Mind the conversion risk: contingent convertible bonds and self-fulfilling panics

Gaëtan Le Quang*

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Abstract: We develop a model to assess the risk associated with contingent convertible (coco) bonds. When their conversion is related to changes in their market price – in the perspective of what the literature as coined as indirect market discipline –, coco bonds can act as a transmission channel of systemic risk. In this case, a self-fulfilling crisis can indeed occur because of panic sales of coco bonds motivated by the expectation of conversion by coco bonds' holders. In addition, when the bank mainly relies on funding instruments other than capital, we show that increasing the precision of the information disclosed by the bank through its financial statements decreases the probability that such a crisis happens. On the contrary, increasing the precision of the information privately held by coco bonds' holders has the opposite effect. This paper therefore calls for cautiousness when it comes to discussing coco bonds as an instrument to implement market discipline.

Keywords: contingent convertible bonds; market discipline; banks; systemic risk

JEL codes: G13; G21; G28; G32; G33

1 Introduction

Regulatory capital may be the hottest issue post-crisis banking regulation has to tackle. This problem actually raises two intertwined questions: that of the very definition of regulatory capital and that of the setting of minimum requirements. Basel III has moved forward on those two problems. First, the definition of regulatory capital has been narrowed

*EconomiX (UMR7235), GATE-LSE (UMR5824) and Université Paris-Nanterre, 200 Avenue de la République, 92001 Nanterre cedex, France. E-mail: glequang@parisnanterre.fr

and many hybrids that were previously considered as capital are no longer admitted as such. Second, minimum requirements have been augmented and counter-cyclical cushions added. Some doubts however remain concerning the ability of the new capital requirements to ensure the soundness of the banking system and thus to prevent costly bailouts from occurring. Implementing a minimum requirement of properly designed contingent convertible (coco) bonds is one of the proposals that have been put forward to strengthen capital requirements. The Squam Lake Working Group (2009) for instance praises those instruments and strongly advocates for their inclusion in banking regulation:

> "We recommend support for a new regulatory hybrid security that will expedite the recapitalization of banks. This instrument resembles long-term debt in normal times, but converts to equity when the financial system and the issuing bank are both under financial stress. The goal is to avoid *ad hoc* measures such as those taken in the current crisis, which are costly to taxpayers and may turn out to be limited in effectiveness. The regulatory hybrid security we envision would be transparent, less costly to taxpayers, and more effective." (Squam Lake Working Group, 2009, p.2).

Coco bonds are hybrid securities that are characterized by two main features (Avdjiev *et al.*, 2013): a trigger that modifies the repayment terms and a loss-absorption mechanism. Conversion can specifically be triggered either mechanically – for instance whenever the capital of the bank falls below a pre-defined threshold – or discretionarily – in which case the regulatory institution in charge of the bank decides when to trigger the conversion. This conversion can either lead to write coco bonds down or to turn them into common equity.

In this paper, we develop a theoretical model to assess the systemic risk associated with coco bonds. We model a bank that relies on three different funding sources: equity, deposits and coco bonds. Coco bonds are assumed to be mechanically written off whenever the CET1 capital of the bank falls below a pre-defined threshold. In addition, they are discretionarily written off by the central bank whenever the market value of the Tier 1 regulatory capital of the bank falls below a certain threshold. This second risk of conversion captures the idea of indirect market discipline. Bliss and Flannery (2001) indeed define market discipline as a two-step process. Market participants first *monitor* banks' activities in the sense that they observe the risk associated with those activities. Then, an *influence* can be exerted over the behavior of those banks based on the information produced through the monitoring process. If the influence is exerted indirectly by a third party (a regulatory institution reacting to changes in market prices for instance), market discipline is said to be indirect. In this context, there is a game between the central bank and coco bonds' holders since the latter are incentivized to sell their coco bonds when the probability of conversion increases, while the former is more likely to force this conversion as panic sales of coco bonds are more likely to happen (since those sales are expected to have a negative impact on the market value of regulatory capital). Using the global game technique (Carlsson and Van Damme, 1993; Morris and Shin, 1998; Metz, 2002; Morris and Shin, 2003; Morris and Shin, 2004), we exhibit situations where a self-fulfilling crisis occurs. In those situations, coco bonds could act as a transmission channel of systemic risk since they could eventually spread a market-wide panic. More precisely, when the bank relies strongly on funding instruments other than capital, which is the case in reality, we show that such a crisis is more likely to occur when coco bonds' holders are sophisticated investors, in the sense that they privately hold accurate information concerning the bank. On the contrary, the more the information found in the financial statements of the bank is precise, the less likely a crisis is to occur.

Coco bonds are recent financial instruments. In 2009, LLoyds issued what was called "enhanced capital notes", which can be considered as the first coco bonds ever issued. Those notes would automatically be converted into equity whenever LLoyds' CET1 capital would fall below 5%. In 2011, the Credit Suisse issued in turn two billions francs worth of coco bonds. Those coco bonds have a dual trigger: their conversion into equity is triggered either by regulatory decision or whenever the Credit Suisse ratio of equity over risk-weighted assets falls below 7%. In May 2013, BBVA issued for the first time coupon cancellable coco bonds. The novelty is that when the conversion is triggered, coupons are canceled but the coco bond is not converted into equity. According to Avdjiev *et al.* (2017) banks all around the world issued a total of $521 billions in coco bonds between 2009 and December 2015.

The literature on coco bonds has been constantly growing in the last few years. Raviv (2004) and Flannery (2005) were precursors when they discussed what they called "debt-for-equity swap" (Raviv, 2004) and "reverse convertible debentures" (Flannery, 2005) whose main features were close to those of coco bonds. More recently, the Squam Lake

Working Group (2009), McDonald (2013), Pennacchi *et al.* (2014) and Flannery (2016) have defended the idea of contingent capital requirements. Among the advantages associated with coco bonds, their ability to provide banks with the incentives to manage safely their balance sheet is particularly put forward. Himmelberg and Tsyplakov (2014) indeed show that if the conversion is dilutive for existing shareholders, coco bonds may provide managers with the incentives to reduce the likelihood of conversion by maintaining high capital ratios.

Because of the conversion risk, pricing coco bonds is however a tricky exercise. Glasserman and Nouri (2012) manage to derive closed-form expressions for the market value of coco bonds associated with a capital-ratio trigger when the firm's asset value is modeled as a geometric Brownian motion. Glasserman and Nouri (2016) show that for a pricing equilibrium to exist in the case of a stock price trigger, the conversion should be disadvantageous to shareholders. For coco bonds associated with a market trigger based on common equity price, Sundaresan and Wang (2015) show that the pricing equilibrium is not necessarily unique. For the equilibrium to be unique, the conversion must not transfer value from equity holders to coco bonds' investors. Pennacchi and Tchistyi (2019) however point out an error in the paper by Sundaresan and Wang (2015) that amends their results. Pennacchi and Tchistyi (2019) indeed show that, the error made by Sundaresan and Wang (2015) once corrected, they obtain an equilibrium price very similar to that found by Glasserman and Nouri (2016).

