detailed description of the conditions for a unique pricing equilibrium.

#### 4.1 Payoffs

We now consider an economy with two assets: a safe asset yielding 1 at date 2 and the risky common stock of the firm with an aggregate supply of  $M$ . For simplicity, we set debt  $B = 0$  without loss of generality. The common stock has a terminal payoff that consists of two components,  $\tilde{A} - C + f(P, \tilde{\theta})$ . The first component is the payoff that is based on the realized asset value of the bank with

$$\tilde{A} = A_0 + \eta \text{ with } \eta \sim \mathcal{N}(0, \nu^2), \quad (15)$$

where  $\nu^2$  is the historical volatility of the asset value. The second component depends on the market clearing price and the fundamental value  $\tilde{\theta}$  of some additional activity of the bank.<sup>17</sup> The price dependence of this second component reflects the dilution of the share value if contingent capital is triggered.<sup>18</sup> The fundamental value on the additional activity  $\tilde{\theta}$  is drawn from the uniform distribution over the real line (informed investors have an improper prior). We assume that  $\tilde{\theta}$  and  $\nu$  are independently

17. This could be, for example, private information on new projects and investments, the realizations of operational risks, or international exchange exposures.

18. To reflect our basic model, we could write

$$f(P, \tilde{A}, \tilde{\theta}) = \begin{cases} \tilde{\theta} - \frac{m(\tilde{A} - C + \tilde{\theta}) - C}{1+m} & \text{if } P \leq L \\ \tilde{\theta} & \text{if } P > L, \end{cases}$$

which is increasing in  $\theta$  and in  $P$  in the region where multiple equilibria can occur. With this specific function, the absolute difference between the value of the second component before and after triggering would replace the more general condition on the marginal effect of a price change  $\alpha$  in Proposition 6.

distributed.<sup>19</sup> The dilution term of the CoCo bond triggering is increasing in both the market clearing price  $P$  and the fundamental  $\tilde{\theta}$ .

The share price  $P$  clears the market in equilibrium thereby, aggregating all information about  $\tilde{A}$  and  $\tilde{\theta}$ , including some noise. The risky terminal payoff for investors depends on the two risky components, including the potential change in value resulting from the triggered conversion of the contingent capital.

### Types of investors

There are now three types of investors: risk-neutral informed investors that speculate on the feedback effect of the triggering of the contingent capital, risk-averse, uninformed liquidity traders that trade based on the public signal and the observed price without taking into account the possible regime switch, and random noise traders.

### 4.2 Informed Traders

A measure one continuum of informed investors receives a noisy private signal on the additional asset value component realization  $\theta$

$$s_i = \theta + \sigma_s \epsilon_i, \quad (16)$$

where  $\epsilon_i$  is uniformly distributed on  $[-1, 1]$ . We assume that both noise terms  $\epsilon_i$  and  $\eta$  are i.i.d. Informed traders are restricted to trade  $x_i \in [-z, z]$ .<sup>20</sup> The total demand of informed traders is therefore

$$X = \int_0^1 x_i di. \quad (17)$$

An informed traders are assumed to be risk-neutral, which allows us to focus on the strategic interaction among them. Informed traders maximize their expected profit, given  $A_0$ , their private signal  $s_i$  and the market clearing price  $P$ . Informed investor's utility from buying  $c \in [-z, z]$  units of the stock is given by<sup>21</sup>

$$c(E(\tilde{A} - C) + f(P, \tilde{\theta}) - P).$$

Because of their risk neutrality, informed investors always trade up to their position limit  $z$  or  $-z$ .

19. This is a simplification assumption to allow us to derive explicit solutions. In general, the private signal could also be based on the asset value such that informed investors update their prior with the public information on the asset value and their private signal.

20. This position limit could reflect leverage constraints faced by investors. As traders are assumed to be risk neutral, they would otherwise invest or (short) sell infinite amounts. As before, the position limit replaces risk-aversion and allows us to derive explicit conditions.

21. Note that the net benefits from buying versus selling the stock are  $c(E(\tilde{A} - C) + f(P, \tilde{\theta}) - P - (E(\tilde{A} - C) + f(P, \tilde{\theta}) - P)) = 2c(E(\tilde{A} - C) + f(P, \tilde{\theta}) - P)$ . Hence, we can focus on the benefit from buying because the indifferent investor's condition is equal.

