Self-Fulfilling Liquidity and the Coordination Premium

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Abstract

Liquidity, defined as the ease with which an asset may be marketed, has a self-fulfilling dimension. If investors in the primary market for a new asset fear an illiquid secondary market, the issuance does not take off, thereby vindicating the initial concern about an illiquid secondary market. The fear of future illiquidity suffices to trigger current illiquidity.

The purpose of this paper is to outline a simple model of self-fulfilling liquidity.

It develops an issuance model where (i) investors are not financially constrained and (ii) have no market power, (iii) there are no transaction costs and (iv) none withholds private information. Interestingly, assets are illiquid in this frictionless world because of coordination failure among investors. There is room for coordination failure only because investors fear a *future* adverse selection discount if the issuance does not take off, but there is *no* informational concern, neither as the issuance takes place, nor in the secondary market at the equilibria.

Illiquidity as a coordination failure is sufficient to predict stylized facts regarding the design and diffusion of financial innovations, without invoking the much stronger informational imperfections required in the existing literature.

1 Introduction

Broadly speaking, the liquidity of an asset is the ease with which it may be sold. More precisely, an asset is not perfectly liquid if the expected proceeds from selling it are strictly less than a fair valuation of the cash flows it generates from the sell side's standpoint. This difference may be termed "liquidity premium", "bid-ask spread" or "transaction costs" depending upon the context.

The imperfections identified in the literature as sources of illiquidity are essentially of four types:

1. The buy side has some market power.

2. There are significant transaction costs such as matching costs, transportation costs, certification costs or property rights enforcement costs.

3. The buy side is financially constrained. In this case, she may be unable to afford the fair price. Financial constraints may stem from a limited borrowing capacity itself driven by imperfections such as inalienability of human capital (Hart and Moore 1991, Diamond and Rajan 2000), incompleteness of contracts (e.g. Aghion and Bolton 1992) or moral hazard (e.g. Holmstrom and Tirole 1997).

4. Some people have private information. The agent endowed with private information may be the seller, hence an adverse selection discount (Akerlof 1970). It may also be the buyers, who then bid strategically and may derive a nonnegative expected profit (e.g. Axelson 2002) if the issuance mechanism does not allow full signal extraction.

The purpose of this paper is to show that illiquidity may occur *even absent all these imperfections*. The central intuition is that liquidity is self-fulfilling, because deals create positive externalities for deals by increasing the depth of the secondary market, and thus the price of a future resale. The only primitive invoked to obtain this result is that acquiring an asset today will provide more information about it tomorrow. As a consequence, today's potential buyers are concerned to experiencing a lemons problem in case of future resale if they face only outsiders. Thus, the fear of future adverse selection suffices to trigger coordination failure, *although none has private information, neither in the primary market nor in the secondary market at the equilibria*. The investors current and future reluctances to buy reinforce each other. In other words, current illiquidity is triggered by the fear of future illiquidity only.

Overcoming this liquidity externality seems the key to success for financial innovation. Liquidity externality is indeed a good candidate to explain why financial innovations such as index based derivatives promoted by large exchanges experience difficulties to take off, eventhough their design and institutional context precisely aims at getting rid of the four sources of illiquidity mentioned above. Cuny (1993) provides several examples of futures markets innovations which failed because they were competing with products seeming intrisically less appealing, but with a better established liquidity. This paper shows that liquidity as a coordination failure is sufficient to explain stylized facts regarding the design and diffusion of financial innovations absent any other friction.

1.1 Related Literature

Several contributions have dealt with this broad idea of liquidity externality in capital or credit markets. In Shleifer and Vishny (1992), the central claim is that debt capacity within an industry is endogenously determined by business conditions, because economic conjoncture drives the redeployability of collateral. In a concluding heuristic remark, the authors note that debt capacity, in turn, impacts positively the liquidity of the secondary market by increasing its size. They conjecture that this feedback, causing liquidity to be self-fulfilling (it is worth investing if many other people are willing to), may give rise to multiple equilibria. In Pagano (1989), stocks prices are all the more sensitive to buy and sell orders because few investors participate in the market. This sensitivity deters risk averse investors from paying an exogenous cost to enter the stock market. Hence, low participation and high volatility reinforce each other, giving rise to two equilibria, a "liquid" and an "illiquid" one. In a model a la Kyle (1985), featuring informed speculators and uninformed hedgers, Dow (2003) endogenizes the behavior of hedgers. They are all the less willing to hedge because prices are volatile. As a result, a low amount of noise trading and a high volatility reinforce each other, so that both "illiquid" and "liquid" equilibria may be supported.

These contributions have two features in common:

1. They build upon an important market imperfection (financial constraints in Shleifer and Vishny 1992, transaction costs in Pagano 1989, private information in Dow 2003) which is amplified by the liquidity externality but would significantly plague the market anyway, even absent this coordination problem.

2. They obtain (or conjecture in the case of Shleifer and Vishny) sunspots equilibria.

The contribution of this paper is twofold. *First,* it captures this self-fulfilling dimension of liquidity in a setup which would be first best at first order (in a sense precised later) absent this coordination problem. This suggests that coordination failure may, at least theoretically, be the primary driver of illiquidity and not only act as an amplification device. *Second,* a unique equilibrium is obtained, which allows to measure the cost of coordination failure and predict some stylized facts regarding the design and diffusion of financial innovations.

1.2 Organization Of The Paper

Section 2 captures the intuition with multiple equilibria in an elementary 2×2 complete information game between 2 potential investors. Section 3 presents a reduction to an unique equilibrium using the insightful technique of global games introduced in Carlsson and van Damme (1993). Section 4 closes the model by explicitly introducing the seller and derives a liquidity premium. Section 5 extends this result to an arbitrary number of investors. Sections 6, 7 and 8 are applications. Section 6 dwells on the relationship between risk and liquidity. Section 7 derives the optimality of debt like securities. Section 8 predicts the exponential diffusion of financial innovations, eventhough there is no such trend in the underlying risk. Section 9 concludes.

Proofs are in the Appendix.

2 An Elementary Issuance Game

2.1 Outline Of The Model

There are three dates, $t = 0, 1, 2$. There are two identical investors indexed by i and $-i$. At $t = 0$, each of them is being made the take-it-or-leave-it offer to pay π for a 50% share in the cash flows generated by a given asset. The asset pays off either $2 \times R_H$ with probability p or $2 \times R_L$ with probability $1 - p$ *at date 2*, where

$$R_H > R_L \geq 0 \text{ and } p \in (0, 1)$$

Let

$$\Delta R = R_H - R_L$$

Investors are risk neutral and do not discount future cash flows.

Each investor may be of two types, either patient or impatient. Her consumption takes places at date 2 if she is patient, at date 1 if she is impatient. Investors learn privately their type at date 1 only. At date 0, each of them puts a *prior* probability $q \in (0, 1)$ on being impatient. These liquidity shocks a la Diamond and Dybvig (1983) are not an important concern *per se* because investors may of course trade the asset in the secondary market at date 1. In this case, it is assumed that the seller makes a take-it-or-leave-it offer to the buyer: Sellers have all the bargaining power in this model.

Investors' types and the asset payoff are assumed to be independent random variables[1].

[1] This is for simplicity. All that is really required is liquidity shocks not being perfectly correlated.

The only grain of sand in the wheels of this otherwise frictionless economy is the following. It is assumed that an investor knows more about the asset at date 1 if she has acquired a stake at date 0 than if she has not. There are two justifications for this "learning by owning". First, it is the case for most securities (stocks, notes, assets backed securities,...) that the issuer is legally constrained to provide investors with more information than the public information available to outsiders. Second, it may just reflect some learning by doing, investors having been in the market between 0 and 1 having observed the behavior of the asset (e.g. its sensitivity to various factors) in more detail than the others.

To keep things simple, it is actually assumed that an investor learns perfectly the future payoff at date 1 if she has invested while she receives no additional information otherwise.

From now on, an investor is referred to as an insider if she has bought the asset at date 0, as an outsider if she has not.