Koziol and Lawrenz (2012) show that coco bonds distort risk-taking incentives and therefore conclude that those instruments should be used with great caution. Goodhart (2010) does not believe that coco bonds will be able to fulfill their main objective since banks in distress mostly need cash, which coco bonds are not able to provide. Furthermore, Goodhart (2010) recalls that the assessment of coco bonds cannot only focus on their expected impact on one particular bank but should also take their impact on the financial system as a whole into account. As Allen (2012) states it, expectations of conversions can indeed lead to panic sales and coco bonds can thus weaken the financial system instead of strengthening it. Bologna *et al.* (2018) provide empirical evidence that shows how contagion can spread in the coco bonds market. Using two stressed episodes that have affected the European coco bonds market in 2016, the authors show that there exists a significant coco bonds-specific contagion that can be the consequence of the reassessment by investors of coco bonds' riskiness. Corcuera *et al.* (2014) state that because of the conversion risk, coco bonds exhibit a death-spiral effect. To hedge the conversion risk, coco bonds' holders may indeed short sell shares. Doing so they may find themselves in a position of selling shares whose price is decreasing and therefore they may contribute actively to the materialization of the conversion risk. By hedging the conversion risk, investors thus make it more likely. Hence the spiral effect. Corcuera *et al.* (2014) however show that such a death-spiral effect is less likely to occur for coupon cancellable coco bonds than for coco bonds that convert into equity. Because coco bonds are hard to price and can spark off a crisis in financial markets due to contagion mechanisms, they can fail to establish a strong market discipline. Admati *et al.* (2013) therefore call for a sharp increase in equity requirements instead of designing regulatory requirements in hybrid securities.

We model a bank that invests in an asset portfolio. The bank relies on three funding sources: equity, deposits and coco bonds. Contrary to Glasserman and Nouri (2012, 2016) we consider principal write-off coco bonds instead of coco bonds that convert into common equity. To study under which circumstances a crisis occurs in the coco bonds' market we define the following game: investors decide to sell their coco bonds when they expect those coco bonds to be written off, while the central bank discretionarily decides to write coco bonds off when their market value falls below a certain threshold. We assume that investors do not know the true financial situation of the bank. They are granted a public signal that accounts for the information displayed by the bank in its financial statements. Additionally, we assume that each investor has its own assessment of the situation of the bank. This assessment is based on elements that are not found in the financial statements but relies on the "sophistication" of investors. This second source of information is referred to as the private signal. Investors therefore base their decisions on two noisy signals that are informative of the financial situation of the bank. To our knowledge this paper is the first to tackle the question of the systemic risk associated with coco bonds through a theoretical model. By showing that coco bonds could create a panic, this paper indeed underlines the necessity to take this risk into account while assessing coco bonds.

The next section presents the general framework of the model. Section 3 introduces coco bonds and develops a simple pricing model. Section 4 describes a game that allows us to study how a panic can materialize in the coco bonds' market. In section 5, we study the impact of information precision on the probability that a crisis happens. Section 6 discusses policy implications. Section 7 concludes.

2 General framework

There are three periods.

In $t = 0$, the bank invests in an asset portfolio that yields a random return θ. This portfolio is funded thanks to equity, deposits and coco bonds. Let us denote by E the proportion of equity, by D the proportion of deposits and by C that of coco bonds. The funding structure of the bank is exogenous. Creditors are in all cases assumed to be risk-neutral. Let us denote by r_2 the return associated with coco bonds. We assume that deposits pay the riskless return 1. Coco bonds enter regulatory capital. More precisely, we make a distinction between common equity Tier 1 (CET1) capital and additional Tier 1 (AT1) capital. CET1 capital is made of equity – it thus amounts to E – and AT1 capital is made of coco bonds – it thus amounts to C. In $t = 0$, the book value of total Tier 1 capital therefore amounts to $E + C$. We assume that $E + C + D = 1$.

In $t = 1$, coco bonds' holders can sell their coco bonds. Coco bonds are long-term bonds and are associated with a liquidity risk in the short-run. To take this liquidity risk into account, we assume that the $t = 1$ market price of coco bonds is equal to:

$$p(r_2) = r_2^* - \gamma s, \tag{1}$$

where $s \in [0, 1]$ is the proportion of coco bonds' holders that decide to sell. $\gamma \geq 0$ is thus a parameter that accounts for the liquidity (more precisely the depth) of the coco bonds' market. The higher γ is, the more illiquid this market is. The linear demand function described in equation (1) can, for instance, be thought of as that of a potential representative buyer characterized by an exponential utility function and a normal distribution with mean r_2^* over the return associated with coco bonds. Coco bonds' holders do not know the true distribution of θ. They are granted a public signal through the financial statements of the bank that allows them to know that θ is normally distributed with mean μ and variance $\frac{1}{\alpha}$. α is thus the precision of the information disclosed by the bank: an increase in α – because of regulatory requirements such as the third pillar of

Basel III – consists in an increase in the precision of the public signal. The public signal is common knowledge to all coco bonds' holders. Each investor also has its own assessment of the financial situation of the bank. This assessment is summarized in a private signal $v_i = \theta + \varepsilon_i$ with $\varepsilon_i \hookrightarrow \mathcal{N}(0, \frac{1}{\beta})$. β is here the precision of the private signal. When β is large, i.e. when private signals are very accurate, investors are sophisticated in the sense that they are able to assess precisely the financial situation of the bank on their own. We assume that the noises associated with the private signals are independent of each other (i.e. $\mathbb{E}(\varepsilon_i \varepsilon_j) = 0$ for $i \neq j$) and of θ (i.e. $\mathbb{E}(\varepsilon_i \theta) = 0$). At the same time as coco bonds' holders can sell their bonds, the central bank can discretionarily decide to write them off.

In $t = 2$, the asset portfolio pays and creditors are paid. Table 1 summarizes the timing of the model.

$t = 0$	$t = 1$	$t = 2$
The bank invests in an asset portfolio that yields a random return θ.	Coco bonds' holders can sell their bonds or not. The central bank can write coco bonds off or not.	The asset pays and creditors are paid.

Table 1: Timing of the model

3 A first glimpse into coco bonds

3.1 Definition

Coco bonds are associated with both a mechanical and a discretionary trigger.[1] The mechanical trigger is a capital trigger that forces coco bonds to be written off whenever the CET1 capital of the bank falls below a certain threshold. We assume that coco bonds are written off whenever the $t = 2$ equity value of the bank is below a threshold $\chi_1 \geq 0$. That is when:

$$\underbrace{\theta - D - Cr_2}_{\text{CET1}} \leq \chi_1 \iff \theta \leq \theta^* \equiv D + Cr_2 + \chi_1. \tag{2}$$

[1]According to CRD IV, to be included in AT1 capital, coco bonds need to be associated with both a mechanical and a discretionary trigger.

Coco bonds can also be discretionarily written off by the central bank. More precisely, we assume that the central bank takes information from market prices and decide to write coco bonds off when the market value of the Tier 1 capital falls below a threshold $\chi_2 \geq 0$. That is when the following inequality holds true:

$$\begin{aligned} &\underbrace{\underbrace{\theta - D - Cr_2}_{\text{CET1}} + \underbrace{C(r_2 - \gamma s)}_{\text{AT1}}}_{\text{Tier 1}} \leq \chi_2 \\ \iff \quad &\theta \leq \theta^{**} \equiv D + C\gamma s + \chi_2. \end{aligned} \tag{3}$$

The central bank exerts an indirect market discipline over the bank in the sense of Bliss and Flannery (2001). Coco bonds' holders monitor the bank and decide to sell under certain circumstances. Doing so, they produce information (through prices) based on which the central bank may decide to exert an influence over the bank. Since coco bonds enter the regulatory capital of the bank, sales of coco bonds deplete the market value of this capital. Observing market prices, the central bank notices this depletion and may decide to write coco bonds off to prevent the bank from going insolvent. In this case, the probability with which coco bonds are written off is an increasing function in the expected proportion s of coco bonds' holders that decide to sell. According to equation (3), θ^{**} is indeed an increasing function in s. In other words, when s increases, coco bonds are more likely to be written off and creditors are thus more inclined to sell them. In this sense, selling decisions are strategic complements since creditor i is more incentivized to sell if creditor j does so and *vice versa*. This is in line with the empirical evidence provided by Bologna *et al.* (2018) according to which coco bonds markets are subject to self-fulfilling behaviors.