### 4.3 Liquidity Traders

We assume that there is a measure  $\omega$  continuum of uninformed, liquidity traders, which are mean-variance investors with identical risk aversion parameter  $\rho$ .<sup>22</sup> Uninformed investors are liquidity providers that are trading on the basis of liquidity needs and the public information available. Therefore, we assume that uninformed liquidity traders neglect the possibility of the triggering of the contingent capital and its feedback effect on the value of the stock.<sup>23</sup> By maximizing their expected utility, liquidity traders have an upward-sloping aggregate demand for the asset

$$L(P) = \omega \frac{E(\tilde{A}) - C - P}{\rho \text{Var}(\tilde{A})} = \frac{\omega}{\rho v^2} (A_0 - C - P). \quad (18)$$

Uninformed investors therefore provide liquidity in the market. If the price falls below  $E(\tilde{A}_1 - C) - P$ , uninformed investors will buy the asset. The slope of the uninformed demand curve is  $\frac{\omega}{\rho v^2}$ .

Note that in the recent forced takeover of Credit Suisse by UBS, some market participants were surprised at the treatment of Credit Suisse's CoCo bonds, as they were fully wiped out, while equity holders retained some claim on the bank. Perotti (2023) provides an insightful description, arguing that "this is precisely the risk that investors in high trigger contingent convertible bonds bought into," but some investors may not have fully comprehended it. The Credit Suisse case illustrates that some investors might be reasonably well informed about fundamentals while not being fully informed about the subtleties of contingent capital conversion.

### 4.4 Noise Traders

As is standard in rational expectations models of asset prices, we assume that there is a noise demand shock in the market that introduces noise in the information aggregation process and prevents the market clearing price from fully revealing the private information. The demand from noise traders is assumed to be  $\sigma_y \tilde{y}$ , where  $\sigma_y > 0$  and  $\tilde{y}$  is a standard normal random variable that is independent of  $v^2$  and  $\tilde{\theta}$ .

#### Equilibrium

An equilibrium consists of a price function  $P(\tilde{\theta}, \tilde{y})$ , strategies  $\pi(s_i, P : R^2 \rightarrow [-1, 1])$ , and the corresponding aggregate demand  $L(P)$  and  $X(P, \tilde{\theta})$ , such that

1. For each informed agent  $i$ ,
 
$$\pi(\tilde{s}_i, P) : \mathbb{R}^2 \rightarrow [-1, 1] = \arg \max_{\pi} z\pi E[\tilde{A} - C + f(P, \tilde{\theta}) - P | \tilde{s}_i = s_i, P].$$

22. Implicitly, we adopt the Grossman (1976) specification of CARA-normal utility for liquidity traders, where each agent  $i$  has utility  $V(W_i) = -e^{-\rho w_i}$ , where  $w_i = w_0 - k_i P + (E(A) - C)k_i$  is final wealth and  $w_0$  is the initial wealth.

23. In a generalization, Ozdenoren and Yuan (2008) also allow uninformed liquidity traders to learn from the price about the function  $f(\theta)$ . This uninformed learning adds an additional effect on the backward-bending aggregate demand and therefore makes price multiplicity more likely, *ceteris paribus*. However, the qualitative insight remains the same as derived in our extension. The equilibrium price is unique if there is enough noise in the market.

2. Uninformed investors demand  $L(P)$  is given by  $\omega \frac{E(\tilde{A}-C)-P}{\rho v^2}$ .
3. The market clearing condition is satisfied by  $X(P, \tilde{\theta}) + L(P) + \sigma_y \tilde{y} = M$ .