The timing of the game is summarized as follows:

- At $t = 0$, investors decide simultaneously whether to accept or decline the offer.
- At $t = 1$, investors learn privately their type and observe date 0 decisions. Insiders also learn whether the asset pays off $2 \times R_H$ or $2 \times R_L$. An insider may make a take-it-or-leave-it offer to sell the asset to the other investor. Then consumption of impatient investors takes place.
- At $t = 2$, asset pays off and consumption of patient investors takes place.

2.2 The Equilibria

At $t = 1$, an impatient insider faces a lemons problem if her counterpart is an outsider. Thus, the purchase of the asset by investor $-i$ creates a positive externality on investor i. Indeed, it ensures that the liquidation value of the asset at date 1, if i is impatient, will not be discounted by $-i$ for adverse selection. Hence the coordination problem and the multiplicity of equilibria. Formally,

Proposition 1

If

$$\left(1-q^2\right)(R_L + p\Delta R) - \pi < 0$$

there is one unique equilibrium where no investor invests,

If

$$\left(1-q^2\right)(R_L + p\Delta R) - p^2 q\,(1-q)^2\,\Delta R - \pi > 0$$

there is one unique equilibrium where both investors invest,

Otherwise, there are two pure strategies equilibria, one where no investor invests, one where both investors invest.

Proof. See the Appendix. ■

As precised above, the multiplicity of equilibria stems basically from positive externalities for one investor if the other one invests, because it eliminates the adverse selection discount in case of "fire sale".

More precisely, the situation at date 1 may be analyzed as follows. Assume i invests at date 0 while $-i$ does not. If i is patient but learns that the asset performs poorly at date 1, she may sell it to $-i$, provided $-i$ is patient, at a pooling price and pockets $pq\Delta R$. Thus, outsider's ignorance provides her with a hedge on the asset. The expected according *ex ante* gain is

$$(1-q)^2 \times (1-p) \times pq\Delta R$$

The flip side of this hedge is that, conversely, if i is impatient, she faces the lemons problem caused by this behavior. The *ex ante* according expected loss is

$$-q(1-q) \times p(1-q)\Delta R$$

Proposition 1 simply states that this latter negative effect overcomes the former positive one, leading to a global expected cost equal to

$$-p^2 q(1-q)^2 \Delta R$$

Classically, multiplicity of equilibria captures "self-fulfilling liquidity" for a given set of parameters. In this relevant range of parameters, the issuance takes off only if investors are convinced that it is going to take off.

As noted in the Introduction, an important body of literature views the liquidity premium as an adverse selection discount. Here, potential illiquidity is only driven by fear of future adverse selection, but there is no lemons problem, neither *ex ante,* nor *ex post* (at the equilibria). Adverse selection is only a threat triggering coordination failure.

For the rest of the paper, the following assumption is made:

Assumption 1 *(Small liquidity shocks)*

> *The consequences of liquidity shocks which are not first order with respect to q are negligible.*

It must be emphasized that except for Proposition 4, none of the results derived in the rest of the paper depends in any way upon this assumption. It is made only to ease their interpretation. Indeed, under this assumption, it is straightforward that Proposition 1 becomes

Proposition 1bis

Under Assumption 1 (small liquidity shocks), if

$$R_L + p\Delta R - \pi < 0$$

there is one unique equilibrium where no investor invests,

If

$$R_L + p\Delta R - p^2 q\Delta R - \pi > 0$$

there is one unique equilibrium where both investors invest,

Otherwise, there are two pure strategies equilibria, one where no investor invests, one where both investors invest.

It means in particular that if some form of coordination were implementable, liquidity shocks would not be a source of illiquidity *per se*, in the sense that claims against the asset would be floated at a price equating the expected payoff $R_L + p\Delta R$. This is because investors would neglect the risk that everybody experiences a liquidity shock. However, these negligible liquidity shocks are sufficient to trigger a coordination failure which makes them in turn become a first order problem. As a result, under this assumption, it is possible to isolate the pure effect of coordination failure in an otherwise "first best at first order" world, where liquidity shocks do not impact prices at all.

A crucial property of this elementary model is the existence of values of the parameters for which either purchasing the asset or not are dominant strategies. This enables to build a global game characterized by an unique symmetric equilibrium upon this simple coordination game. This is the purpose of the next Section.

3 An Associated Global Game

The terminology of "global game" has been introduced by Carlsson and van Damme (1993). They define it as "an incomplete information game where the actual payoff structure is determined by a random draw from a given class of games and where each player makes a noisy observation of the selected game". Carlsson and van Damme obtain the spectacular result that throwing an amount of doubt, *even arbitrarily small*, in a complete information game may yield a shift from multiple sunspots equilibria to an unique equilibrium.

Going beyond sunspots equilibria in coordination games is of course highly relevant in financial economics: Multiple equilibria are very much a theoretical dead-end preventing to push the analysis further. For instance, Goldstein and Pauzner (2000) point out that because of sunspots equilibria, it is not possible to tell whether banks are desirable or not in the model of Diamond and Dybvig (1983).

The financial application dealt with here is very different, but from a pure game theoretic standpoint, the situation is close to the treatment of currency attacks or bank runs by Morris and Shin (1998, 2001, 2002, 2003). The only additional source of complexity is that the payoff functions are not linear in the sense of Morris and Shin (2002).

The complete information game of the former Section is modified as follows.

1. The probability p is normally distributed, with mean $\overline{p}$ and precision α. Let

   $$\widetilde{\alpha} = p - \overline{p}$$

   This distribution is common knowledge but p is not observed.

2. Before making her decision, investor $j \in \{i, -i\}$ observes privately only a noisy version of the actual probability p,

   $$s_j = p + \widetilde{\beta}_j$$

   where $\widetilde{\beta}_j$ is a centered Gaussian with precision β. $\left(\widetilde{\alpha}, \widetilde{\beta}_i, \widetilde{\beta}_{-i}\right)$ are mutually independent and independent from the other sources of uncertainty[2].

3. At date 1, not only do insiders keep learning the actual asset's payoff, but all investors, either insiders or outsiders, also learn the actual value of p[3].

Finally, the set of parameters is restricted as follows:

[2] A rigorous specification would of course require the distribution of $\widetilde{\alpha}$ being truncated so that p belongs to $(0, 1)$ almost surely. However, the only case considered in what follows is the asymptotic one where α and β are arbitrarily large. In this case, truncated distributions can be taken arbitrarily close to the non truncated ones and working directly with non truncated distributions is an innocuous shortcut only meant to simplify the exposition.

[3] This assumption is not crucial but simplifies the exposition.

Assumption 2

$\pi \in [R_L, R_H]$. *Moreover,* $q < \min\left(\frac{R_H - \pi}{\Delta R}, \frac{1}{2}\right)$.

The first part of the Assumption just rules out absurd prices. Note that the second one is consistent with Assumption 1 (small q).

The reader may point out that the introduction of private information is a substantial deviation from the aim outlined in the Introduction, namely capturing illiquidity in a frictionless setup. In some anticipation, the rest of the paper actually focuses on the asymptotical situation where α and β are taken arbitrarily large. In this limit case, the situation is arbitrarily close to one of complete information.

Following Morris and Shin (1998), such private signals are interpreted as "grains of doubts", which are not a source of undepricing *per se* but suffice to obtain an unique equilibrium. The situation I have in mind is one where investors have the same public information, which may be extremely accurate, but differ arbitrarily slightly in their interpretations. For instance, in the case of a securitization deal, investors are very likely to assess the prepayment risk in slightly different ways eventhough very detailed public information about the collateral is available. In the case of a new derivative issuance, the estimation of its sensitivity should vary at least slightly across investors even if the product and its underlying asset are perfectly well defined and common knowledge.

Proposition 2 characterizes simply the unique symmetric equilibrium of this game.