Regulatory coco bonds are associated with a "low" mechanical trigger that makes their conversion before the point of non-viability unlikely (Cahn and Kenadjian, 2014). In the terms of our model, this means that χ_1 is low so that coco bonds are written off only when the bank is close to insolvency. We assume that the mechanical trigger is indeed low so that conversions, if they occur, are always discretionary. A sufficient condition for conversions to be always discretionary is $\chi_2 \geq \chi_1 + Cr_2$. In this case, the central bank is determined to act in a going-concern perspective and to write coco bonds off before the point of non-viability is reached.

3.2 Pricing

We assume that only the mechanical conversion risk is taken into consideration when pricing coco bonds. In reality, coco bonds associated with both a mechanical trigger and a discretionary trigger are likely to be priced this way since it is *ex ante* virtually impossible to assess the probability of a discretionary conversion. Since creditors are risk-neutral, the expected return associated with coco bonds should be equal to the riskless return 1. Let us denote by r_2^* the equilibrium value of r_2. r_2^* is thus the solution of the following equation:

$$\int_{\theta^*}^{+\infty} r_2 f(\theta) d\theta = 1 \iff [1 - F(\theta^*)] \, r_2 = 1, \tag{4}$$

where $f(\cdot)$ is the probability density function of θ and $F(\cdot)$ its cumulative distribution function. We assume that θ is normally distributed with mean μ and variance σ^2. Equations (2) and (4) allow us to compute the equilibrium value of r_2. We show that such an equilibrium does not always exist. In other words, the bank is not always able to issue coco bonds.

Proposition 1. *There does not necessarily exist an equilibrium value r_2^*. For such an equilibrium to exist, E needs to be larger than a threshold Emin defined as the minimum on $\mathbb{R}_+^*$ of the function $1 + C(x-1) + \chi_1 - \frac{1}{x} F^{-1}\left(1 - \frac{1}{x}\right)$. Emin is a decreasing function in μ.*

Proof. See Appendix A. □

Figure 1 plots *Emin* as a function of μ. When E is below the curve *Emin*, no equilibrium value of r_2 can be found. In this case, the bank cannot issue coco bonds. In accordance with Proposition 1, we notice that *Emin* is a decreasing function in μ. In particular, for values of μ larger than approximately 1.2, we have $Emin < 0$ and thus E is always greater than *Emin*. In that case, the bank is always able to issue coco bonds.

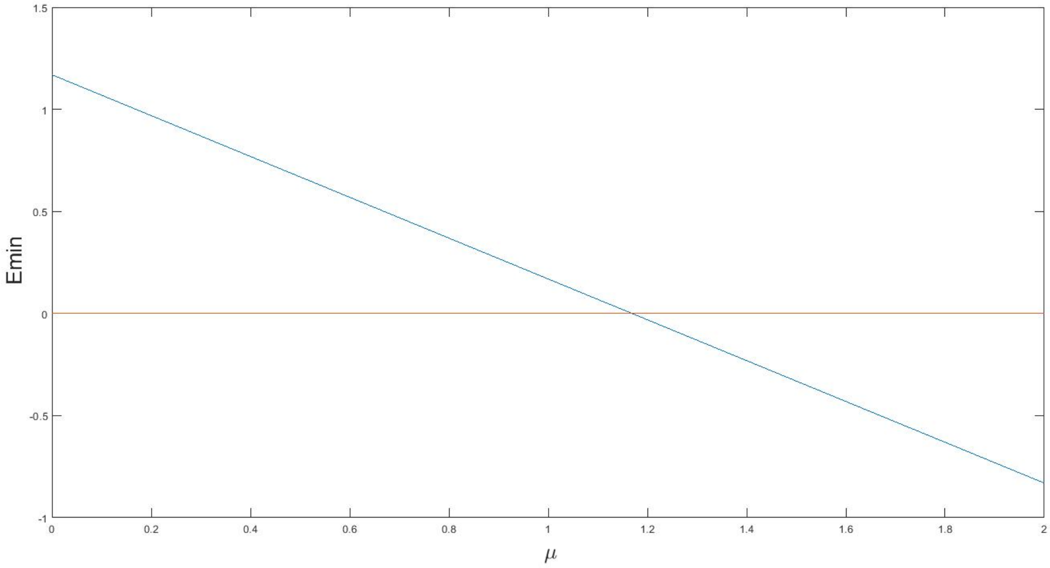

Figure 1: $Emin$ as a function of μ ($C = 0.3$ and $\chi_1 = 0$)

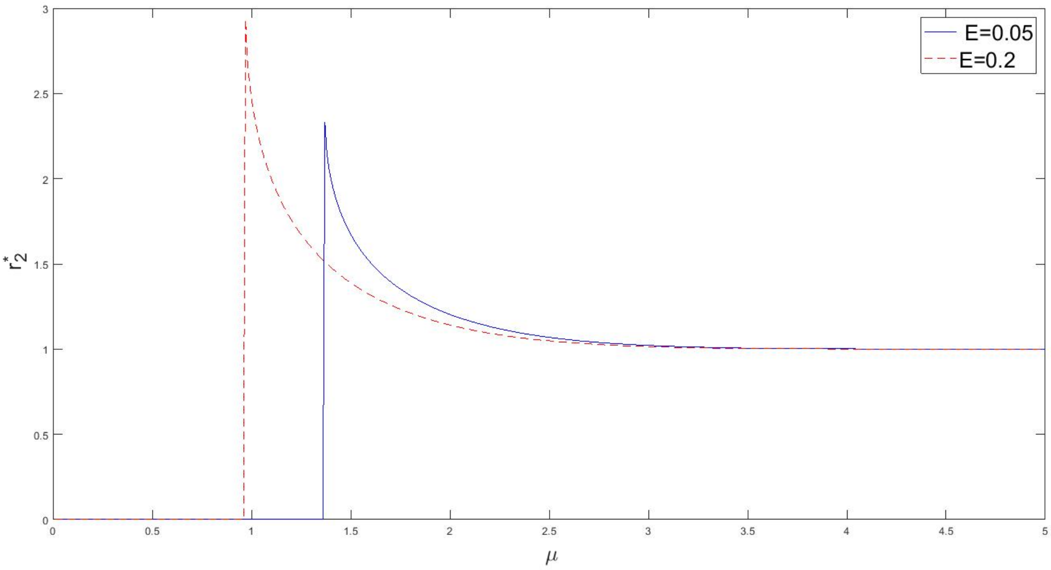

Figure 2: The equilibrium return r_2^* as a function of μ for some values of E ($D = 0.5$ and $\chi_1 = 0$)

Proposition 1 states that weakly-capitalized banks can find themselves unable to issue coco bonds. This is a theoretical rationale for the empirical evidence according to which larger and stronger banks were among the first wave of coco bonds issuers (Avdjiev *et al.*, 2017). Figure 2 plots r_2^* as a function of μ for some values of E. When r_2^* does not exist, we arbitrarily define $r_2^* = 0$. In accordance with Proposition 1, we notice that for the smallest value of E (0.05), the bank is not able to issue coco bonds when μ is below approximately 1.4. When the value of E is larger (0.2), the bank is always able to issue coco bonds when μ is greater than 1.

