

Liquidity and Risk Management

By NICOLAE GÂRLEANU AND LASSE HEJE PEDERSEN*

This paper provides a model of the interaction between risk-management practices and market liquidity. Our main finding is that a feedback effect can arise. Tighter risk management leads to market illiquidity, and this illiquidity further tightens risk management.

Risk management plays a central role in institutional investors' allocation of capital to trading. For instance, a risk manager may limit a trading desk's one-day 99 percent value at risk (VaR) to \$1 million. This means that the trading desk must choose a position such that, over the following day, its value drops no more than \$1 million with 99 percent probability. Risk management helps control an institution's use of capital while limiting default risk, and helps mitigate agency problems. Phillippe Jorion (2000, xxiii) states that VaR "is now increasingly used to allocate capital across traders, business units, products, and even to the whole institution."

We do not focus on the benefits of risk management within an institution adopting such controls, but, rather, on the aggregate effects of such practices on liquidity and asset prices. An institution may benefit from tightening its risk management and restricting its security position, but as a consequence it cannot provide as much liquidity to others. We show that, if everyone uses a tight risk management, then market liquidity is lowered in that it takes longer to find a buyer with unused risk-bearing capacity, and, since liquidity is priced, prices fall.

Not only does risk management affect liquidity; liquidity can also affect risk-management practices. For instance, the Bank for International Settlements (2001, 15) states, "For the internal risk management, a number of institutions are exploring the use of liquidity adjusted-VaR, in which the holding periods in the risk assessment are adjusted to account for market liquidity, in particular by the length of time required to unwind positions." For instance, if liquidation is expected to take two days, a two-day VaR might be used instead of a one-day VaR. Since a security's risk over two days is greater than over one day, this means a trader must choose a smaller position to satisfy his liquidity-adjusted value at risk (LVaR) constraint. One motivation for this constraint is that, if an institution needs to sell, its maximum loss before the completion of the sale is limited by the LVaR.

The main result of the paper is that subjecting traders to an LVaR gives rise to a multiplier effect. Tighter risk management leads to more restricted positions, hence longer expected selling times, implying higher risk over the expected selling period, which further tightens the risk management, and so on. This feedback between liquidity and risk management can help explain why liquidity can suddenly drop. We show that this "snowballing" illiquidity can arise if volatility rises, or if more agents face reduced risk-bearing capacity—for instance, because of investor redemptions, losses, or increased risk aversion.

Our link between liquidity and risk management is a testable prediction. While no formal empirical evidence is available, to our knowledge, our prediction is consistent with anecdotal evidence on financial market crises. For example, in August 1998 several traders lost money due to a default of Russian bonds and, simultaneously, market volatility increased. As a result, the (L)VaR of many investment banks and other institutions increased. To bring risk back in line, many investment banks reportedly asked traders to reduce positions, leading to falling prices and

[†]*Discussants:* Dimitri Vayanos, London School of Economics; Neil Wallace, Pennsylvania State University; Manuel Amador, Stanford University.

*Gârleanu: Wharton School, University of Pennsylvania, 3620 Locust Walk, Philadelphia, PA 19104-6367, and National Bureau of Economic Research, and Centre for Economic Policy Research (e-mail: garleanu@wharton.upenn.edu); Pedersen: Stern School of Business, New York University, 44 West Fourth Street, Suite 9-190, New York, NY 10012-1126, NBER, and CEPR (e-mail: lpederse@stern.nyu.edu). We are grateful for helpful conversations with Franklin Allen, Dimitri Vayanos, and Jeff Wurgler.

lower liquidity. These market moves exacerbated the risk-management problems, fueling the crisis in a similar manner to the one modeled here.

