

Fragility of Safe Asset Markets

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Abstract

We model a safe asset market with investors valuing safety, investors valuing liquidity, and constrained dealers. While safety investors and liquidity investors can interact symbiotically with offsetting trades in times of stress, we show that liquidity investors' strategic interaction harbors the potential for self-fulfilling fragility. Surprisingly, standard flight to safety in times of stress can have a destabilizing effect and trigger liquidity investors' dash for cash. This explains how safe asset markets can experience price crashes as in March 2020. The announcement and execution of policy interventions play important roles for the functioning of safe asset markets.

JEL codes: C7, G01, G1, G2, E4, E5

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1 Introduction

Safe assets play several special roles in the economy. In this paper we argue that safe asset markets suffer from fragility because of two key characteristics of the assets — safety and liquidity — that interact with each other and with frictions in how the markets operate. Combining these three features, our model helps to understand the unprecedented events in U.S. Treasury markets at the onset of the Covid-19 pandemic in March 2020 and highlights the risks of such events repeating in the future in safe asset markets more broadly.

First, safe assets are *safe* in the sense that they will pay par at maturity with very high probability so investors hold them as a store of value, useful for diversification and intertemporal smoothing (e.g., [Caballero and Farhi, 2017](#)). As a result, safe asset markets tend to feature “flight to safety” during times of stress, in which demand for safe assets and therefore their price increases. Panel A of [Figure 1](#) documents this behavior from mid-February to early March of 2020 where the gradual realization of the severity of the Covid outbreak led to a decline in the price of risk assets as reflected by the S&P 500 index and a concurrent increase in the price of safe assets as reflected by the 10-year Treasury.

Second, safe assets are *liquid* meaning that they are “money-like” and trade at a convenience yield (e.g. [Krishnamurthy and Vissing-Jørgensen, 2012](#)). Some investors hold safe assets to sell them when in need of liquidity for consumption or to meet obligations. During times of stress, investors’ liquidity needs can increase, leading to a “dash for cash” that competes with the usual “flight to safety” and exerts downward pressure on the price of safe assets. As illustrated in Panel A of [Figure 1](#), Treasury prices suddenly reversed their increase in mid-March 2020 and declined together with stock prices in a break-down of the usual negative correlation of safe and risky assets during times of stress.

Third, markets for safe assets such as U.S. Treasuries tend to rely heavily on dealers to intermediate trades. When dealers face costs for intermediating on their balance sheets due to, e.g. the Supplemental Leverage Ratio rule (SLR), they can become a bottleneck during times of stress, increasing price volatility in safe asset markets and contributing to market dysfunction. Panel B of [Figure 1](#) shows that dealer balance sheet space allocated to Treasuries (via direct holdings and reverse repos) increased through both the run-up in Treasury prices and their crash. Treasury markets also became unusually illiquid during this period with bid-ask spreads increasing by a factor of 10 ([Duffie, 2020](#)). The recovery in Treasury prices after March 18 coincided with dealer balance sheet pressure receding as the Federal Reserve’s Treasury purchases ramped up ([Figure 1, Panel B](#)).

Why did the market for Treasuries turn so suddenly in March 2020? Panel C of [Figure 1](#) shows the main sellers of Treasuries in 2020q1: Foreign investors, mutual funds,