4 Panic in the coco bonds' market

4.1 The central bank

The central bank observes the market value of the regulatory capital (CET1 plus AT1) of the bank and decides to write coco bonds off whenever the capital is below a threshold χ_2. There therefore is a threshold value θ^{**} of θ (see equation (3)) for which the central bank is indifferent between writing coco bonds off or not:

$$\theta^{**} \equiv D + C\gamma s + \chi_2. \tag{5}$$

We assume that creditors follow a threshold strategy, meaning that creditor i decides to sell when the private signal v_i he observes is smaller than or equal to a threshold v^*. Since ε_i is independent of ε_j and of θ, we know that s is given by the probability with which a creditor i observes a private signal below v^*:

$$s = \Pr\left[v_i \leq v^* | \theta^{**}\right] = \Phi\left(\sqrt{\beta}(v^* - \theta^{**})\right), \tag{6}$$

where $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution. Combining equations (5) and (6), we can derive the indifference curve of the central bank:

$$\begin{aligned} & \theta^{**} = D + C\gamma\Phi\left(\sqrt{\beta}(v^* - \theta^{**})\right) + \chi_2 \\ \Longleftrightarrow \quad & v^*_{CB} = \tfrac{1}{\sqrt{\beta}}\Phi^{-1}\left[\tfrac{\theta^{**}-D-\chi_2}{C\gamma}\right] + \theta^{**}. \end{aligned} \tag{7}$$

v^*_{CB} is the threshold value of the private signal derived from the objective function of the central bank.

4.2 Coco bonds' holders

Coco bonds' holders decide to sell when they expect coco bonds to be written off. Since they do not know the true distribution of θ, coco bonds' holders can only base their estimation of the probability of conversion on the noisy information they possess. More precisely, creditor i decides to sell its coco bonds whenever the probability that coco bonds are not written off times the return associated with coco bonds is smaller than their market price. That is when the following inequality holds true:

$$\underbrace{\Pr\left[\{\,\theta \geq \theta^*\,\}\cup\{\,\theta \geq \theta^{**}\,\}|\mu, v_i\right]}_{\text{Probability of no conversion conditional on the signals}} \qquad r_2^* \leq r_2^* - \gamma s. \tag{8}$$

Since we assumed that $\theta^{**} \geq \theta^*$, condition (8) can therefore be rewritten as follows:

$$\Pr\left[\theta \geq \theta^{**}|\mu, v_i\right] r_2^* \leq r_2^* - \gamma s. \tag{9}$$

As we assumed that the noise parameters ε_i are normally distributed, we know that the distribution of θ conditional on μ and v_i is normal as well. The expected value of θ conditional on μ and v_i is thus:

$$\mathbb{E}[\theta|\mu, v_i] = \frac{\alpha\mu + \beta v_i}{\alpha + \beta}, \tag{10}$$

and its variance is

$$\mathrm{Var}[\theta|\mu, v_i] = \frac{1}{\alpha + \beta}. \tag{11}$$

Since creditors are assumed to follow a threshold strategy, we have:

$$s|v_i = \Pr[v_j \leq v^*|v_i] = \Phi\left[\sqrt{\frac{\beta}{2}}(v^* - v_i)\right]. \tag{12}$$

We can therefore rewrite (9) as follows:

$$1 - \Phi\left[\sqrt{\alpha + \beta}\left(\theta^{**} - \frac{\alpha\mu + \beta v_i}{\alpha + \beta}\right)\right] r_2^* \leq r_2^* - \gamma\Phi\left[\sqrt{\frac{\beta}{2}}(v^* - v_i)\right]. \tag{13}$$

Coco bonds' holders are thus indifferent between selling or holding their coco bonds when:

$$\begin{aligned} & 1-\Phi\left[\sqrt{\alpha+\beta}\left(\theta^{**}-\frac{\alpha\mu+\beta v^{*}}{\alpha+\beta}\right)\right] r_2^{*}=r_2^{*}-\frac{\gamma}{2} \\ \Longleftrightarrow \quad & v_{coco}^{*}=\frac{\alpha+\beta}{\beta}\theta^{**}-\frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{1-r_2^{*}+\frac{\gamma}{2}}{r_2^{*}}\right)-\frac{\alpha\mu}{\beta}. \end{aligned} \tag{14}$$

v_{coco}^{*} is therefore the threshold value of the private signal below which creditors decide to sell their coco bonds. A creditor i that would observe a private signal v_i below v_{coco}^{*} would sell its coco bonds, while it would hold them otherwise. According to equation (14), we notice that for v_{coco}^{*} to exist and to be finite we need to have $r_2^{*} \in \left]\frac{1}{2}\left(1+\frac{\gamma}{2}\right), 1+\frac{\gamma}{2}\right[$. When $r_2^{*} \leq \frac{1}{2}\left(1+\frac{\gamma}{2}\right)$, equation (14) is never verified, sales of coco bonds never occur in this case because the market is too illiquid (i.e. γ is too large) and coco bonds' holders always prefer to keep holding their bonds. On the contrary, when $r_2^{*} \geq 1+\frac{\gamma}{2}$, coco bonds are always sold.

4.3 The equilibrium

Equations (7) and (14) allow us to find the equilibrium value of θ:

$$\begin{aligned} & \frac{1}{\sqrt{\beta}}\Phi^{-1}\left[\frac{\theta^{**}-D-\chi_2}{C\gamma}\right]+\theta^{**}=\frac{\alpha+\beta}{\beta}\theta^{**}-\frac{\sqrt{\alpha+\beta}}{\beta}\Phi^{-1}\left(\frac{1-r_2+\frac{\gamma}{2}}{r_2}\right)-\frac{\alpha\mu}{\beta} \\ \Longleftrightarrow \quad & \theta^{**}=D+C\gamma\Phi\left[\frac{\alpha}{\sqrt{\beta}}\theta^{**}-\frac{\alpha}{\sqrt{\beta}}\mu-\sqrt{\frac{\alpha+\beta}{\beta}}\Phi^{-1}\left(\frac{1-r_2+\frac{\gamma}{2}}{r_2}\right)\right]+\chi_2. \end{aligned} \tag{15}$$

Proposition 2. *Provided that* $r_2^{*} \in \left]\frac{1}{2}\left(1+\frac{\gamma}{2}\right), 1+\frac{\gamma}{2}\right[$ *and if* $\beta > \frac{\alpha^2}{2\pi}$ *(sufficient condition), there exists a unique equilibrium value of* θ *that satisfies* (15)*.*

Proof. For the equilibrium value of θ to be unique, v_{CB}^{*} and v_{coco}^{*} need to cross only once. This is the case if $\frac{\partial v_{CB}^{*}}{\partial\theta} > \frac{\partial v_{coco}^{*}}{\partial\theta}$ for all θ. We have:

$$\begin{aligned} \frac{\partial v_{CB}^{*}}{\partial\theta} &= \frac{1}{\sqrt{\beta}}\frac{\partial\Phi^{-1}(\cdot)}{\partial\theta}+1, \\ \frac{\partial v_{coco}^{*}}{\partial\theta} &= \frac{\alpha+\beta}{\beta}. \end{aligned} \tag{16}$$

As $\min\left\{\frac{\partial\Phi^{-1}(\cdot)}{\partial\theta}\right\} = \frac{1}{\max\{\phi(\cdot)\}} = \sqrt{2\pi}$ with $\phi(\cdot)$ the probability density function of the standard normal distribution, a sufficient condition for $\frac{\partial v_{CB}^{*}}{\partial\theta} > \frac{\partial v_{coco}^{*}}{\partial\theta}$ is $\beta > \frac{\alpha^2}{2\pi}$. □

For a panic equilibrium to exist, three conditions are finally required:

1. r_2^{*} must exist,

2. $r_2^* \in \left]\frac{1}{2}\left(1+\frac{\gamma}{2}\right), 1+\frac{\gamma}{2}\right[$,

3. $\beta > \frac{\alpha^2}{2\pi}$.