We capture these effects by extending the search model for financial securities of Darrell Duffie, Gârleanu, and Pedersen (2005, forthcoming, henceforth DGP). This framework of time-consuming search is well suited for modeling liquidity-based risk management as it provides a natural framework for studying endogenous selling times. While DGP relied on exogenous position limits, we endogenize positions based on a risk-management constraint, and consider both a simple and a liquidity-adjusted VaR. Hence, we solve the fixed-point problem of jointly calculating endogenous positions given the risk-management constraint and computing the equilibrium (L)VaR given the endogenous positions that determine selling times and price volatility. Pierre-Olivier Weill (forthcoming) considers another extension of DGP in which market maker liquidity provision is limited by capital constraints. Our multiplier effect is similar to that of Markus K. Brunnermeier and Pedersen (2006) who show that liquidity and traders' margin requirements can be mutually reinforcing.

I. Model

The economy has two securities: a “liquid” security with risk-free return r (i.e., a “money-market account”), and a risky illiquid security. The risky security has a dividend-rate process X and a price $P(X)$, which is determined in equilibrium. The dividend rate is Lévy with finite variance. It has a constant drift normalized to zero, $E_t(X(t + T) - X(t)) = 0$, and a volatility $\sigma_X > 0$, i.e.,

$$(1) \quad \text{var}_t(X(t + T) - X(t)) = \sigma_X^2 T.$$

Examples include Brownian motions, (compound) Poisson processes, and sums of these.

The economy is populated by a continuum of agents who are risk neutral and infinitely lived, have a time-preference rate equal to the risk-free interest rate $r > 0$, and must keep their wealth bounded from below. Each agent is characterized by an intrinsic type $i \in \{h, l\}$, which is a Markov chain, independent across agents, and switching from l (“low”) to h (“high”) with intensity λ_h , and back with intensity λ_l . An agent of type i

holding θ , shares of the asset incurs a holding cost of $\delta > 0$ per share and per unit of time if he violates his *risk-management constraint*

$$(2) \quad \text{var}_t(\theta_t[P(X_{t+\tau}) - P(X_t)]) \leq (\sigma^i)^2,$$

where σ^i is the risk-bearing capacity, defined by $\sigma^h = \bar{\sigma} > 0$ and $\sigma^l = 0$. The low risk-bearing capacity of the low-type agents can be interpreted as a need for more stable earnings, hedging reasons to reduce a position, high financing costs, or a need for cash (e.g., an asset manager whose investors redeem capital).¹

We use this constraint as a parsimonious way of capturing risk constraints, such as the very popular VaR constraint,² which are used by most financial institutions. Our results are robust in that they rely on two natural properties of the measure of risk: the risk measure increases with the size of the security position, and the length of the time period τ over which the risk is assessed. While the constraint is not endogenized in the model, we note that its wide use in the financial world is probably due to agency problems, default risk, and the need to allocate scarce capital.

We consider two types of risk management: (a) “simple risk management,” in which the variance of the position in (2) is computed over a fixed time horizon τ ; and (b) “liquidity-adjusted risk management,” in which the variance is computed over the time required for selling the asset to an unconstrained buyer, which will be a random equilibrium quantity.

Because agents are risk neutral and we are interested in a steady-state equilibrium, we restrict attention to equilibria in which, at any given time and state of the world, an agent holds either 0 or $\bar{\theta}$ units of the asset, where $\bar{\theta}$ is the largest

¹ An interesting extension of our model would consider the direct benefit of tighter risk management, which could be captured by a lower λ_d .

² A VaR constraint stipulates that $\Pr(-\theta[P(X_{t+\tau}) - P(X_t)] \geq VaR) \leq \pi$ for some risk limit VaR and some confidence level π . If X is a Brownian motion, this is the same as (2). We note that rather than considering only price risk, we could alternatively consider the risk of the gains process (i.e., including dividend risk) $G_{i,\tau} = P(X(t + \tau)) - P(X(t)) + \int_t^{t+\tau} X(s) ds$. This yields qualitatively similar results (and quantitatively similar for many reasonable parameters since dividend risk is orders of magnitude smaller than price risk over a small time period).