A monotone equilibrium consists of a cutoff strategy where  $\pi(\tilde{s}_i, P) = 1$  if  $\tilde{s}_i > g(P)$ , and  $\pi(\tilde{s}_i, P) = -1$  otherwise. If investors use a simple switching strategy at  $g(P)$ , they switch if their signal is greater than  $g(P)$ , that is, they sell the stock whenever  $s_i \leq g(P)$  and buy if they receive signal  $s_i > g(P)$ . In such a monotone equilibrium, the demand of informed investors is given as

$$X(P, \tilde{\theta}) = \begin{cases} -z & \text{if } \tilde{\theta} < g(P) - \sigma_s \\ z \left( \frac{\tilde{\theta} - g(P)}{\sigma_s} \right) & \text{if } g(P) - \sigma_s < \tilde{\theta} < g(P) + \sigma_s \\ z & \text{if } g(P) + \sigma_s < \tilde{\theta}. \end{cases} \quad (19)$$

Substituting the uninformed demand into the market clearing condition, we obtain

$$P = \frac{\rho v^2}{\omega} X + A_0 - C + \frac{\rho v^2}{\omega} \sigma_y \tilde{y} - \frac{\rho v^2}{\omega} M. \quad (20)$$

Substituting (19), we obtain

$$P = \begin{cases} -\frac{\rho v^2}{\omega} z + A_0 - C + \frac{\rho v^2}{\omega} \sigma_y \tilde{y} - \frac{\rho v^2}{\omega} M & \text{if } \tilde{\theta} < g(P) - \sigma_s \\ \frac{\rho v^2}{\omega} z \left( \frac{\tilde{\theta} - g(P)}{\sigma_s} \right) + A_0 - C + \frac{\rho v^2}{\omega} \sigma_y \tilde{y} - \frac{\rho v^2}{\omega} M & \text{if } g(P) - \sigma_s < \tilde{\theta} < g(P) + \sigma_s \\ \frac{\rho v^2}{\omega} z + A_0 - C + \frac{\rho v^2}{\omega} \sigma_y \tilde{y} - \frac{\rho v^2}{\omega} M & \text{if } g(P) + \sigma_s < \tilde{\theta}. \end{cases} \quad (21)$$

The market clearing price is only informative about the private information of informed traders if  $g(P) - \sigma_s < \tilde{\theta} < g(P) + \sigma_s$  for which we can rewrite

$$\tau \equiv \left( \frac{\omega}{z} \frac{\sigma_s}{\rho v^2} (P - A_0 + C) + g(P) + \frac{\sigma_s}{z} M \right) = \tilde{\theta} + \frac{\sigma_s \sigma_y}{z} \tilde{y}. \quad (22)$$

As the market clearing price is observable for informed investors and is not correlated with their private signals conditional on  $\tilde{\theta}$ ,  $\tau$  is a sufficient statistic for the information in the market clearing price  $P$  in the intermediate region. This sufficient statistic  $\tau$  is normally distributed with mean  $\tilde{\theta}$  and standard deviation  $\sigma_s \sigma_y / z$ . The precision of the market clearing price as a signal of the fundamental  $\tilde{\theta}$  is endogenous. It decreases with the variance of the private signal and the noise in the demand. However, it increases in the size of the informed investors' position limit  $z$ .

**PROPOSITION 5.** *An informed investor's monotone equilibrium strategies are uniquely determined. A given price  $P$  leads to a unique demand from informed and uninformed investors for the realization of fundamentals.*

The detailed proof can be found in Section A.6 of our Online Appendix.

Now, we have to show under what conditions the equilibrium price that satisfies (21) is unique. Therefore, we define the conditions under which equation (21) has

a unique solution. The multiplicity of equilibrium prices can occur in our extended model if the aggregate investor demand has a region in which a price decrease might not result in a demand increase. Without the feedback effect, informed and uninformed investors would always be willing to buy more of the asset in response to a lower price given the information on the asset value received. However, a lower price might also imply that other investors had worse signals about the asset value and coordinate on selling the stock, which would eventually trigger the conversion of the contingent capital, resulting in a diluted stock value. Therefore, an informed investor may be reluctant to buy despite the lower price. Due to this information effect, an informed investor might sell the asset at a higher signal even though the price has decreased. Multiplicity therefore does not arise because informed investors infer the information about the actual fundamental value but rather because of the effect of coordinated behavior as in our basic model. Price uniqueness in equilibrium is maintained if the effect of coordinated behavior on the value of the asset is weaker than the price effect of coordination in market clearing. To illustrate this, we follow Ozdenoren and Yuan (2008) and assume a linear form for the feedback effect  $f(P, \theta) = \alpha P + \theta$ .