Assuming that r_2^* exists and that $\beta > \frac{\alpha^2}{2\pi}$, Table 2 summarizes the situations where a panic occurs in the coco bonds' market.

$r_2^* \leq \frac{1}{2}\left(1+\frac{\gamma}{2}\right)$	$r_2^* \in \left]\frac{1}{2}\left(1+\frac{\gamma}{2}\right), 1+\frac{\gamma}{2}\right[$	$1+\frac{\gamma}{2} \leq r_2^*$
Sales of coco bonds never occur	Panic sales of coco bonds occur when θ is below θ^{**}	Coco bonds are always sold

Table 2: Panic sales of coco bonds

From now on, panic sales refer to sales that occur when $r_2^* \in \left]\frac{1}{2}\left(1+\frac{\gamma}{2}\right), 1+\frac{\gamma}{2}\right[$. Since we cannot compute r_2^* analytically, we resort to simulations to exhibit situations where such panic sales arise. The values of exogenous parameters are set as follows: $D = 0.9$, $E = 0.05$, $\chi_1 = 0$, $\chi_2 = 0.1$, $\alpha = 1$ and $\beta = 2$. The bank therefore funds 5% of its total asset through equity E, 90% through bonds D and 5% through coco bonds C. In $t = 0$, CET1 capital amounts to 5% and Tier 1 capital to 10% of the total asset. Coco bonds are mechanically converted whenever the point of non-viability is reached ($\chi_1 = 0$) and the central bank discretionarily writes coco bonds off whenever the market value of Tier 1 capital falls below 0.1. We run simulations to compute the probability of crisis as a function of μ and γ. Results are presented in Figure 3.

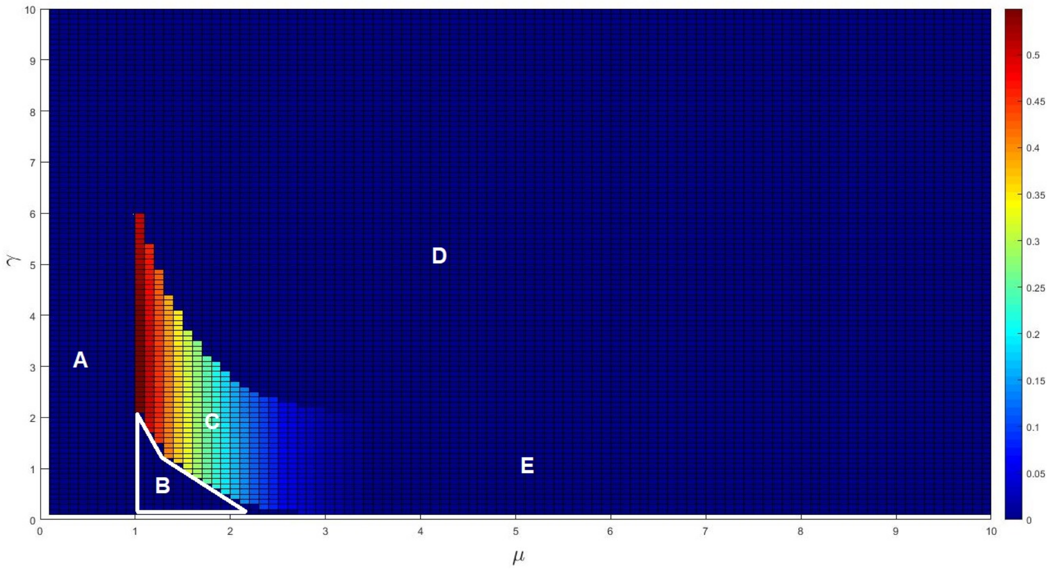

Figure 3: The probability of a panic-driven crisis as a function of μ and γ

The probability that a panic-driven crisis occurs is the probability that θ is below θ^{**}. When θ^{**} does not exist, because at least one of the conditions does not hold, this probability thus equals 0. Five situations are worth distinguishing:

- Situation A: μ is smaller than the riskless return 1, the bank does not invest in the asset.
- Situation B: when γ and μ are such that $r_2^* \geq 1 + \frac{\gamma}{2}$, coco bonds are always sold no matter the behavior of the central bank. In this case, θ^{**} does not exist and the probability of a panic-driven crisis is therefore 0.
- Situation C: θ^{**} exists and the probability that a crisis happens is given by the probability that θ is below θ^{**}. When μ is small the probability that the bank ends up insolvent is large and so is the probability that coco bonds are written off. In this case, coco bonds' holders are very likely to sell. Notice however that, even for the smallest values of μ, panic sales of coco bonds only occur provided that γ is under a certain value (6 here). Above this value of γ, the market is so illiquid that coco bonds' holders never find it interesting to sell.
- Situation D: when γ and μ are such that $r_2^* \leq 1 + \frac{\gamma}{2}$, the market is too illiquid and coco bonds are never sold no matter the behavior of the central bank.
- Situation E: θ^{**} exists but the expected return μ associated with the asset is large so that the probability that the bank ends up insolvent is close to 0, and so is consequently the probability that a crisis happens.

5 Information precision and the probability of crisis

In this section, we study the impact of information precision on the probability of crisis. We thus assume that θ^{**} exists and is unique.

5.1 Comparative statics

Proposition 3. *Increasing the precision of the public signal has an ambiguous impact on the probability of crisis:*

- *when $\gamma \leq \bar{\gamma}$, we have $\frac{\partial \theta^{**}}{\partial \alpha} \geq 0$ when $\theta^{**} \geq \bar{\theta}_{\alpha}^{**}$, while we have $\frac{\partial \theta^{**}}{\partial \alpha} < 0$ otherwise,*

- *when $\gamma > \bar{\gamma}$, we have $\frac{\partial \theta^{**}}{\partial \alpha} \geq 0$ when $\theta^{**} \leq \bar{\theta}^{**}_{\alpha}$, while we have $\frac{\partial \theta^{**}}{\partial \alpha} < 0$ otherwise.*

Proof. We differentiate θ^{**} with respect to α:

$$\frac{\partial \theta^{**}}{\partial \alpha} = \frac{\frac{\gamma C}{\sqrt{\beta}} \left[\theta^{**} - \mu - \frac{1}{2\sqrt{\alpha+\beta}} \Phi^{-1} \left(\frac{1 - r_2^* + \frac{\gamma}{2}}{r_2^*} \right) \right] \phi(\cdot)}{1 - \gamma \frac{C\alpha}{\sqrt{\beta}} \phi(\cdot)}. \tag{17}$$

When $\gamma \leq \bar{\gamma} \equiv \frac{1}{C \frac{\alpha}{\sqrt{\beta}} \phi(\cdot)}$, we indeed have $\frac{\partial \theta^{**}}{\partial \alpha} \geq 0$ when $\theta^{**} \geq \bar{\theta}^{**}_{\alpha} \equiv \mu + \frac{\Phi^{-1}\left(\frac{1 - r_2^* + \frac{\gamma}{2}}{r_2^*} \right)}{2\sqrt{\alpha+\beta}}$ and $\frac{\partial \theta^{**}}{\partial \alpha} < 0$ otherwise. On the contrary, when $\gamma > \bar{\gamma}$, we indeed have $\frac{\partial \theta^{**}}{\partial \alpha} \geq 0$ when $\theta^{**} \leq \bar{\theta}^{**}_{\alpha}$ and $\frac{\partial \theta^{**}}{\partial \alpha} < 0$ otherwise. □

The impact of an increase in the precision α of the public signal on the probability of crisis thus depends both on the liquidity γ of the market and on the value of θ^{**}. On the contrary, when the market is rather liquid ($\gamma \leq \bar{\gamma}$), public information should not bee too precise when the probability of crisis is high.