position that satisfies (2) with $\sigma^j = \bar{\sigma}$, taking the prices and search times as given.³ Hence, the set of agent types is $\mathcal{T} = \{ho, hn, lo, ln\}$, with the letters “*h*” and “*l*” designating the agent’s current intrinsic risk-bearing state as high or low, respectively, and with “*o*” or “*n*” indicating whether the agent currently owns $\bar{\theta}$ shares or none, respectively. We let $\mu_\zeta(t)$ denote the fraction at time t of agents of type $\zeta \in \mathcal{T}$. These fractions add up to 1 and markets must clear:

$$(3) \quad 1 = \mu_{ho} + \mu_{hn} + \mu_{lo} + \mu_{ln},$$

$$(4) \quad \Theta = \bar{\theta}(\mu_{ho} + \mu_{lo}),$$

where $\Theta > 0$ is the total supply of shares per investor.

Central to our analysis is the notion that the risky security is not perfectly liquid, in the sense that an agent can trade it only when she finds a counterparty. Every agent finds a potential counterparty, selected randomly from the set of all agents, with intensity λ , where $\lambda > 0$ is an exogenous parameter characterizing the market liquidity for the asset. Hence, the intensity of finding a type- ζ investor is $\lambda\mu_\zeta$, that is, the search intensity multiplied by the fraction of investors of that type. When two agents meet, they bargain over the price, with the seller having bargaining power $q \in [0, 1]$.

This model of illiquidity directly captures the search that characterizes over-the-counter (OTC) markets. In these markets, traders must find an appropriate counterparty, which can be time consuming. Trading delays also arise due to time spent gathering information, reaching trading decisions, mobilizing capital, etc. Hence, trading delays are commonplace, and, therefore, the model can also capture features of other markets such as specialist and electronic limit-order-book markets, although these markets are, of course, distinct from OTC markets.

II. Equilibrium Risk Management, Liquidity, and Prices

We now proceed to derive the steady-state equilibrium agent fractions μ , the maximum-

³ Note that the existence of such an equilibrium requires that the risk limit $\bar{\sigma}$ not be too small relative to the total supply Θ , a condition that we assume throughout.

holding $\bar{\theta}$, and the price P . Naturally, low-type owners *lo* want to sell and high-type non-owners *hn* want to buy, which leads to

$$(5) \quad 0 = -2\lambda\mu_{hn}(t)\mu_{lo}(t) - \lambda_u\mu_{lo}(t) + \lambda_d\mu_{ho}(t)$$

and three more such steady-state equations. Equation (5) states that the change in the fraction of *lo* agents has three components, corresponding to the three terms on the right-hand-side of the equation. First, whenever a *lo* agent meets a *hn* investor, he sells his asset and is no longer a *lo* agent. Second, whenever the intrinsic type of a *lo* agent switches to high, he becomes a *ho* agent. Third, *ho* agents can switch type and become *lo*. Duffie, Gârleanu, and Pedersen (2005) show that, taking $\bar{\theta}$ as fixed, there is a unique stable steady-state mass distribution as long as $\bar{\theta} \geq \Theta$. Here, agents’ positions $\bar{\theta}$ are endogenous and depend on μ , so that we must calculate a fixed point.

Agents take the steady-state distribution μ as fixed when they derive their optimal strategies and utilities for remaining lifetime consumption, as well as the bargained price P . The utility of an agent depends on his current type $\zeta(t) \in \mathcal{T}$ (i.e., whether he is a high or a low type and whether he owns zero or $\bar{\theta}$ shares), the current dividend $X(t)$, and the wealth $W(t)$ in his bank account:

$$(6) \quad V_\zeta(X(t), W_t) = W_t + 1_{\{\zeta \in \{ho, lo\}\}} \bar{\theta} X(t)/r + \bar{\theta} v_\zeta,$$

where the type-dependent utility coefficients v_ζ are to be determined. With q the bargaining power of the seller, bilateral Nash bargaining yields the price

$$(7) \quad P\bar{\theta} = (V_{lo} - V_{ln})(1 - q) + (V_{ho} - V_{hn})q.$$

We conjecture, and later confirm, that the equilibrium asset price per share is of the form

$$(8) \quad P(X(t)) = X(t)/r + p,$$

for a constant p to be determined. The value-function coefficients v_ζ and p are given by a set of Hamilton-Jacobi-Bellman equations, stated and solved in the Appendix available at www.e-aer.org/data/may07/p07048_app.pdf. The Appendix contains all the proofs.