**PROPOSITION 6.** *Price uniqueness in equilibrium requires that the marginal feedback effect on the asset value is not too large compared to the noise in the market. For  $f(P, \theta) = \alpha P + \theta$ , price uniqueness requires that*

$$\alpha < 1 + \frac{\sigma_s}{z} \frac{\omega}{\rho v^2} \Lambda \left( \frac{\omega}{\rho v^2} (P - A_0 + C) + M, z, \sigma_y \right) \quad (23)$$

for all prices.

The detailed proof can be found in Section A.7 of our Online Appendix. The intuition is straightforward. If a one unit price change causes the asset value to drop less than one ( $\alpha < 1$ ), the equilibrium clearing market price is always unique. In our context,  $\alpha$  reflects the marginal change in the price caused by the triggering of contingent capital conversion. If  $\alpha > 1$ , price uniqueness in equilibrium is maintained if (i) the private signal of informed investors ( $\sigma_s$ ) is noisy (in contradiction to the case with pure market orders), (ii) the relative share of liquidity to informed traders is large ( $\frac{\omega}{z}$ ), (iii) the public signal is very noisy, and (iv) the fraction of expected price change caused by noise traders ( $\Lambda$ ) is large. Specifically, as long as the private signal has some noise ( $\sigma_s > 0$ ), a sufficient condition for a unique price equilibrium with  $\alpha > 1$  is that there is enough noise trading in the market. The market characteristics and signal precision constraint the optimal design of contingent capital as we discuss in greater detail in the next section. To preserve a unique price equilibrium in a full demand schedule market, contingent capital cannot be too dilutive ( $\alpha$  cannot be too high).

## 5. IMPLICATIONS FOR THE DESIGN OF CONTINGENT CAPITAL

Our results have several important implications for regulators and policymakers. We showed that market-triggered contingent capital works even when the “no value transfer” condition does not hold, provided that the precision of private information relative to asset risk is sufficiently high. Our results emphasize the possibility of designing contingent capital contracts with unique conversion equilibria that maximize social welfare, for instance, by discouraging excessive risk-taking and promoting early recapitalization of banks. Indeed, the possibility of influencing banks’ behavior with appropriately designed contingent capital has been at the center of various academic writings on this topic (Koziol and Lawrenz 2012, Calomiris and Herring 2013, Albul, Jaffee, and Tchisty 2016, Hilscher and Raviv 2014), Himmelberg and Tsyplakov (2012), Berg and Kaserer (2015), Pennacchi, Vermaelen, and Wolff (2014), Eufinger and Gill (2016)).<sup>24</sup>

Our model does not allow us to quantify the trade-off between mitigating agency frictions and triggering the instability associated with conversion events because doing so would require a quantitative model of both agency friction and the costs associated with a conversion event. In our model, the conversion of contingent capital shifts value from the buyer to the seller in a zero-sum game and therefore does not affect the overall welfare. However, the results from our model have three major implications for policymakers.

First, we show that contingent capital conversion is always triggered at a market price above the conversion trigger  $S_H(\Lambda) > L$ . To see this, note that we can write the equilibrium condition as:

$$S_H(\kappa(\Lambda)) = L + F(\sqrt{\alpha + \lambda}(\Lambda - \kappa(\Lambda))(S_H(\kappa(\Lambda)) - S_L(\kappa(\Lambda))) \quad (24)$$

with  $\kappa(\Lambda) = \frac{\alpha}{\alpha + \beta}A_0 + \frac{\beta}{\alpha + \beta}\Lambda$ . In the absence of a public signal, with  $\alpha \rightarrow 0$ , we obtain  $\kappa(\Lambda) \rightarrow \Lambda$  such that we obtain the solution from equation (10)

$$S_H(\Lambda) = L + \frac{1}{2}(S_H(\Lambda) - S_L(\Lambda)). \quad (25)$$

The stock price that triggers the conversion of contingent capital consists of the trigger price plus a term that reflects the strategic complementarity among investors. As it must hold that  $S_H > S_L$  for any  $A \geq \underline{A}$ , it directly follows that  $S_H(\Lambda) > L$  in the absence of public information. Moreover, as the historical asset value must be  $A_0 > \Lambda$  (otherwise, a conversion would have already occurred),  $S_H(\kappa(\Lambda)) > S_L(\kappa(\Lambda))$  must also hold for an imprecise public signal  $\alpha > 0$  such that the asset value at which