Proposition 4. *Increasing the precision of the private signal has an ambiguous impact on the probability of crisis:*

- *when $\gamma \leq \bar{\gamma}$, we have $\frac{\partial \theta^{**}}{\partial \beta} \geq 0$ when $\theta^{**} \leq \bar{\theta}^{**}_{\beta}$, while we have $\frac{\partial \theta^{**}}{\partial \beta} < 0$ otherwise,*
- *when $\gamma > \bar{\gamma}$, we have $\frac{\partial \theta^{**}}{\partial \beta} \geq 0$ when $\theta^{**} \geq \bar{\theta}^{**}_{\beta}$, while we have $\frac{\partial \theta^{**}}{\partial \beta} < 0$ otherwise.*

Proof. We differentiate θ^{**} with respect to β:

$$\frac{\partial \theta^{**}}{\partial \beta} = \frac{\frac{\gamma C\alpha}{2\beta\sqrt{\beta}} \left[-\theta^{**} + \mu + \frac{1}{\sqrt{\alpha+\beta}} \Phi^{-1} \left(\frac{1 - r_2^* + \frac{\gamma}{2}}{r_2^*} \right) \right] \phi(\cdot)}{1 - \gamma \frac{C\alpha}{\sqrt{\beta}} \phi(\cdot)}. \tag{18}$$

When $\gamma \leq \bar{\gamma} \equiv \frac{1}{C \frac{\alpha}{\sqrt{\beta}} \phi(\cdot)}$, we indeed have $\frac{\partial \theta^{**}}{\partial \beta} \geq 0$ when $\theta^{**} \leq \bar{\theta}^{**}_{\beta} \equiv \mu + \frac{\Phi^{-1}\left(\frac{1 - r_2^* + \frac{\gamma}{2}}{r_2^*} \right)}{\sqrt{\alpha+\beta}}$ and $\frac{\partial \theta^{**}}{\partial \beta} < 0$ otherwise. On the contrary, when $\gamma > \bar{\gamma}$, we indeed have $\frac{\partial \theta^{**}}{\partial \beta} \geq 0$ when $\theta^{**} \geq \bar{\theta}^{**}_{\beta}$ and $\frac{\partial \theta^{**}}{\partial \beta} < 0$ otherwise. □

Similarly, the impact of an increase in the precision of the private signal depends on the values of γ and θ^{**}. Tables 3 and 4 summarize the results presented in Propositions 3 and 4.

$\theta^{**} < \theta^{**}_\alpha$	$\theta^{**} \in [\theta^{**}_\alpha; \theta^{**}_\beta]$	$\theta^{**}_\beta < \theta^{**}$
$\frac{\partial\theta^{**}}{\partial\alpha} < 0$	$\frac{\partial\theta^{**}}{\partial\alpha} \geq 0$	$\frac{\partial\theta^{**}}{\partial\alpha} \geq 0$
$\frac{\partial\theta^{**}}{\partial\beta} \geq 0$	$\frac{\partial\theta^{**}}{\partial\beta} \geq 0$	$\frac{\partial\theta^{**}}{\partial\beta} < 0$

Table 3: Precision of information and risk of crisis when the market is liquid ($\gamma \leq \bar{\gamma}$)

$\theta^{**} \leq \theta^{**}_\alpha$	$\theta^{**} \in]\theta^{**}_\alpha; \theta^{**}_\beta[$	$\theta^{**}_\beta \leq \theta^{**}$
$\frac{\partial\theta^{**}}{\partial\alpha} \geq 0$	$\frac{\partial\theta^{**}}{\partial\alpha} < 0$	$\frac{\partial\theta^{**}}{\partial\alpha} < 0$
$\frac{\partial\theta^{**}}{\partial\beta} < 0$	$\frac{\partial\theta^{**}}{\partial\beta} < 0$	$\frac{\partial\theta^{**}}{\partial\beta} \geq 0$

Table 4: Precision of information and risk of crisis when the market is illiquid ($\gamma > \bar{\gamma}$)

Depending on the liquidity of the coco bonds' market and on the initial probability of crisis, the impact of an increase in the precision of the signals is not the same. In particular the nature of the information has to be taken into consideration.

5.2 Simulations

According to Propositions 3 and 4, the impact of an increase in the precision of information (either private or public) depends on the initial values of α and β. Conclusions on the impact of information disclosure on the probability that a crisis occurs cannot therefore be formulated solely from those two propositions. We resort to simulations to disentangle the impact of information precision on the probability of crisis. To do so, we compute $\frac{\partial\theta^{**}}{\partial\alpha}$ and $\frac{\partial\theta^{**}}{\partial\beta}$ for different values of μ, γ, α and β. Exogenous parameters are as follows: $D = 0.9$, $E = 0.05$, $\chi_1 = 0$ and $\chi_2 = 0.1$. In this case, Figure 3 shows that the probability that a crisis happens is equal to 0 for all μ above 4 and for all γ above 6. Simulations are thus run for values of μ below 4 and values of γ below 6. More precisely, we proceed in two steps:

1. we first compute the values of $\frac{\partial\theta^{**}}{\partial\alpha}$ and $\frac{\partial\theta^{**}}{\partial\beta}$ for α and β ranging from 1 to 1000 for all couples (γ, μ),
2. for each couple (γ, μ), we then sum the values of, on the one hand, all the $\frac{\partial\theta^{**}}{\partial\alpha}$ (meaning for all α and β) and, on the other hand, all the $\frac{\partial\theta^{**}}{\partial\beta}$ to determine the impact of an increase in information precision for every couple (γ, μ).

Results are presented in Figure 4. At each crossing between μ and γ, Figure 4 provides the value of the sum of all the $\frac{\partial \theta^{**}}{\partial \alpha}$ (upper plot) and all the $\frac{\partial \theta^{**}}{\partial \beta}$ (lower plot) for α and β ranging from 1 to 1000. A positive value, as is for instance the case in situation A in the upper plot, is therefore indicative of an average positive impact of an increase in the precision of the public signal on θ^{**}. In this case, increasing the precision of the public signal increases the probability that a crisis happens. In both plots, two situations are worth distinguishing:

- Situations A and A': for the smallest values of μ, we have $\sum \dfrac{\partial \theta^{**}}{\partial \alpha} > 0$ and $\sum \dfrac{\partial \theta^{**}}{\partial \beta} < 0$. In this situation, increasing the precision of the public signal increases the probability of crisis, while increasing the precision of the private signal decreases this probability.
- Situations B and B': for a sufficiently large value of μ, we have $\sum \dfrac{\partial \theta^{**}}{\partial \alpha} < 0$ and $\sum \dfrac{\partial \theta^{**}}{\partial \beta} > 0$. In this situation, increasing the precision of the public signal decreases the probability of crisis, while increasing the precision of the private signal increases this probability.