Proposition 2

For α, β and $\frac{\beta}{\alpha^2}$ sufficiently large, there is one unique symmetric equilibrium. Equilibrium strategies are characterized by a threshold value s_e such that investor $j \in \{i, -i\}$ invests only if

$$s_j \geq s_e$$

Moreover,

$$\lim_{\substack{\alpha \to \infty \\ \beta \to \infty \\ \frac{\beta}{\alpha^2} \to \infty}} s_e = \frac{\pi - R_L}{\Delta R} + \frac{q}{2}\left(\frac{\pi - R_L}{\Delta R}\right)^2$$

Proof. See the Appendix. ■

The spectacular part of this result is that uniqueness holds even for arbitrarily accurate public and private information. All that matters is that this game is not one of pure complete information.

The keystone is that there are strictly dominant strategies for extreme values of the signal, either small or large. This is sufficient to ignite a "chain reaction" eliminating all the strategies by iterated strict dominance. Intuitively, if an investor receives a signal smaller than s_e, she puts a sufficiently high probability on the "higher order beliefs"[4] of her fellow investor lying in the area where not investing is dominant, so that it is not worth investing. The process is of course symmetric for signals larger than s_e. As noted by Morris and Shin (1998), the reason why a small "grain of doubt" is sufficient to obtain this reduction to an unique equilibrium is that it is sufficient to have the higher orders beliefs spanning all the possible values of p. The relevant parameter is not the overall degree of uncertainty but the relative degrees of

[4]investor's belief about other investor's belief, investor's belief about other investor's belief about investor's belief...

"fundamental uncertainty" (uncertainty about the value of p) and "strategic uncertainty" (uncertainty about others' beliefs). This is the reason why the precision of private signals must grow faster than the precision of public information[5] to ensure equilibrium uniqueness in the limit case dealt with here. This is a general property of global games (see Morris and Shin 2003 for detailed comments). Broadly, because of a complex interplay between "fundamental" and "strategic" uncertainty, with an insufficient amount of fundamental uncertainty, strategic uncertainty does not suffice to have investors higher order beliefs about each other's strategy sufficiently diffuse to yield the coordination on an unique equilibrium.

4 The Seller

This Section introduces straightforwardly the seller in the model developed in the former Section.

The seller is a risk neutral[6] agent who, for unmodelled reasons, needs to raise cash against her asset at date 0. She makes a take-it-or-leave-it offer π to the potential investors so as to maximize her expected sales proceeds.

All that was common knowledge among investors in the former Section is common knowledge among them and the seller here.

It is worth reminding that the aim of this paper is to analyze the pure effect of coordination failure among investors. This is why the issuer is not endowed with any sort of private information: It allows to abstract from any signalling considerations. But then, the reader may point out that the

[5] $\frac{\beta}{\alpha^2} \to \infty$

[6] Introducing risk aversion would not change the equilibrium price in the limit case.

issuer has much better to do than a take-it-or-leave-it offer and should enter into some signal extraction. This inefficiency does not matter here because I will focus on the asymptotic case where $\alpha, \beta \to \infty$. In this limit situation, investors rents due to asymmetric information are arbitrarily small and the cost of coordination only plays a role[7].

The following Proposition shows that the liquidity premium has a simple form in these conditions:

Proposition 3

$$\lim_{\substack{\alpha \to \infty \\ \beta \to \infty \\ \frac{\beta}{\alpha^2} \to \infty}} \pi = R_L + \overline{p}\Delta R - \frac{q}{2}\overline{p}^2 \Delta R$$

Proof. See the Appendix. ■

This result shows that coordination failure, or "fear of future adverse selection", even absent all other kinds of imperfections since private information vanishes here, is sufficient to discount the first best (coordinated investors) price.

In the literature capturing liquidity premiums because of private information withheld by buyers or sellers, this premium vanishes as private information vanishes. This is not the case here, because the private information introduced is just a "global game trick" to reduce the number of equilibria, but is not the major source of imperfection, which is a pure coordination problem. Coordination failure creates a first order concern out of second order, and thus negligible, liquidity shocks, were buyers coordinated.

[7] For instance, bidders' expected rents tend to 0 as uncertainty vanishes in auctions whatever the format.

The reader may wonder at this stage whether this coordination discount has any hope to be at least theoretically significant in comparison with other sources of illiquidity such as adverse selection. The answer is: Yes. Assume indeed that the seller knows that the asset pays off $2 \times R_H$, but cannot signal it credibly to investors. In this case, she faces a total discount equal to

$$\underbrace{(1-\overline{p})\,\Delta R}_{\text{Adverse selection discount}} + \underbrace{\frac{\overline{p}^2 q}{2}\Delta R}_{\text{Coordination discount}}$$

The coordination discount dominates the adverse selection discount as $\overline{p}$ gets close to 1.

Section 5 shows that this closed and simple form for the liquidity premium extends quite naturally to a model featuring more than 2 investors. This very tractable liquidity premium gives rise to three simple applications. Section 6 investigates the relationship between the risk profile of a bond and its liquidity premium. Section 7 derives debt as an optimal response to this coordination failure when the seller is allowed to design securities. Section 8 introduces strategic interaction between multiple issuers to predict a stylized fact regarding the timing of financial innovations.

For these extension and applications, the model developed in this Section 4 is referred to as "the main model". The mean $\overline{p}$ is denoted p again for simplicity and without ambiguity since only the limit case with infinite precisions α and β is considered.

5 More Investors

Let n be a nonnegative integer. In this Section, the main model of Section 4 is extended to the case where $n+1$ investors face simultaneously the decision whether to buy or not a $\frac{1}{n+1}^{th}$ of the cash flows of the asset, whose total payoff is accordingly normalized to $(n+1) \times R_H$ or $(n+1) \times R_L$.

Besides this extension, the rest of the model, in particular the fact that investors face independent liquidity shocks with probability q at date 1 and receive conditionally independent private signals with precision β, is unchanged.

The following Proposition shows that the optimal price is the following in these conditions:

Proposition 4

$$\lim_{\substack{\alpha \to \infty \\ \beta \to \infty \\ \frac{\beta}{\alpha^2} \to \infty}} \pi = R_L + p\Delta R - \frac{q}{n+1} p^2 \Delta R$$

Proof. Sketched in the Appendix. ■

A straightforward prediction is that liquidity should increase as, other things equal, the dispersion of investors increases. This result is obtained absent any market power exerted by investors.

In the rest of the paper, writing down the results at first order w.r.t. q is only for interpretation convenience. Conversely, the assumption that liquidity shocks are small seems necessary to derive this Proposition. Combinatory algebra is hardly tractable otherwise. This assumption is very simplifying because it amounts to posit that an investor is no more concerned by a future lemons problem as soon as one fellow investor invests. Two is a crowd under this assumption.

6 Credit Risk and Liquidity

The main model yields a surprising prediction about the relationship between the risk profile of a newly issued bond and its liquidity or coordination premium.

In this Section, the issued securities are viewed as fixed income instruments. It is commonplace in practice to summarize the riskiness of a note with its respective probability of default and expected recovery rate conditionally to a default. Here, each note has a face value of R_H, a probability of default $1-p$ and a recovery rate equal to $1-\frac{\Delta R}{R_H}$.

The liquidity premium as a percentage of the face value, denoted l, is:

$$l = \frac{q}{2} \times p^2 \times \frac{\Delta R}{R_H}$$

Coordination failure among investors entails that the liquidity premium l of a new bond increases with the conditional expected loss, *but more counterintuitively decreases with the probability of default.*

The reason for this is subtle. As p increases, a positive first-order effect is that the gain from re-selling a poorly performing asset to an outsider at the pooling price increases. An according negative first order effect, which offsets it, is that the potential adverse selection discount $p(1-q)\Delta R$ increases. An increase in p has however a further negative second order impact because the probability of benefiting from the positive effect decreases while p has no impact on the frequency of the negative effect.

As a consequence, the model predicts that pure credit risk should explain a decreasing part of the total issuance spread of a new bond as the rating increases. To illustrate this, the following table computes the ratio

$$\frac{\text{Liquidity premium}}{\text{Actuarial credit risk premium}} = \frac{qp^2}{(n+1)(1-p)}$$

for several probabilities of default.

q is set to 10%, $n+1$ the number of investors to 50 . The probability of defaults are the average cumulative default rates over 5 years for all the corporate issuers rated by Moody's over 1970-2000 (see Hamilton 2001).