24. Another important factor for the adoption of contingent capital is the tax treatment. While interest payments on contingent capital are tax-deductible in Europe, in the U.S., they are not. See Flannery (2016) and Hirst (2011) for a discussion on the tax treatment of contingent capital.

conversion occurs must be weakly greater than the value implied by the conversion trigger.<sup>25</sup>

Second and most important, Proposition 2 and its robustness to a public signal imply that given  $A_0$ , the particular design of the contingent capital contract affects the distance between  $\Lambda$  and  $\underline{A}$ . Policymakers can therefore affect the critical state that leads to conversion by regulating the bank and the contingent capital contract. Increased precision of the private signal, lower bank leverage, and a lower face value reduce the probability that conversion is triggered. Regulation requiring higher capital reduces the probability of triggered conversion by reducing leverage. In contrast, our results suggest that if a bank replaces regulatory equity with contingent capital, it faces a higher probability of triggered conversion than if it issued contingent capital in addition to the existing equity. Another policy-relevant result is that highly dilutive contingent capital converts with a higher probability than a similar claim that is less dilutive. This finding has important implications: while a high dilution can mitigate agency concerns, particularly lowering incentives for excessive risk-taking, see Berg and Kaserer (2015) and Hilscher and Raviv (2014)), it also increases the likelihood of conversion. If triggering contingent capital has associated costs—either private costs such as a change in control costs or public costs arising from financial instability associated with conversion events (see Admati et al. 2013 and Berg and Kaserer 2015)—then highly dilutive contingent capital might not be optimal.

Third, our robustness exercise with respect to public signals offers insights for policymakers to understand which contract parameters guarantee the uniqueness of market outcomes. This understanding is crucial because multiple equilibria are undesirable, as they could cause sudden stock price shifts that impair market efficiency. Calomiris and Herring (2013) argue that contingent capital should be designed to absorb losses and reduce risk-taking. They elaborate that contingent capital can only do so if it is market-triggered at a high equity-to-asset ratio and if the triggered conversion is highly dilutive to existing shareholders. We show that private signal precision in relation to asset risk naturally constrains this optimal design. To preserve a unique equilibrium in the presence of a precise public signal, contingent capital cannot be too dilutive or must be triggered at a relatively low value.

The current treatment of contingent capital under Basel III distinguishes between low and high trigger contingent capital. Contingent capital with a trigger above a threshold of 5.125% (in terms of CET1/RWA), so-called “high-trigger CoCos,” receives equity-like treatment from regulators. In response, banks have increasingly issued contingent capital with a trigger set exactly at that level (Avdjiev, Kartasheva, and Bogdanova 2013). Our analysis implies that high-trigger CoCocs have a higher

25. If the asset risk is low but the private signal is sufficiently precise to ensure a unique equilibrium, the investors place a high weight on informative prior  $A_0$ , the solution for  $\Lambda$  is smaller than it was previously. If we let the public signal again become uninformative, that is, let  $\alpha \rightarrow 0$ , the influence of the past stock price becomes negligible, and the critical fundamental asset value that triggers conversion approaches the value defined in (24).

potential for multiple equilibria than otherwise comparable low-trigger CoCos.<sup>26</sup> To reduce this potential for multiple equilibria, policymakers can focus on transparency reforms that enhance the precision of private signals. Ahnert and Kakhbod (2017) present a model in which banks can decrease their opacity to prevent inefficient bank runs by increasing the precision of the private signal. However, policy reforms that increase public signal precision make the occurrence of multiple equilibria more likely. Our results therefore indicate that contingent capital issued by banks with a precise private signal relative to the public signal is more robust for equilibrium uniqueness. Moreover, in a market with a high share of strategic traders placing limit orders, Condition 6 shows that price uniqueness also requires a high share of noise traders.

## 6. CONCLUSION

In this paper, we argue that it is important to understand the design of contingent capital under the assumption that banks' assets are not common knowledge. Employing a global game framework, we show that if investors receive noisy but relatively precise private information on the issuer's risky asset value, a unique equilibrium exists in the form of an endogenous threshold value below which conversion is always triggered. We show that the probability of the conversion of market-triggered contingent capital increases when the bank has more debt—contingent and noncontingent—on its balance sheet. Market-triggered contingent capital is more likely to convert when the issuing bank is more leveraged. Moreover, we show that the particular contract structure of contingent capital crucially affects the probability with which contingent capital will convert. Conversion is more likely when the contracted trigger value is higher and the conversion is more dilutive for shareholders.