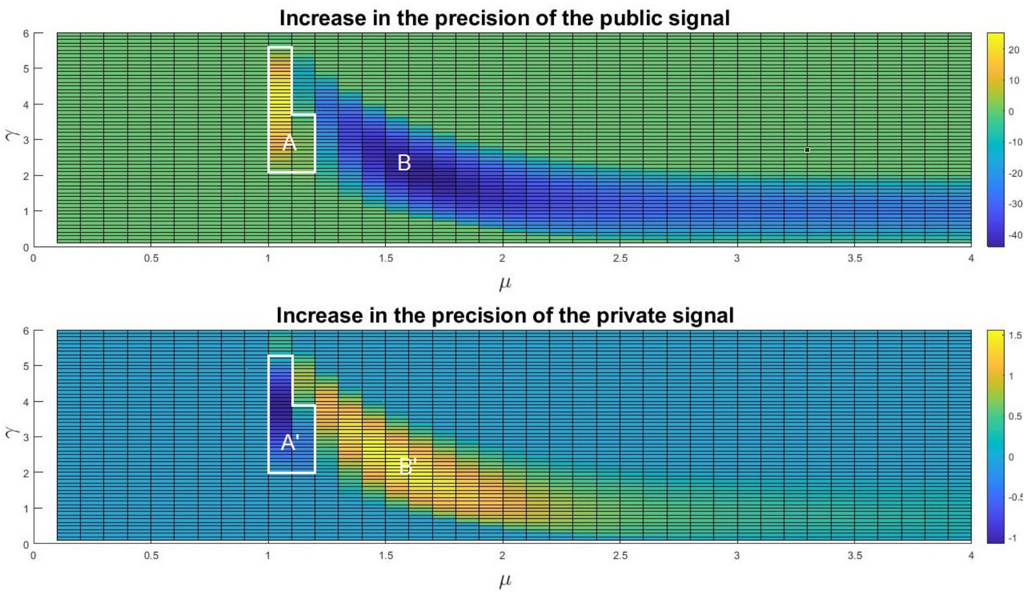

Figure 4: The impact of an increase in information precision on the probability of crisis as a function of μ and γ

We demonstrated in section 5.1 that the impact of an increase in the precision of the signals rests on the value of θ^{**} and on three thresholds:

$$\bar{\gamma} = \frac{1}{C\frac{\alpha}{\sqrt{\beta}}\phi(\cdot)}, \tag{19}$$

$$\theta_{\alpha}^{**} = \mu + \frac{\Phi^{-1}\left(\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*}\right)}{2\sqrt{\alpha+\beta}}, \tag{20}$$

$$\theta_{\beta}^{**} = \mu + \frac{\Phi^{-1}\left(\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*}\right)}{\sqrt{\alpha+\beta}}. \tag{21}$$

Because of the uniqueness condition stated in Proposition 2, we know that $\frac{\alpha}{\sqrt{\beta}}\phi[\cdot) \leq 1$. Therefore, $\bar{\gamma}$ is greater than $\frac{1}{C\frac{\alpha}{\sqrt{\beta}}\phi[\cdot)} \geq \frac{1}{0.05} = 20$. All the values of γ for which θ^{**} exists are thus below $\bar{\gamma}$ and we are consequently in the situation described in Table 3.

When $\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*} \geq \frac{1}{2}$, we know that $\Phi^{-1}\left(\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*}\right) \geq 0$ and we thus have both θ_{α}^{**} and θ_{β}^{**} greater than μ. Since $\max\{\theta^{**}\} = D + \gamma C + \chi_2$, we have $\frac{\partial\theta^{**}}{\partial\alpha} < 0$ and $\frac{\partial\theta^{**}}{\partial\beta} > 0$ provided that $D + \gamma C + \chi_2 < \mu$ (see Table 3). This is what happens in situations B and B'.

On the contrary, when $\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*} < \frac{1}{2}$, we have $\Phi^{-1}\left(\frac{1-r_2^*+\frac{\gamma}{2}}{r_2^*}\right) < 0$. We thus always have $\theta_{\alpha}^{**} < \theta^{**}$ and $\theta_{\beta}^{**} < \theta^{**}$ for sufficiently small values of μ. In this situation, according to Table 3, we indeed have $\frac{\partial\theta^{**}}{\partial\alpha} > 0$ and $\frac{\partial\theta^{**}}{\partial\beta} < 0$. This is what happens in situations A and A'.

On average, when the funding structure of the bank is such that it strongly relies on funding instruments other than capital ($D = 0.9$), which is the case in reality, increasing the precision of the public signal decreases the probability of a panic-driven crisis, while increasing the precision of the private signal increases the probability of such a crisis. To conclude, apart from the situation where μ is very close to the riskless return, increasing the precision of the public signal has a negative impact on the probability that a crisis happens, while increasing the precision of the private signal has a positive impact on this probability.

6 Discussion and policy implications

After the crisis, banking regulation has narrowed the definition of regulatory capital. Under Basel III, banks are indeed constrained to hold 4.5% of their risk-weighted assets (RWA) in CET1 capital, which is more than twice the constraint under Basel II. In addition, counter-cyclical buffers have been added to the main framework and raised to 7% of the RWA the constraint in CET1 capital. Simultaneously, Basel III allows a certain proportion of AT1 capital to be made of coco bonds.[2] To be included in regulatory capital, coco bonds have however to be designed in a specific way. According to CRD IV – the European transposition of the Basel III framework – regulatory coco bonds have indeed to be associated with both a discretionary and a mechanical trigger and the latter has to be capital-based with a threshold greater than or equal to 5.125% of the RWA.

Our model allows us to discuss the impact of the introduction of coco bonds in regulatory capital. The main result of our paper is that if the conversion of coco bonds is related to changes in their market value, self-fulfilling behaviors may arise and a panic-driven crisis may occur. As a tool meant to improve market discipline, coco bonds are thus a potential channel of systemic risk. If market discipline is thought of as a regulatory intervention triggered by market signals – this is what Bliss and Flannery (2001) referred to as *indirect* market discipline –, expected sales of coco bonds could indeed increase the likelihood of a conversion, which in turn could increase the likelihood of panic sales and so on. This is what has been introduced as the "reflection problem" by Morris and Shin (2018): when a policy is based on market prices and when those prices are influenced by this policy, there is a circularity that can impede the effectiveness of the regulatory intervention.

Section 5 of this paper raises another concern related to the identity of ideal coco bonds' buyers. In a macroprudential perspective, it does not make sense for banks to buy other banks' coco bonds since this would only consist in building new transmission channels that could eventually prove a great factor of systemic risk. Retail customers are not sophisticated enough and therefore have to be prevented from investing in coco bonds. Persaud (2014) strongly objects the idea according to which long-term investors should invest in coco bonds. He argues that this would go against their business model and thus could be detrimental to the funding of long-term investments. Hedge funds remain potential investors. However, we showed that when the private information available to coco bonds' holders is very precise, the probability of a crisis happening increases. As well-informed traders, hedge funds could therefore be a potential factor of instability in the coco bonds' market.

[2] Precisely 1.5% of the RWA.