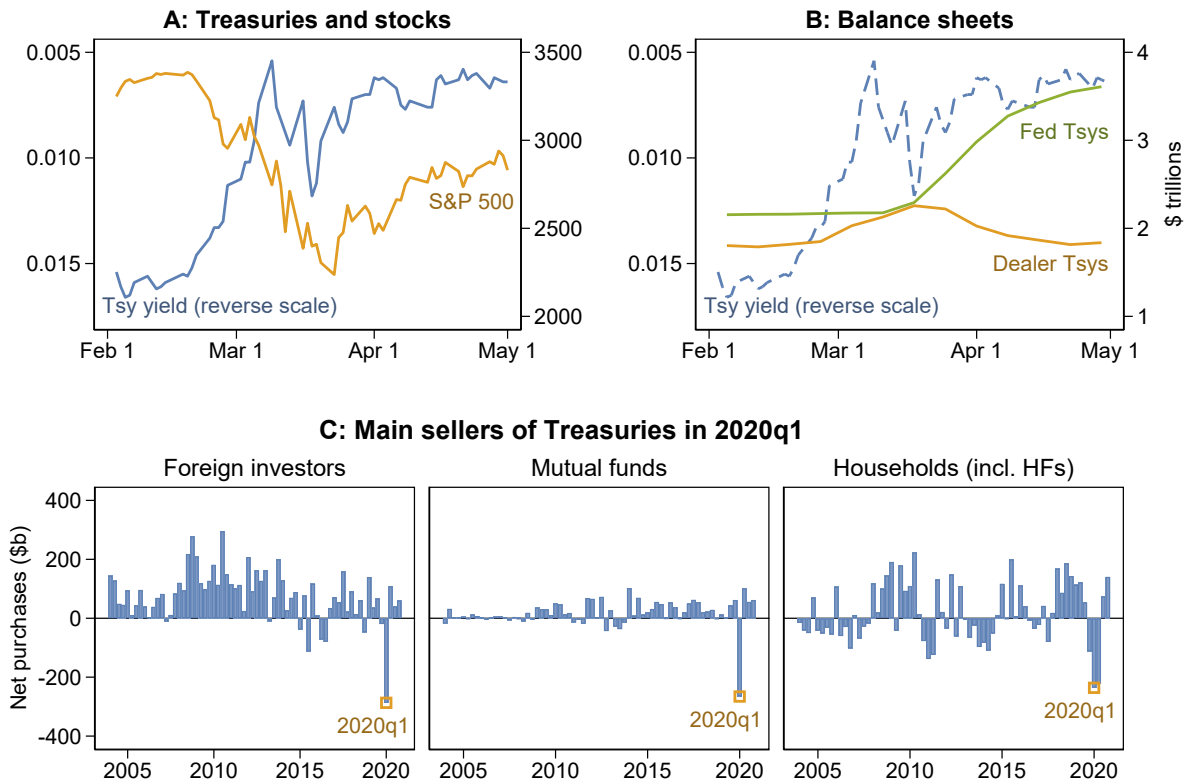


Figure 1: The market for U.S. Treasuries in early 2020. Panel A shows the market yield on 10-year Treasuries and the S&P 500 index. Panel B shows Treasuries on the balance sheets of the Federal Reserve (outright holdings) and of Primary Dealers (net positions and gross reverse repo). Panel C shows net purchases of Treasuries of the three sectors with the largest sales in 2020q1. For details on the data see Appendix A.

and households (which includes hedge funds) each sold roughly \$250 billion. The figure shows that for foreign investors and mutual funds the sales were unprecedented, an order of magnitude larger than their sales in any previous quarter. In addition, there is suggestive evidence in the detailed analysis of [Vissing-Jørgensen \(2021\)](#) that a considerable fraction of these sales were not due to genuine liquidity needs: Among foreign investors, foreign official agencies sold \$196 billion of Treasury bonds but “consumed” only 24% of that in the form of a \$48 billion reduction in their total U.S. Dollar assets.¹ Among mutual funds, those in the CRSP data sold \$157 billion of Treasuries but “consumed” only 66% of that to satisfy outflows as \$54 billion sales were “in excess of outflows” (Table 6 in [Vissing-Jørgensen, 2021](#)). Consistent with this evidence, the [Inter-Agency Working Group for Treasury Market Surveillance \(2021\)](#) reports that “some Treasury holders appeared to react to the decline in market liquidity by selling securities for precautionary reasons lest conditions worsen further, and these sales only added to the stress on the market.”

In this paper, we show that a safe asset market is stable and well-functioning as long as the market is sufficiently deep. In this case, flight to safety and dash for cash are complementary phenomena, with investors who buy the assets for *safety* absorbing sales from investors who sell the assets for *liquidity*. However, we show how the market can break down with prices falling precipitously if trade involves dealers that are subject to balance sheet constraints. The risk of market break-down can be self-fulfilling as it leads to *strategic* or *preemptive* selling by investors without genuine liquidity needs who want to avoid potentially having to sell at lower prices in the future. Surprisingly, we show that flight to safety *purchases* of safe assets can exacerbate the dash for cash when markets are fragile.