Rating	$1-p$	Liquidity/Credit
Aaa	0.12%	166%
Aa	0.31%	64%
A	0.45%	44%
Baa	1.82%	11%
Ba	11.23%	1%
B	27.92%	0%

Another consequence is that for a given expected credit loss, the coordination discount is maximal for notes with a "catastrophe" profile, namely with the lowest frequency and highest severity of defaults.

Interestingly, recent financial innovations, the so-called "catastrophe bonds" or "acts of God bonds", have precisely this catastrophe profile, and several observers were struck by their very high issuance spreads in spite of their low informational asymmetry. Catastrophe bonds are meant to provide insurance and reinsurance companies with a source of financing alternative to the traditional reinsurance market. The common features of cat bonds is as follows. An intermediary structure (special purpose vehicle or SPV) is setup between the insurance company and investors. The assets of this structure are very high grade bonds, liabilities are several classes of notes. The occurence and extent of defaults on the issued notes are contractually made contingent upon the realization of some meteorological or seismological variables. As such default triggering events occur, the defaulted amount is paid to the insurance company by the SPV. Reciprocally, the company pays a premium for this contingent claim which is used to finance the risk premium loading coupons. Note that payments to the insurance company are triggered by events over which she has little control and are expressed as function of variables she can hardly manipulate. This is an essential difference with classical reinsurance treaties. This is meant to eliminate moral hazard and adverse selection, but comes of course at the cost of a basis risk.

In spite of this very low sensitivity to private information, catastrophe bonds have turned out to be very illiquid, with strikingly high issuance spreads. Anderson, Bendimerad, Canabarro and Finkenmeier (2000) or Woo (2001) provide evidence that the spread on three different issuances exceeded very significantly the risk premium. Claiming that this is strong evidence of a coordination failure would require a much more careful analysis, but casual discussions with practitioners suggest it may be one of the causes of this spread. Several of them point that cat bonds are good diversification tools in theory, but that their illiquidity makes them unappealing at this point. This has a flavor of self fulfilling liquidity.

7 Another Liquidity Based Model Of Security Design

The title of this Section is borrowed from DeMarzo and Duffie (1999). One of the strongest messages of the security design literature is that designing a debt like security may be the optimal way to cope with many different imperfections, be it private information on the sell side (DeMarzo and Duffie 1999), private information on the buy side (Axelson 2002), moral hazard (Innes 1990), costly state verification (Townsend 1979) or incompleteness of contracts (Dewatripont and Tirole 1994) among others.

It is shown in this Section that issuing a debt like security may be motivated by the coordination discount derived here, absent any of these imperfections.

The main model is modified as follows.

- The reason why the seller is willing to raise funds against her assets is explicitly modelled. A secret redeployment opportunity, with a constant expected yield r, is available to her. Moreover, she is able to market her assets only partially by designing a security. This is reminiscent of DeMarzo and Duffie (1999).

- The asset payoff is now a real valued, positive random variable R with bounded support. Let F_H and F_L denote its distributions conditional to the state of nature being high (still with probability p) or low.

The high state of nature is high because F_H dominates F_L in the sense of hazard rate stochastic dominance:

$$\Phi : \begin{cases} \mathsf{R}^{+} \rightarrow \mathsf{R} \cup \{\infty\} \\ R \mapsto \frac{1-F_H(R)}{1-F_L(R)} - 1 \end{cases} \text{ is increasing.}$$

The state of nature is revealed to insiders at date 1. The main model is thus a particular case of this one where $r \rightarrow \infty$ and both distributions are degenerated.

A security is a continuous piecewise differentiable real valued function $P(R)$ such that:

$$\forall R \in \mathsf{R}_{+}, P'(R) \in [0, 1]$$

These boundaries for P' stem from limited liability and unmodelled moral hazard reasons (see Innes 1990).

In these conditions, optimal designs are either debt or equity:

Proposition 5

As $\alpha, \beta, \frac{\beta}{\alpha^2} \rightarrow \infty$,

If $\frac{1+r}{2r} pq \leq 1$, $P(R) = R$ *is optimal. The seller retains no risk and issues equity.*

If $\frac{1+r}{2r} pq > 1$, *the seller issues debt with face value* $D = \Phi^{-1}\left(\frac{1}{p\left(\frac{1+r}{2r}pq-1\right)}\right)$ *and retains leveraged equity.*

Proof. See the Appendix. ■

Figure 1 depicts the *loci* where debt and equity are optimal in the plane (r, p) :

[Figure 1 about here]

Interestingly, this initial coordination discount on publicly traded securities is sufficient to predict the following well-known stylized facts in corporate finance, usually derived from stronger informational imperfections:

(i) Firms with low growth opportunities (r low) tend to issue more public debt;

(ii) Firms with stable ongoing business (p high) tend to rely more on publicly held debt;

(iii) When they do so, the leverage increases with the quality of collateral (Φ close to 1).

8 How Does A Financial Innovation Take Off?

The aim of this Section is to illustrate simply how this coordination failure among potential investors may trigger, in turn, strategic interactions between potential issuers. This causes delays in the diffusion of financial innovations even in this "almost" complete information framework.

The most successful financial innovations of the last decades, namely derivatives products and assets backed securities, have three features in common:

(i) Their initial purpose is, in many cases, to make tradeable and liquid claims out of risks which are "stuck" into banks balance sheets until maturity otherwise.

(ii) The trigger of such innovations is a sudden exogenous shock, such as a significant shift in the risk volatility or a regulatory change (capital requirements).

(iii) The diffusion of these products is fairly slow at the early stages and

experiences a sudden outburst at some point, which is not clearly driven by any change in the underlying risk.

As detailed in Silber (1975, 1983), these three stylized facts actually characterize most financial innovations.

An illustrative evidence regarding the third stylized fact is a study by the Bank of International Settlements (1995) regarding the growth of interest rate derivatives during the 80s. Figure 3 reproduces a very suggestive graph provided in this study comparing the turnover on the futures on 3 months eurodollar deposits and the underlying according volatility between 1980 and 1995.

[Figure 2 about here]

While, as pointed out in the BIS study, there is no trend in the volatility over the period, the future contract has experienced a sharp, exponential like, growth. Other examples abound, the most recent one being credit derivatives: Their notional amount is roughly multiplied by 2 every year since 1997.

The coordination problem among potential investors derived in the main model is sufficient to trigger strategic interactions between multiple issuers; and the resulting diffusion pattern obtained at the equilibrium gives a flavor of such an exponential growth.

To capture this, I modify the main model as follows.

- There are two potential issuers. Each of them seeks to market 50% of the asset.[8].

- There are $T+3$ dates indexed by $t \in \{0, ..., T+2\}$, where T is a nonnegative integer. Investors are potentially hit by liquidity shocks at date $T+1$, the asset pays off at date $T+2$.

- Issuers may market their share in the asset at any date between 0 and T. The reason why they sell is because, from date 0 on, holding the asset in their balance sheet comes at a per period cost δ. This is meant to capture simply stylized facts *(i)* and *(ii)*. The situation I have in mind is that issuers are commercial banks hit at date 0 by a regulatory change, e.g. higher capital requirements on some class of loans, hence they contemplate securitization.

- The issuance process is as follows. At date t^-, investors decide independently and simultaneously whether to announce an issuance at date t or not. They observe the other seller's decision at t^+ and set the issuance price accordingly. Because of unmodeled costs of an announcement (due to legal procedures for instance), each seller has only one chance to issue and thus commits to her announcement.

I focus on the interesting case where

$$\delta < L$$

where $L = \frac{p^2 q}{4} \Delta R$ is the coordination discount faced by each investor, so that waiting is not a dominated strategy.

[8]The assumption that there are only 2 issuers can be relaxed at the cost of notational complexity.

Let

$$\gamma = \sqrt{\frac{\delta}{L}}$$

The other features of the main model are unchanged.

The reason why, in this setup, coordination issues among investors causes coordination failures among issuers is transparent. If both sellers issue simultaneously at date 0, they face the coordination discount, while they can obtain the "fair" (no discounted) price if they do not issue at the same time. This is because investors are sure a second issuance will take place after the first one: Sequentiality kills their coordination problem. However, delaying issuance comes at a cost that no issuer is willing to bear. Another way of saying that is that liquidity is a public good, hence a free riding problem among issuers.