It is therefore not clear whether or not coco bonds could possibly fulfill their objective of improving market discipline. In at least two respects, they appear as a fantastic transmission channel of systemic risk. On the one hand, if banks invest in other banks' coco bonds, conversions would automatically propagate a crisis from the defaulting bank to the rest of the banking sector. On the other hand, short-term buying/selling behaviors from sophisticated traders such as hedge funds could be a great factor of instability that could eventually lead to a crisis. It is therefore of the utmost importance to cautiously take the potential destabilizing impact of coco bonds into account before considering going further in the direction of regulatory requirements in coco bonds.

7 Conclusion

We develop a model where a bank relies on three funding sources: equity, deposits and coco bonds. Because of the conversion risk, pricing coco bonds is a tricky exercise. We indeed show that there does not necessarily exist an equilibrium return for coco bonds and therefore the bank is not always able to issue coco bonds. In particular, when the bank is too weakly capitalized and/or when the expected return associated with its asset portfolio is too low, no equilibrium price for coco bonds can be found.

In section 4, we explore how the conversion risk associated with coco bonds gives rise to self-fulfilling behaviors that can lead to panics. In particular, when the conversion of coco bonds is related to changes in their market value, a self-fulfilling crisis can occur because of the interaction between the expectation of conversion by creditors and the expectation of panic sales by the central bank. Since panic sales are motivated by the risk of conversion and since a discretionary conversion is related to the proportion of coco bonds that is panic sold, self-fulfilling crises can occur.

In section 5, we study the impact of information disclosure on the probability that a crisis happens. Doing so, we show that when the funding structure of the bank relies strongly on funding instruments other than capital, increasing the precision of the information publicly disclosed by the bank through its financial statements decreases the probability that a panic-driven crisis occurs. On the contrary, increasing the precision of the information privately held by coco bonds' holders has the opposite effect.

Those results allow us to formulate policy implications that are discussed in section 6.

What is finally worth pointing out is that coco bonds are complex financial instruments that could eventually act as a channel through which systematic risk could propagate. The expectation of conversion could indeed nourish self-fulfilling panic sales of coco bonds and thus precipitate a market-wide panic that could spread to the whole financial system. The empirical evidence recently provided by Bologna *et al.* (2018) is the sign that such a self-fulfilling crisis could actually unfold. It is therefore of the utmost importance to keep in mind that one of the reasons why the global financial crisis was so severe was because the systemic risk associated with some securitized products had been largely overlooked. The current will to ensure market discipline through complex financial instruments, such as coco bonds, thus appears as a dangerous forgetfulness of history.

A Proof of Proposition 1

The equilibrium return of coco bonds is defined as the first value of r_2 that satisfies the following equation:

$$[1 - F(\theta^*)]\, r_2 = 1, \tag{22}$$

where $\theta^* \equiv D + r_2 C + \chi_1$. We denote the equilibrium value of r_2 by r_2^*. According to the balance sheet identity, when $E = 1$ we immediately have $r_2^* = \frac{1}{1-F(\chi_1)}$. Equation (22) can be rewritten as follows:

$$E = 1 + C(r_2 - 1) + \chi_1 - F^{-1}\left(1 - \frac{1}{r_2}\right), \tag{23}$$

where $F^{-1}(\cdot)$ is the inverse function of $F(\cdot)$. For all $r_2 \in [1, +\infty[$, let us define the function $h(r_2)$ as $h(r_2) = 1 + C(r_2 - 1) + \chi_1 - \frac{1}{r_2}F^{-1}\left(1 - \frac{1}{r_2}\right)$. We notice that $\max\{h(r_2)\} = +\infty$. For every $E \in [0, 1[$, it is therefore possible to find one r_2 such that we have $E < h(r_2)$. However, for some values of μ (see Figure 5), we have $\min\{h(r_2)\} > 0$. It is therefore not possible to find one r_2 in $[1, +\infty[$ such that $E \geq h(r_2)$ for every $E \in [0, 1[$. In that case, there are situations where we always have $E < h(r_2)$ and equation (23) does not have a solution. In other words, r_2^* does not necessarily exist.

r_2^* exists if and only if $E \geq \min\{h(r_2)\}$ for $r_2 \in [1, +\infty[$. We can easily show that $F^{-1}(\cdot)$ is an increasing function in μ. Therefore $h(r_2)$ is a decreasing function in μ. Thus when μ increases, $\min\{h(r_2)\}$ decreases and r_2^* is more likely to exist. Similarly, according to equation (23), r_2^* is more likely to exist when C and χ_1 are small.

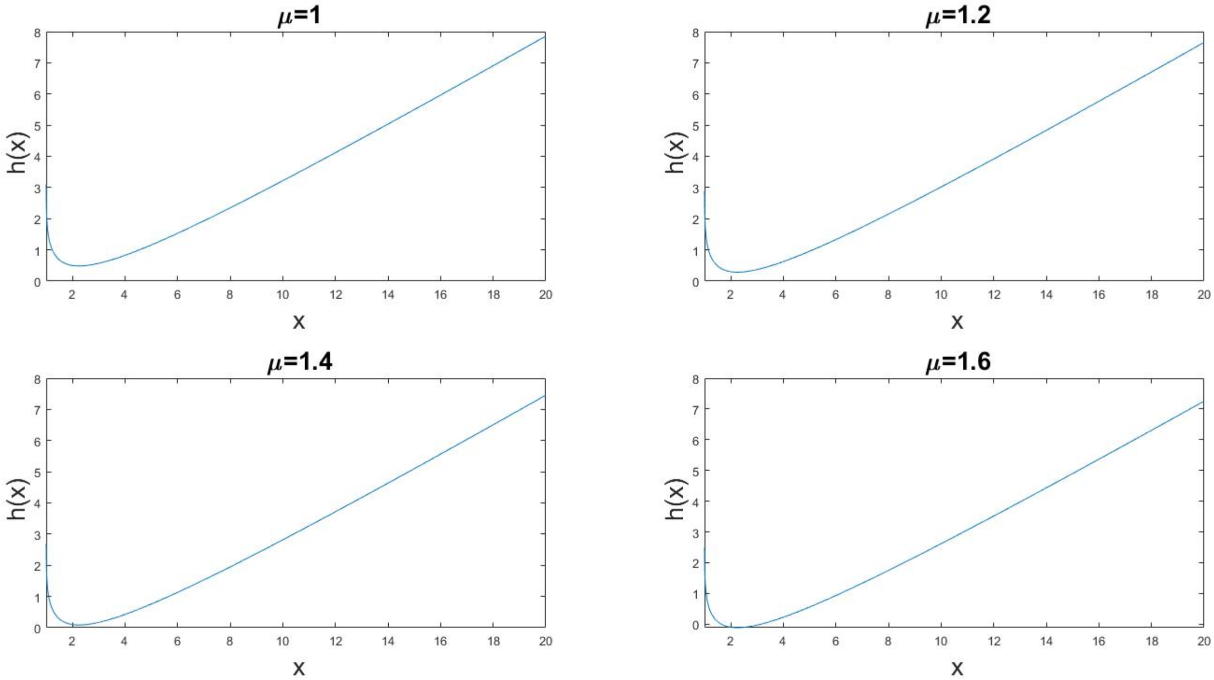

Figure 5: $h(x)$ as a function of x for some values of μ ($C = 0.5$ and $\chi_1 = 0$)

To summarize, we showed that E and/or μ need to be large enough for r_2^* to exist.

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