To show these results, we model market fragility in the spirit of the seminal papers by [Bernardo and Welch \(2004\)](#) and [Morris and Shin \(2004\)](#). As in [Bernardo and Welch \(2004\)](#), “market runs” can arise in equilibrium because investors face an intertemporal decision regarding when (or if) to sell assets, and some investors may strategically choose to sell early to avoid the possibility of being forced to liquidate at depressed prices in the future. As in [Morris and Shin \(2004\)](#), our model can feature strategic complementarities and therefore safe asset markets are endogenously fragile: In some states the market is well-functioning, with flight-to-safety dynamics supporting prices, but in other states the market breaks down with dash-for-cash dynamics leading to a collapse in prices.

Our model reflects the key characteristics of safe assets — safety and liquidity — as well as the relevant market structure through the investor types active in the market: First,

¹From the international transactions data of the Bureau of Economic Analysis, Table 9.1 International Financial Transactions for Liabilities to Foreign Official Agencies. Reported similarly in Panel B of Table 9 in [Vissing-Jørgensen \(2021\)](#).

there are investors who are risk averse and value the asset for its *safety*, holding it in a portfolio together with a risky asset. In times of stress, when fundamentals worsen for the risky asset (e.g., lower expected dividends), these “safety investors” rebalance their portfolio to buy more of the safe asset. This behavior captures the classic flight to safety and has been the focus of most existing analysis of safe assets in times of stress. Second, there are investors who are subject to liquidity shocks and therefore hold the safe asset for its *liquidity*. When faced with an immediate consumption need, these “liquidity investors” sell the safe asset to raise cash in order to consume. Third, there are dealers who buy and sell the safe asset and whose main role is to intermediate over time. Dealers are subject to balance sheet constraints and therefore provide an elastic residual demand for the safe asset. Because dealers’ demand in the present is affected by inventory they took on in the past, they provide an important intertemporal link between prices in different periods.

Importantly, even in times of stress not all liquidity investors suffer a liquidity shock. This leaves a group of liquidity investors who have to decide whether to sell their assets in the current environment or whether to hold on and face the risk of a liquidity shock in the near future. An individual investor may prefer selling preemptively today if they expect conditions to deteriorate sufficiently tomorrow. As a group, liquidity investors interact strategically and introduce the potential for fragility. Sales today have a direct effect on the price today and, through dealer balance sheets, an indirect effect on the price tomorrow. An individual liquidity investor’s payoff from selling preemptively or holding on to the safe asset therefore is a function of other liquidity investors’ decision. Depending on the relative strength of the effect of sales today on the prices today and tomorrow, the interaction between liquidity investors can feature strategic complementarities: The individual investor’s incentive to sell preemptively can be higher if more of the other investors also sell preemptively.

Our model yields two main results. The first result is that the liquidity role of safe assets together with dealer balance sheet constraints implies that a safe asset market can be fragile. Whether the market is fragile or stable depends on the degree of liquidity risk, which governs both the baseline level of non-strategic sales today as well as the likelihood that a strategic investor is forced to sell tomorrow. An individual investor’s incentive to sell preemptively is increasing in the degree of liquidity risk, as is the slope of the incentive with respect to other investors’ sales. For very low liquidity risk, an investor never finds it optimal to sell preemptively, irrespective of what other investors are doing, and the only equilibrium is for all strategic investors to hold on to the safe asset and for only those investors to sell who have a genuine consumption need. For very high liquidity risk, the opposite is true and an individual investor finds it dominant to sell preemptively such

that the only equilibrium is for all liquidity investors to sell. In this case the safe asset market is flooded with sales, including by investors who do not actually have a consumption need — a “market run.” For intermediate levels of liquidity risk and under perfect information, there can be multiplicity with both the hold and the run equilibrium existing. Using standard global game techniques, we resolve the multiplicity and derive a threshold for liquidity risk such that the unique equilibrium is the hold equilibrium for levels of liquidity risk below the threshold and the run equilibrium for levels above the threshold.