The following Proposition characterizes the behavior strategies for the unique symmetric equilibrium of this game.

Proposition 6

As $\alpha, \beta, \frac{\beta}{\alpha^2} \to \infty$,

This game admits an unique symmetric subgame perfect Nash equilibrium, such that for any $t \in [0, T]$*:*

- An issuer issues securities with probability 1 *at date* t *if* $t > 0$, *she has not issued so far and the other seller has issued at date* $t - 1$;

- If none has issued before t, *each seller issues with a probability* p_t *such that*

$$\lim_{\alpha,\beta,\frac{\beta}{\alpha^2}\to\infty} p_t = \gamma \frac{1 + \left(\frac{1-\gamma}{1+\gamma}\right)^{T-t+1}}{1 - \left(\frac{1-\gamma}{1+\gamma}\right)^{T-t+1}}$$

Proof. See the Appendix. ■

The probability to issue at date t given that no issuance has taken place before is an exponentially increasing function of time. This is depicted in Figure 3 for $T = 20$:

[Figure 3 about here]

Issuance is all the more delayed because γ is small. Thus, delay increases with the liquidity premium and decreases with the cost of delaying δ.

The according prediction is that the take off of financial innovations is all the more likely to take time because the underlying risk has a "catastrophe" profile.

An important literature (see Brunnermeier 2001 for a survey) derives such clustering phenomenons in financial markets as a consequence of private information withheld by investors. In this model, strategic delay is simply captured as the outcome of a *complete* information chicken game among issuers. The model developed here is a "general equilibrium" one encompassing the behavior of both buy and sell sides: The delay on the sell side is endogenously derived from an also endogenous coordination problem on the buy side. The only premise is that investors fear an out-of-equilibrium future adverse selection. It is admittedly a very stylized modelling, but it is worth stressing that herding behaviors can be obtained in a setup which is not plagued by the important informational problems usually invoked by this strand of literature.

9 Concluding remarks

The simple model developed in this paper suggests that coordination failure is sufficient to explain illiquidity and yields predictions about the price, design and timing of financial innovations. As emphasized throughout the paper, coordination is the only important concern in this economy: Liquidity shocks are negligible absent this problem and the private information introduced is just a technical trick to obtain a unique equilibrium, but has no consequences on prices *per se* because uncertainty, either "strategic" or "fundamental", can be made arbitrarily small.

In their pioneering paper, Diamond and Dybvig (1983) take illiquidity as given and derive coordination failure among claimholders. Interestingly, the opposite causality is emphasized here in a very similar setup: Illiquidity is an endogenous consequence of coordination failure.

The minimal set of required premises suggest that this theory of endogenous illiquidity may be an useful building block in corporate finance. Indeed, a vast body of literature takes illiquidity of industrial projects as an exogenous parameter as well, and study its consequences on the financial structure of firms through comparative statics. Myers and Rajan (1998) show that these consequences may be very subtle, involving competing effects. An interesting route for future research is to close such models with the one developed here, so as to endogenize illiquidity and link the financial structure of firms with the risk profile of their projects only, a more satisfactory primitive.

10 Appendix

10.1 Proof Of Proposition 1

If $-i$ purchases the asset, i's expected profit or loss from buying it is

$$\begin{aligned} & (1-q)\left(pR_H+(1-p)\,R_L\right)+q\,(1-q)\left(pR_H+(1-p)\,R_L\right)-\pi \\ = & \left(1-q^2\right)\left(R_L+p\Delta R\right)-\pi \end{aligned}$$

The first term on the left hand side is the expected payoff at date 2 if she is patient, the second one the expected proceed from a fire sale if she is impatient while $-i$ is not.

If $-i$ does not purchase the asset, i's expected profit or loss from buying it is

$$\begin{aligned} & (1-q)\left(p\underbrace{R_H}_{(1)}+(1-p)\left((1-q)\left(\underbrace{R_L+pq\Delta R}_{(2)}\right)+q\underbrace{R_L}_{(3)}\right)\right) \\ & +q\,(1-q)\left(\underbrace{R_L+pq\Delta R}_{(4)}\right) \end{aligned}$$

If i is patient,

- If the asset's payoff is high, she holds it (term (1)).
- If the asset's payoff is low and $-i$ is patient, i is better off reselling it at the pooling price (term (2))
- She has no choice but holding it if $-i$ is impatient (term (3)).

If i is impatient, she may resell the asset to $-i$, provided she is patient, at date 1 (term (4)).

Rearranging yields the following expression for i's profit

$$\left(1-q^2\right)\left(R_L+p\Delta R\right)-p^2 q\left(1-q\right)^2\Delta R-\pi$$

Proposition 1 is then obvious.¥

10.2 Proof Of Proposition 2

The proof takes the same steps as in Morris and Shin (1998). It is, however, slightly more complex because this game is not a linear global game in the sense of Morris and Shin (2002).

Let first

$$\begin{cases} f_+\left(p\right)=R_L+p\Delta R-p^2 q\Delta R-\pi \\ f_-\left(p\right)=R_L+p\Delta R-\pi \end{cases}$$

By virtue of Assumption 2, f_- and f_+ are non decreasing and each of these functions admit one unique zero, respectively denoted p_- and p_+, over $\left(0,1\right)$.

Obviously,

$$p_+>p_-$$

Standard normal distribution theory yields that if investor $j\in\{-i,i\}$ observes signal s_j, she thinks that p is normally distributed with mean $\frac{\alpha\overline{p}+\beta s_j}{\alpha+\beta}$ and precision $\alpha+\beta$. Let us denote

$$p\left(s\right)=\frac{\alpha\overline{p}+\beta s}{\alpha+\beta}$$

The strategy of an investor $j\in\{-i,i\}$ is a function $n\left(s_j\right)$ mapping the signal s_j into the probability to acquire the asset.

Let $P_n(s_i)$ the expected profit or loss from investing for i given that she observes s_i and $-i$ plays strategy n.

$$\begin{aligned} P_n(s_i) &= R_L + p(s_i)\Delta R - \left(p(s_i)^2 + \frac{1}{\alpha+\beta}\right) q\Delta R \\ &\quad + q\Delta R \times E\left(p^2 \times E(n(s_{-i}) \mid p) \mid s_i\right) - \pi \end{aligned}$$

Claim 1 is transparent from this expression.

Claim 1

This game is one of strategic complementarity. Formally, if

$$\forall s_{-i}, n(s_{-i}) \geq n'(s_{-i})$$

Then

$$\forall s_i, P_n(s_i) \geq P_{n'}(s_i)$$

Now let

$$n_s = 1_{\{s_{-i} \geq s\}}$$

denote the switching strategy where $-i$ invests only if $s_{-i} \geq s$.

Claim 2 is simple too.

Claim 2

For any s, $P_{n_s}(s_i)$ *is strictly increasing in* s_i.

Proof. $P_{n_s}(s_i)$ can be equivalently written:

$$P_{n_s}(s_i) = \frac{q\Delta R}{\alpha+\beta} + f_+(p(s_i)) + q\Delta R \times E\left(p^2 \times prob(s_{-i} \geq s \mid p) \mid s_i\right)$$

f^+ increases by assumption.

The distribution of s_{-i} conditional to p increases in the sense of first order stochastic dominance as p increases. Indeed, it is normal with an increasing mean. Hence,

$$p \rightarrow prob\left(s_{-i} \geq s \mid p\right)$$

is an increasing function of p.