PROPOSITION 1: *If the risk-limit $\bar{\sigma}$ is sufficiently large, there exists an equilibrium with*

holdings 0 and $\bar{\theta}$ that satisfy the risk management constraint (2) with equality for low- and high-type agents, respectively. With simple risk management, the equilibrium is unique and

$$(9) \quad \bar{\theta} = \frac{r\bar{\sigma}}{\sigma_X} \frac{1}{\sqrt{\tau}}.$$

With liquidity-adjusted risk management, $\bar{\theta}$ depends on the equilibrium fraction of potential buyers μ_{hn} and satisfies

$$(10) \quad \bar{\theta} = \frac{r\bar{\sigma}}{\sigma_X} \sqrt{2\lambda\mu_{hn}}.$$

In both cases, the equilibrium price is given by

$$(11) \quad P(X_t) = \frac{X_t}{r} - \frac{\delta}{r} \frac{r(1 - q) + \lambda_d + 2\lambda\mu_{lo}(1 - q)}{r + \lambda_d + 2\lambda\mu_{lo}(1 - q) + \lambda_u + 2\lambda\mu_{hn}q},$$

where the fractions of agents μ depend on the type of risk management.

These results are intuitive. The “position limit” $\bar{\theta}$ increases in the risk limit $\bar{\sigma}$ and decreases in the asset volatility and in the square root of the VaR period length, which is τ under simple risk management and $(2\lambda\mu_{hn})^{-1}$ under liquidity-adjusted risk management. In the latter case, position limits increase in the search intensity and in the fraction of eligible buyers μ_{hn} .

The price equals the present value of dividends, X_t/r , minus a discount for illiquidity. Naturally, the liquidity discount is larger if there are more low-type owners in equilibrium (μ_{lo} is larger) and fewer high-type nonowners ready to buy (μ_{hn} is smaller).

Of the equilibria with liquidity-adjusted risk management, we concentrate on the ones that are stable, in the sense that increasing $\bar{\theta}$ marginally would result in equilibrium quantities violating the VaR constraint (2). Conversely, an equilibrium is unstable if a marginal change in holdings that violates the constraint would result in

the equilibrium adjusting so that the constraint is not violated. If an equilibrium exists, then a stable equilibrium exists. Indeed, the equilibrium with the largest $\bar{\theta}$ is stable and has the highest welfare among all equilibria.

The main result of the paper characterizes the equilibrium connection between liquidity and risk management.

PROPOSITION 2: *Suppose that $\bar{\sigma}$ is large enough for the existence of an equilibrium. Consider a stable equilibrium with liquidity-adjusted risk management and let $\tau = 1/(2\lambda\mu_{hn})$, which means that the equilibrium allocations and price are the same with simple risk management. Consider any combination of the conditions (a) higher dividend volatility σ_X , (b) lower risk limit $\bar{\sigma}$, (c) lower meeting intensity λ , (d) lower switching intensity λ_u to the high risk-bearing state, and (e) higher switching intensity λ_d to the low risk-bearing state. Then, (i) the equilibrium position $\bar{\theta}$ decreases, (ii) expected search times for selling increase, and (iii) prices decrease. All three effects are larger with liquidity-adjusted risk management.*

To see the intuition for these results, consider the impact of a higher dividend volatility. This makes the risk-management constraint tighter, inducing agents to reduce their positions and spreading securities among more agents, thus leaving a smaller fraction of agents with unused risk-bearing capacity. Hence, sellers’ search time increases and their bargaining position worsens, leading to lower prices. This price drop is due to illiquidity, as agents are risk neutral.⁴

With liquidity-adjusted risk management, the increased search time for sellers means that the risk over the expected liquidation period rises, thus further tightening the risk-management constraint, reducing positions, increasing search times, and so on.