Our analysis indicates that opting for highly dilutive contingent capital with a high trigger value may not be optimal for policymakers aiming to minimize inefficient conversion events or address efficiency losses stemming from the presence of multiple equilibria in market-triggered contingent capital.

## CONFLICT-OF-INTEREST DISCLOSURE STATEMENT

*Tobias Berg*

I have nothing to declare.

*Eva Schliephake*

I have nothing to declare.

26. In Section A.4 of our Online Appendix, we derive an upper bound on  $m$  given trigger value  $L$ .



## LITERATURE CITED

- Admati, Anat R., Peter M. DeMarzo, Martin F. Hellwig, and Paul C. Pfleiderer. (2013) "Fallacies, Irrelevant Facts, and Myths in the Discussion of Capital Regulation: Why Bank Equity Is Not Socially Expensive." *Max Planck Institute for Research on Collective Goods*, 23, 13–17.
- Ahnert, Toni, and Ali Kakhbod. (2017) "Information Choice and Amplification of Financial Crises." *Review of Financial Studies*, 30, 2130–78.
- Albul, Boris, Dwight M. Jaffee, and A. Tchistyi. (2016) "Contingent Convertible Bonds and Capital Structure Decisions." Working Paper.
- Allen, Franklin, Elena Carletti, Itay Goldstein, and Agnese Leonello. (2017) "Government Guarantees and Financial Stability." ECB Working Paper Series, 2032.
- Angeletos, George-Marios, Christian Hellwig, and Alessandro Pavan. (2006) "Signaling in a Global Game: Coordination and Policy Traps." *Journal of Political Economy*, 114, 452–84.
- Avdjiev, Stefan, Anastasia V. Kartasheva, and Bilyana Bogdanova. (2013) "CoCos: A Primer." *BIS Quarterly Review September*.
- Berg, Tobias, and Christoph Kaserer. (2015) "Does Contingent Capital Induce Excessive Risk-Taking?" *Journal of Financial Intermediation*, 24, 356–85.
- Bond, Philip, and Itay Goldstein. (2015) "Government Intervention and Information Aggregation By Prices." *Journal of Finance*, 70, 2777–812.
- Calomiris, Charles W., and Richard J. Herring. (2013) "How to Design a Contingent Convertible Debt Requirement That Helps Solve Our Too-Big-To-Fail Problem." *Journal of Applied Corporate Finance*, 25, 39–62.
- Carlsson, Hans, and Eric E. van Damme. (1993) "Global Games and Equilibrium Selection." *Econometrica*, 61, 647–61.
- Challe, Edouard, and Edouard Chrétien. (2018) "Market Microstructure, Information Aggregation and Equilibrium Uniqueness in a Global Game." *European Economic Review*, 102, 82–99.
- Chan, Stephanie, and Sweder Van Wijnbergen. (2015) "Cocos, Contagion and Systemic Risk." Working Paper.
- Dasgupta, Amil. (2007) "Coordination and Delay in Global Games." *Journal of Economic Theory*, 134, 195–225.
- Davis, Douglas, Oleg Korenok, and Edward Simpson Prescott. (2014) "An Experimental Analysis of Contingent Capital with Market-Price Triggers." *Journal of Money, Credit and Banking*, 46, 999–1033.
- Derksen, Mike, Peter Spreij, and Sweder van Wijnbergen. (2018) "Accounting Noise and the Pricing of Cocos." Working Paper.
- Duffie, Darrell, and David Lando. (2001) "Term Structures of Credit Spreads with Incomplete Accounting Information." *Econometrica*, 69, 633–64.
- Eufinger, Christian, and Andrej Gill. (2016) "Incentive-Based Capital Requirements." *Management Science*, 63, 4101.
- Flannery, Mark J. (2005) *No Pain, No Gain? Effecting Market Discipline via Reverse Convertible Debentures*. Oxford, UK: Oxford University Press.
- Flannery, Mark J. (2016) "Stabilizing Large Financial Institutions with Contingent Capital Certificates." *Quarterly Journal of Finance*, 6, 1650006.