The distribution of p conditional to s_i increases with s_i in the sense of first order stochastic dominance for the same reason. Since

$$p \rightarrow p^2 \times prob\left(s_{-i} \geq s \mid p\right)$$

is an increasing function of p, her expected value conditional to s_i is an increasing function of s_i. ¤

Claim 3

The function

$$s \rightarrow P_{n_s}(s)$$

admits one unique zero s_e over $(0, 1)$ for α, β *and* $\frac{\beta}{\alpha^2}$ *sufficiently large.*

Proof. $P_{n_s}(s)$ is explicitly:

$$R_L + p(s)\Delta R - \left(p(s)^2 + \frac{1}{\alpha+\beta}\right) q\Delta R + q\Delta R \times \sqrt{\alpha+\beta}$$
$$\times \int p^2 \Phi\left(\sqrt{\beta}(p-s)\right) \varphi\left(\sqrt{\alpha+\beta}(p-p(s))\right) dp - \pi$$

where Φ and φ are the respective cdf and pdf of a standard normal distribution.

Replacing

$$u=\sqrt{\alpha+\beta}\,(p-p\,(s))$$

in the integral yields

$$\begin{aligned}P_{n_s}(s) &= R_L+p\,(s)\,\Delta R-\left(p\,(s)^2+\frac{1}{\alpha+\beta}\right)q\Delta R+q\Delta R \\ &\times\int\left(\frac{u}{\sqrt{\alpha+\beta}}+p\,(s)\right)^2\Phi\left(\sqrt{\frac{\beta}{\alpha+\beta}}\left(u+\frac{\alpha}{\sqrt{\alpha+\beta}}\,(\overline{p}-s)\right)\right)\varphi\,(u)\,du-\pi\end{aligned}$$

Hence,

$$\lim_{\substack{\alpha\to\infty\\ \beta\to\infty\\ \frac{\beta}{\alpha^2}\to\infty}}\frac{\partial P_{n_s}(s)}{\partial s}=\Delta R\,(1-qs)>0$$

so that this function is strictly increasing for α, β and $\frac{\beta}{\alpha^2}$sufficiently large. Moreover,

$P_{n_s}(s)<0$ for $s<p_-$ and α,β sufficiently large

$P_{n_s}(s)>0$ for $s>p_+$ and α,β sufficiently large

which yields Claim 3.

¤

Claim 4

For α, β and $\frac{\beta}{\alpha^2}$sufficiently large, this game admits one unique symmetric equilibrium, where each investor j invests if and only if $s_j\geq s_e$.

Proof. Let us first show that any symmetric equilibrium defined by the strategy n is necessarily such that

$$n=n_{s_e}$$

To see this, let

$$\overline{s} = \sup \{s \ s.t. \ n(s) < 1\}$$

$$\underline{s} = \inf \{s \ s.t. \ n(s) > 0\}$$

Note that

$$s \geq \overline{s} \rightarrow n(s) = 1 \rightarrow n(s) > 0 \rightarrow s \geq \underline{s}$$

so that $\overline{s} \geq \underline{s}$.

Now, if s is such that $n(s) < 1$, then investing cannot be a strictly dominant strategy for an investor receiving this signal, hence

$$P_n(s) \leq 0$$

By definition of $\overline{s}$, it is also the case that

$$P_n(\overline{s}) \leq 0$$

And, since obviously $n_{\overline{s}} \leq n$, it comes from claim 1 (strategic complementarity) that

$$P_{n_{\overline{s}}}(\overline{s}) \leq 0$$

Hence, from claim 3,

$$\overline{s} \leq s_e$$

A similar reasoning yields $\underline{s} \geq s_e$ and thus $\overline{s} = \underline{s}$, so that

$$n = n_{s_e}$$

It remains to prove that n_{s_e} is an equilibrium strategy. This is an obvious consequence of claim 2 and the definition of s_e. ¤

Claim 5

$$\lim_{\substack{\alpha\to\infty\\ \beta\to\infty\\ \frac{\beta}{\alpha^2}\to\infty}} s_e = \frac{\pi - R_L}{\Delta R} + \frac{q}{2}\left(\frac{\pi - R_L}{\Delta R}\right)^2$$

Proof. s_e solves

$$P_{n_s}(s) = 0$$

Or, from the proof of Claim 3:

$$R_L + p(s)\Delta R - \left(p(s)^2 + \frac{1}{\alpha+\beta}\right) q\Delta R + q\Delta R$$
$$\times \int \left(\frac{u}{\sqrt{\alpha+\beta}} + p(s)\right)^2 \Phi\left(\sqrt{\frac{\beta}{\alpha+\beta}}\left(u + \frac{\alpha}{\sqrt{\alpha+\beta}}(\overline{p} - s)\right)\right)\varphi(u)\,du = \pi$$

By continuity and uniform convergence, $\lim_{\substack{\alpha\to\infty\\ \beta\to\infty\\ \frac{\beta}{\alpha^2}\to\infty}} s_e$ is solution of

$$R_L + s\Delta R - \frac{q}{2}s^2\Delta R = \pi$$

and has the claimed form at first order in q.¥

10.3 Proof Of Proposition 3

For the seller, the signal of investor i is normally distributed with mean $\overline{p}$ and precision $\frac{\alpha\beta}{\alpha+\beta}$. Hence the expected profit from offering a given (non absurd) price π:

$$2 \times \pi \times \Phi\left(\sqrt{\frac{\alpha\beta}{\alpha+\beta}}\left(\overline{p} - s_e(\pi)\right)\right)$$

As $\alpha, \beta, \frac{\beta}{\alpha^2} \to \infty$, this tends to

$$2 \times \pi \times \mathbf{1}_{\left\{\overline{p} - \frac{\pi - R_L}{\Delta R} - \frac{q}{2}\left(\frac{\pi - R_L}{\Delta R}\right)^2 \geq 0\right\}}$$

By continuity and uniform convergence, the optimal price tends thus to $R_L + \overline{p}\Delta R - \frac{\overline{p}^2 q}{2}\Delta R$ at first order in q.¥

10.4 Sketch Of Proof of Proposition 4

Proposition 4 in a model with $n+1$ investors is obtained rigorously the same way as Proposition 3 in the main model with 2 investors. Namely, the three very same steps are taken:

1. Solving for the equilibria of the complete information game (equivalent of Proposition 1).

2. Solving for the symmetric equilibrium of the associated global game (equivalent of Proposition 2).

3. Introducing the seller and deriving the optimal price (equivalent of Proposition 3).

The extension to an arbitrary number of investor adds no conceptual complexity, but makes computations more tedious. A detailed proof is available upon request, the main differences are exposed here.

1. Solving for the equilibria of the complete information game.

Conditionally to a number $k \in [0, n]$ of other investors investing, the same reasoning as in the proof of Proposition 1 yields the expected profit or loss from investing for a given investor.

Indeed:

- If the investor does not experience a shock at date 1, which occurs with probability $1-q$, if she learns that the asset performs poorly (probability

$1-p$), then she can sell it to a patient outsider if there is any (with probability $1-q^{n-k}$) at the pooling price $R_L + pq^{k+1}\Delta R$.

- If the investor experiences a shock at date 1 (probability q). If the payoff is high, then if at least one insider is patient (probability $1-q^k$), she may sell the asset with no discount. If insiders are all impatient but if at least one outsider is patient (probability $q^k(1-q^{n-k})$, she may sell the asset at the pooling price. She cannot consume otherwise. If the payoff is low, then if at least one outsider is patient (probability $1-q^{n-k}$), she may sell the asset at the pooling price. If outsiders are all impatient but if at least one insider is patient (probability $q^{n-k}(1-q^k)$, she may sell the asset at the price R_L. She cannot consume otherwise.

This yields after simplification the following expected profit/loss from investing:

$$\left(1-q^{n+1}\right)(R_L + p\Delta R) - p^2 q^{k+1}\left(1-q^{k+1}\right)\left(1-q^{n-k}\right)\Delta R - \pi$$

This is clearly increasing in k, so that there are two equilibria in pure strategies, one where everybody invests, one where none invests.

At first order with respect to q, this is

$$R_L + p\Delta R - p^2 q\Delta R \times 1_{\{k=0\}} - \pi$$

so that under Assumption 1 (small liquidity shocks), Proposition 1 is unchanged.