This multiplier also increases the sensitivity of the economy with liquidity-adjusted risk management to the other shocks (b)–(e). Indeed, a lower risk limit (b) is equivalent to a higher

⁴ In a Walrasian market with immediate trade, the price is the present value of dividends X/r when $(\Theta/\bar{\theta}) < \lambda_u/(\lambda_u + \lambda_d)$, a condition that is satisfied in our examples below. (When $\Theta/\bar{\theta} > \lambda_u/(\lambda_u + \lambda_d)$, the Walrasian price is $(X - \delta)/r$.)

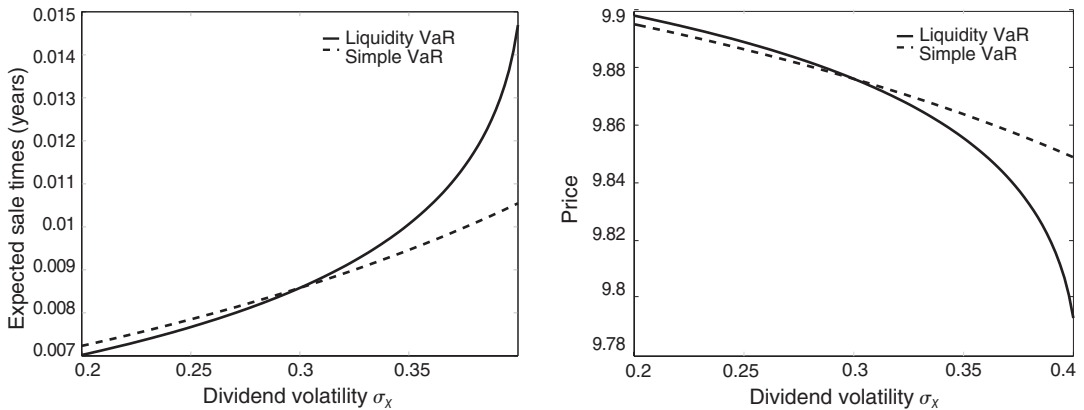


FIGURE 1

Note: The effects of dividend volatility on equilibrium seller search times (left panel) and prices (right panel) with simple (dashed line) and liquidity-adjusted (solid line) risk management, respectively.

dividend risk. The “liquidity shocks” (c)–(e) do not affect the equilibrium position θ with simple risk management, but they do increase the sellers’ search times and reduce prices. With liquidity-adjusted risk management, these liquidity shocks reduce security positions, too, because of increased search times and, as explained above, a multiplier effect arises.

The multiplier arising from the feedback between trading liquidity and risk management clearly magnifies the effects of changes in the economic environment on liquidity and prices. Our steady-state model illustrates this point using comparative static analyses that essentially compare across economies. Similar results would arise in the time series of a single economy if there were random variation in the model characteristic, e.g., parameters switched in a Markov chain as in Duffie, Gârleanu, and Pedersen (forthcoming). In the context of such time-series variation, our multiplier effect can generate the abrupt changes in prices and selling times that characterize crises.

We illustrate our model with a numerical example in which $\lambda = 100$, $r = 0.1$, $X_0 = 1$, $\lambda_d = 0.2$, $\lambda_u = 2$, $\delta = 3$, $q = 0.5$, $\Theta = 1$, and $\bar{\sigma} = 1$. Figure 1 shows how prices (right panel) and sellers’ expected search times (left panel) depend on asset volatility. The solid line shows this for liquidity-adjusted risk management and the dashed line for simple risk management

with $\tau = 0.0086$, which is chosen so that the risk management schemes are identical for $\sigma_X = 0.3$. Search times increase and prices decrease with volatility. These sensitivities are stronger (i.e., the curves are steeper) with liquidity-adjusted risk management due to the interaction between market liquidity (i.e., search times) and risk management.

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