- Flannery, Mark J., Simon H. Kwan, and Mahendrarajah Nimalendran. (2013) "The 2007–2009 Financial Crisis and Bank Opaqueness." *Journal of Financial Intermediation*, 22, 55–84.
- Glasserman, Paul, and Behzad Nouri. (2016) "Market-Triggered Changes in Capital Structure: Equilibrium Price Dynamics." *Econometrica*, 84, 2113–53.
- Goldstein, Itay, and Ady Pauzner. (2005) "Demand–Deposit Contracts and the Probability of Bank Runs." *Journal of Finance*, 60, 1293–327.
- Grossman, Sanford. (1976) "On the Efficiency of Competitive Stock Markets Where Trades Have Diverse Information." *Journal of finance*, 31, 573–85.
- Hellwig, Christian. (2002) "Public Information, Private Information, and the Multiplicity of Equilibria in Coordination Games." *Journal of Economic Theory*, 107, 191–222.
- Hilscher, Jens, and Alon Raviv. (2014) "Bank Stability and Market Discipline: The Effect of Contingent Capital on Risk Taking and Default Probability." *Journal of Corporate Finance*, 29, 542–60.
- Himmelberg, Charles P., and Sergey Tsyplakov. (2012) "Pricing Contingent Capital Bonds: Incentives Matter." Working Paper, Darla Moore School of Business, University of South Carolina.
- Hirst, Scott. (2011) "The Loss Absorbency Requirement and Contingent Capital under Basel III." Harvard Law School Forum on Corporate Governance.
- Koziol, Christian, and Jochen Lawrenz. (2012) "Contigent Convertibles: Solving or Seeding the Next Banking Crisis." *Journal of Banking and Finance*, 36, 90–104.
- Leonello, Agnese. (2018) "Government Guarantees and the Two-Way Feedback Between Banking and Sovereign Debt Crises." *Journal of Financial Economics*, 130, 592–619.
- Morgan, Donald P. (2002) "Rating Banks: Risk and Uncertainty in an Opaque Industry." *American Economic Review*, 92, 874–88.
- Morris, Stephen, and Hyun Song Shin. (1998) "Unique Equilibrium in a Model of Self-Fulfilling Currency Attacks." *American Economic Review*, 88, 587–97.
- Morris, Stephen, and Hyun Song Shin. (2003) "Global Games: Theory and Applications." In *Advances in Economics and Econometrics: Theory and Applications, Eighth World Congress*, edited by Mathias Dewatripont, Lars Peter Hansen, and Stephen J. Turnovsky, volume 1 of *Econometric Society Monographs*, pp. 56–114. Cambridge: Cambridge University Press.
- Morris, Stephen, and Hyun Song Shin. (2004) "Coordination Risk and the Price of Debt." *European Economic Review*, 48, 133–53.
- Ozdenoren, Emre, and Kathy Yuan. (2008) "Feedback Effects and Asset Prices." *Journal of Finance*, 63, 1939–75.
- Pennacchi, George, and Alexei Tchisty. (2018) "Contingent Convertibles with Stock Price Triggers: The Case of Perpetuities." *Review of Financial Studies*, 32, 2302–40.
- Pennacchi, George, and Alexei Tchisty. (2019) "On Equilibrium When Contingent Capital Has a Market Trigger: A Correction to Sundaresan and Wang *Journal of Finance* (2015)." *Journal of Finance*, 74, 1559–76.
- Pennacchi, George, Theo Vermaelen, and Christian C.P. Wolff. (2014) "Contingent Capital: The Case of COERCs." *Journal of Financial and Quantitative Analysis*, 49, 541–74.
- Perotti, Enrico. (2023) "Swiss Authorities Enforced Legitimate Going Concern Conversion." *VoxEU Column*.

Plantin, Guillaume, Haresh Sapra, and Hyun Song Shin. (2008) “Marking-to-Market: Panacea or Pandora’s Box?” *Journal of Accounting Research*, 46, 435–60.

Suresh Sundaresan, M., and Zhenyu Wang. (2015) “On the Design of Contingent Capital with a Market Trigger.” *Journal of Finance*, 70, 881–920.

## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Online Appendix