2. Solving for the symmetric equilibrium of the associated global game.

As in the proof of Proposition 2, let $P_s(s_i)$ the expected profit or loss from investing for investor $i \in [1, n+1]$ given that she observes p_i and the other investors play strategy $a(.)$.

$$P_a(s_i) = R_L + p(s_i)\Delta R - q\Delta R \times E\left(p^2 \times (1 - E(a(s_{-i}) \mid p))^n \mid s_i\right) - \pi$$

The only difference is the power n put on the probability not to invest given strategy $s(.)$ and conditionally to p. Indeed, under Assumption 1, investor i is only concerned to being the only acquirer.

It is straightforward to check that with this very similar expected profit, the five claims of Proposition 2 can be derived exactly the same way without further difficulty. Let us only derive the equivalent of Claim 5 in which the asymptotic value of s_e when $\alpha, \beta, \frac{\beta}{\alpha^2} \to \infty$ is obtained.

Again, s_e is solution of

$$P_{a_s}(s) = 0$$

where a_s is the switching strategy with threshold s. This equation is

$$R_L + p(s)\Delta R - q\Delta R \times \int \left(\frac{u}{\sqrt{\alpha+\beta}} + p(s)\right)^2 \left(\Phi\left(\sqrt{\frac{\beta}{\alpha+\beta}}\left(\frac{\alpha}{\sqrt{\alpha+\beta}}(s-\overline{p}) - u\right)\right)\right)^n \varphi(u)\,du = \pi$$

Hence, by continuity and uniform convergence, $\lim_{\substack{\alpha\to\infty \\ \beta\to\infty \\ \frac{\beta}{\alpha^2}\to\infty}} s_e$ is solution of

$$R_L + s\Delta R - \frac{q}{n+1}s^2\Delta R = \pi$$

So that at first order with respect to q

$$\lim_{\substack{\alpha\to\infty \\ \beta\to\infty \\ \frac{\beta}{\alpha^2}\to\infty}} s_e = \frac{\pi - R_L}{\Delta R} + \frac{q}{n+1}\left(\frac{\pi - R_L}{\Delta R}\right)^2$$

3. Introducing the seller and deriving the optimal price.

Identical to the proof of Proposition 3.¥

10.5 Proof Of Proposition 5

As $\alpha, \beta, \frac{\beta}{\alpha^2} \to \infty$, the seller's program tends to:

$$\max_{P(.)} (1+r) \int \left[P' \left((1-F_L) + \left(p - p^2 \frac{q}{2} \right) (F_L - F_H) \right) \right]$$
$$+ \int \left[(1-P') \left((1-F_L) + p (F_L - F_H) \right) \right]$$

$$s.t. P' \in [0,1]$$

Straightforward computations yield equivalently

$$\max_{P' \in [0,1]} P' \times \left[\left(1 - \frac{1+r}{2r} pq \right) p \times \Phi + 1 \right]$$

Proposition 5 is then obvious.¥

10.6 Proof Of Proposition 6

For simplicity again, I address directly the asymptotic case where $\alpha, \beta, \frac{\beta}{\alpha^2} \to \infty$.

The symmetric subgame perfect Nash equilibrium is derived backwards.

Obviously, one seller issues immediately after observing an issuance from her opponent. To characterize strategies, it suffices thus to solve the subgames starting at date $t \in [0,T]$ where none has issued earlier. I denote this subgame S_t.

By assumption, sellers issue for sure and simultaneously at date T if none of them has done it earlier.

Now, for $t < T$, there is obviously no pure strategies symmetric equilibrium for S_t: Issuing immediately is the best response to a delay and delaying is the best response to an immediate issuance since $\delta < L$. There is one unique symmetric equilibrium in mixed strategies.

Indeed, let us denote p_t the probability that a seller issues at date t, and Π_t the expected benefit for each player from playing S_t. At the equilibrium, each seller should be indifferent between issuing at date t or delaying given p_t and Π_{t+1} :

$$L(1 - p_t) = -\delta + Lp_t + (1 - p_t)\Pi_{t+1}$$

Issuing immediately saves the liquidity premium if the other seller does not (left term), delaying costs δ and saves L if the other seller has issued at date t or provides the expected profit of the next subgame otherwise. Hence,

$$p_t = \frac{L + \delta - \Pi_{t+1}}{2L - \Pi_{t+1}}$$

Moreover,

$$\Pi_t = L(1 - p_t)$$

Indeed, issuing and delaying yield the same expected profit at the equilibrium. Thus,

$$p_t = \frac{\delta + L \times p_{t+1}}{L + L \times p_{t+1}}$$

Hence,

$$p_t - \gamma = (1 - \gamma)(p_{t+1} - \gamma)$$

$$p_t + \gamma = (1+\gamma)\,(p_{t+1} + \gamma)$$

And

$$\frac{p_t - \gamma}{p_t + \gamma} = \frac{1-\gamma}{1+\gamma} \times \frac{p_{t+1} - \gamma}{p_{t+1} + \gamma}$$

An obvious recursion yields then Proposition 5.¥

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Figure 1

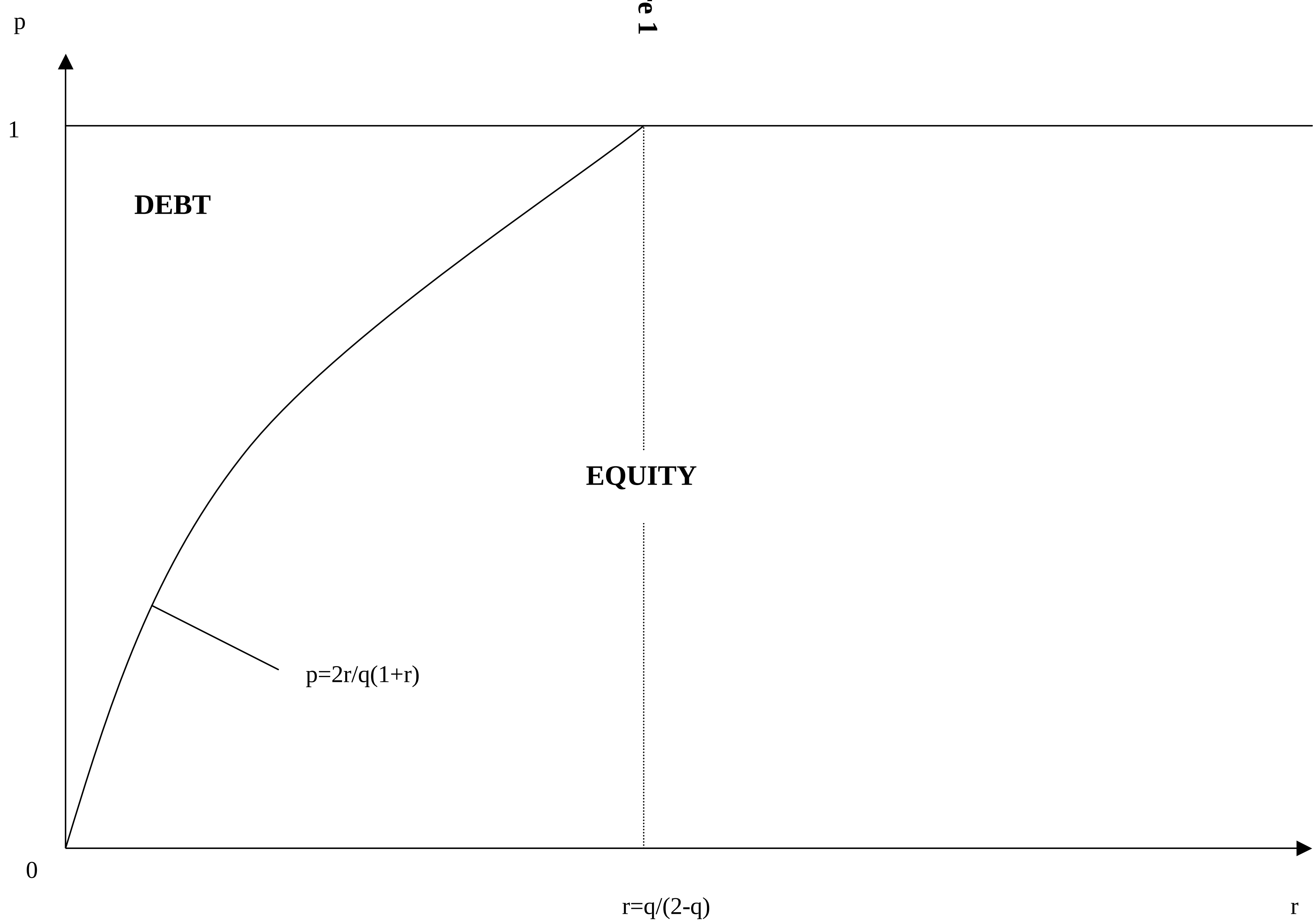
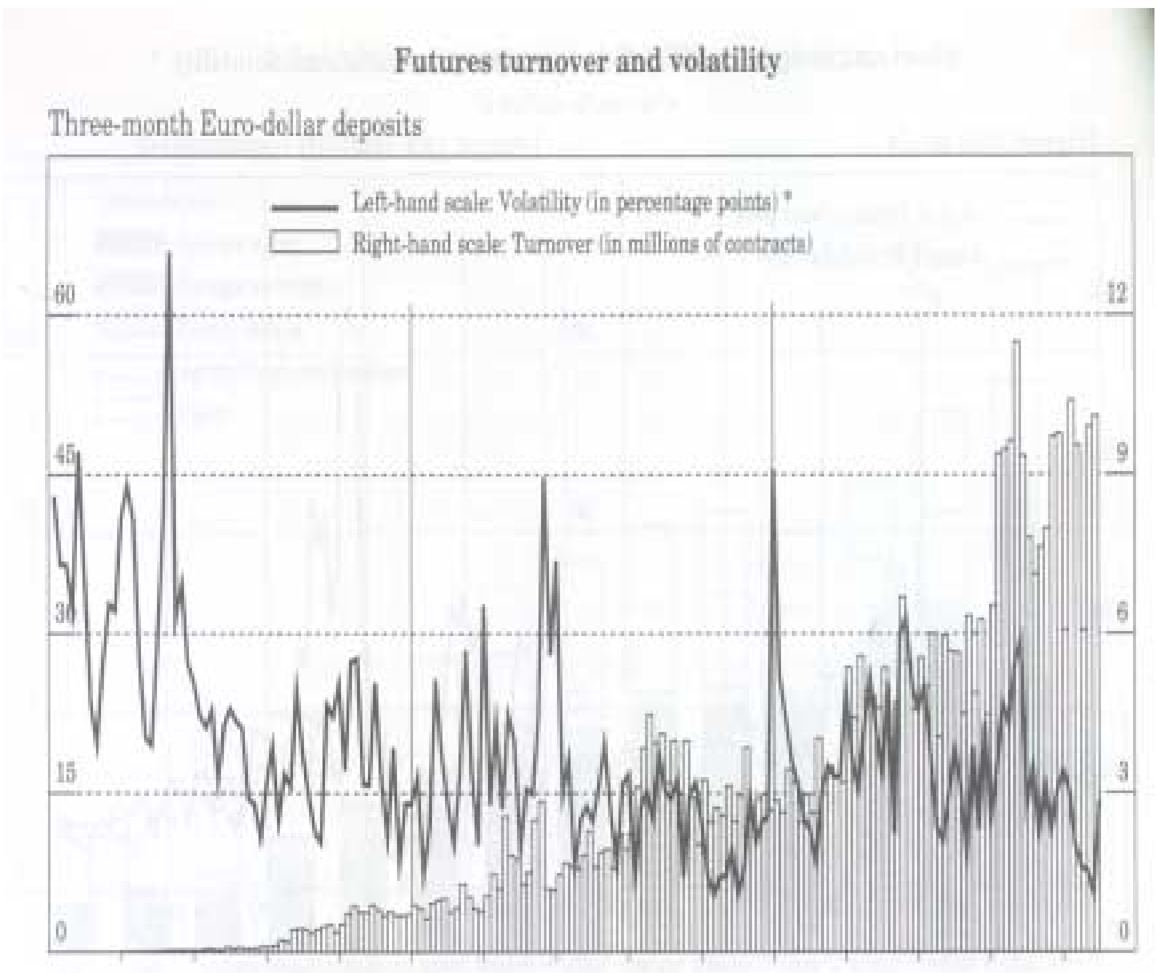
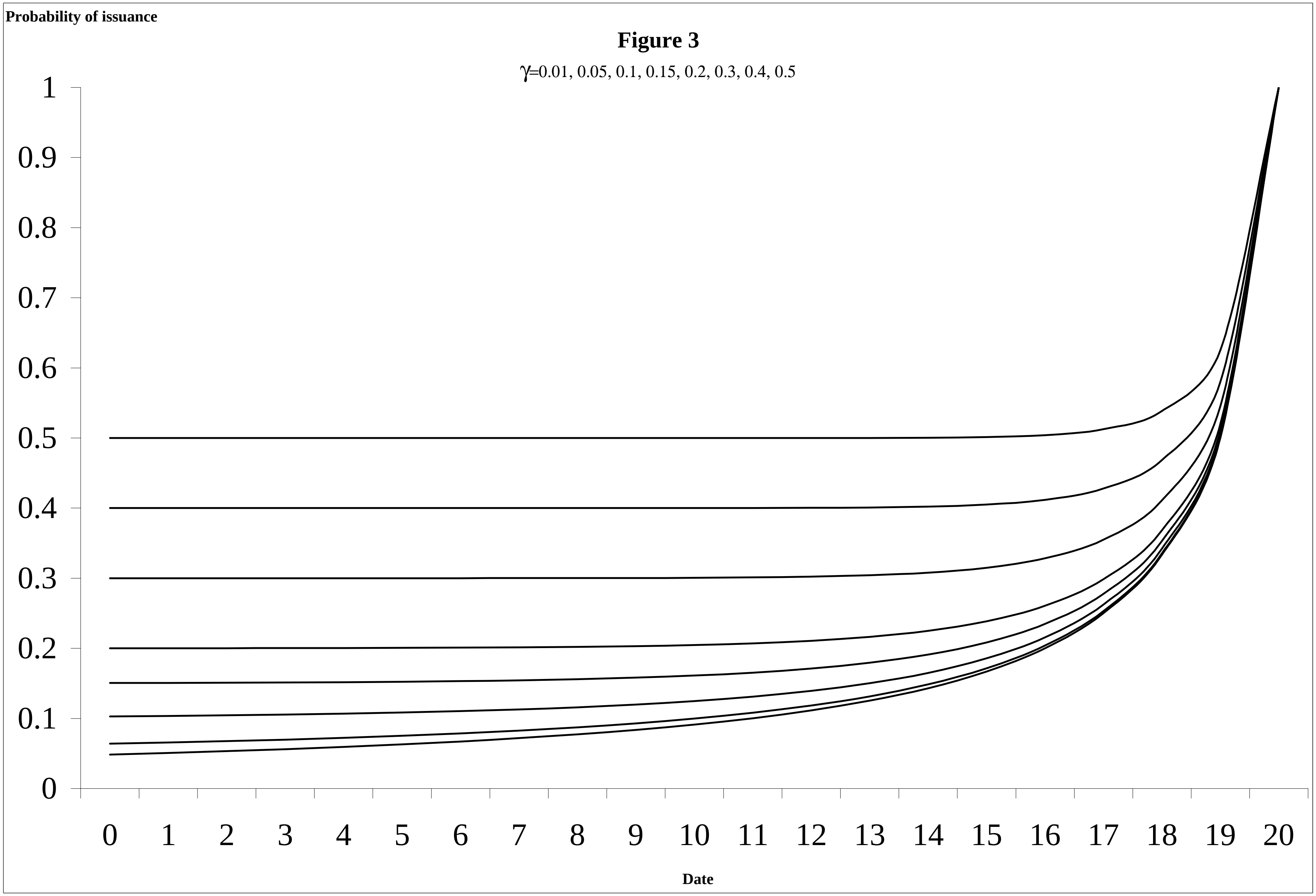


Figure 2

Volatility is a one year moving average of monthly volatilities. Each point is a month between January 1980 and June 1995.




Probability of issuance
Figure 3
γ=0.01, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Date