Our second result is that the *safety* and *liquidity* roles of safe assets can interact in such a way that flight to safety can *worsen* fragility, making dash for cash more likely. Recall that in most stress episodes, safety investors form a natural partnership with liquidity investors as their trades offset. Demand from safety investors absorbs sales from liquidity investors so that safe asset prices remain stable or even increase. However, the timing of safety investor demand is key as it affects the intertemporal tradeoff of strategic liquidity investors. Safety investor demand early on in a stress episode increases prices contemporaneously and in the future by relaxing dealer balance sheets. If the strategic concerns of liquidity investors are sufficiently strong, then additional demand from safety investors today can *induce* liquidity investors to sell today, precisely because the market today has (relatively higher) capacity to absorb sales. With sufficient fragility, a flight to safety can therefore trigger a dash for cash. The relative effects are such that safety investors increase the incentive to sell if liquidity risk is low and vice versa. Given how the strategic interaction depends on liquidity risk (hold if low, sell if high), this means that safety investors have an *amplification effect* on market fragility: When the market is already stable, they stabilize it further (flight to safety prevents a dash for cash); while if the market is already fragile, they destabilize it even more (flight to safety precipitates a dash for cash).

The behavior of the markets for Treasuries in March 2020 is particularly striking in contrast to the great financial crisis in 2007–2009 (GFC), during which Treasury markets rallied and did not feature dysfunction and illiquidity. Our model provides a helpful lens to understand the differences between these two episodes that lead to such dramatically different outcomes. First, our model highlights the central role of dealer balance sheet constraints which are a result of post-GFC regulation such as the SLR. During the GFC, dealers’ activities in Treasury markets were relatively unconstrained and thus investors did not need to worry about dealers running out of balance sheet space and Treasury prices collapsing. Second, the size of the liquidity shock during the Covid crisis appears to have been much larger. As our analysis shows, very large increases in liquidity risk and flight to safety can tilt the system into a fragile region in which investors sell strategically. Because the GFC did not feature dealers constrained by balance sheet costs, and because

the shock to liquidity needs was arguably smaller, the Treasury market remained in the stable region in which flight to safety prevents a dash for cash, which is why the market behaved as usual despite the tremendous stress in the financial sector. The Covid shock, in contrast, was sufficiently large, and dealers were sufficiently constrained, that the Treasury market became fragile, and flight to safety precipitated a dash for cash. In sum, our analysis suggests that these episodes did not feature fundamentally different shocks or shocks of different direction, but rather shocks that differed in degree within different (regulatory) environments.

Our analysis has policy implications, in particular, for asset purchase facilities, dealer balance sheet regulation, and market structure. Fragility in our model hinges on the intertemporal considerations of strategic liquidity investors who compare prices today to prices tomorrow. In general, there is scope for policy interventions that increase prices both in the present and in the future. However, due to the intertemporal considerations and the coordination effects, the timing of policy interventions is important and announcements can have large effects well before the interventions are executed. We show that an asset purchase facility can have a large effect upon announcement even if it does not become active until a future date by shifting strategic investors from the run equilibrium to the hold equilibrium, consistent with the evidence of [Haddad, Moreira, and Muir \(2021\)](#). Similarly, policy interventions that relax dealer balance sheet constraints can be stabilizing. However, because the strategic incentive to sell is caused by fear of low prices in the future, effective policy has to relax balance sheet constraints in the future as well.

Finally, our model shows that markets where trading occurs in a decentralized, sequential way and where dealers play a large role intermediating flow imbalances over time are inherently fragile. These elements generate a strategic tradeoff where an investor can hope to receive the average in-run price when selling preemptively but has to worry about bearing the full impact of dealer inventory when being forced to sell in the future. Changes to market structure that lead to more pooling of trades and that reduce the role of dealers as a bottleneck for trade flow can therefore reduce the fragility of safe asset markets. As [Duffie \(2020\)](#) shows, the growth of the Treasury market since the GFC has greatly outpaced the capacity of dealers balance sheets and that trend is expected to continue. The strategic mechanism in our model will therefore become increasingly relevant unless balance sheet constraints are relaxed. Episodes like March 2020 are likely to become more frequent as dash for cash motivations become more pronounced.

The rest of the paper proceeds as follows. After discussing related literature, we provide the model setup in [Section 2](#). We discuss the strategic interaction of liquidity investors

in Section 3 and then analyze the equilibrium without safety investors in Section 4. In Section 5, we add safety investors and derive their ambiguous effect on market fragility. We discuss policy implications in Section 6 and conclude in Section 7.

Related Literature. In contrast to market runs, bank runs have received much greater attention (e.g., [Diamond and Dybvig, 1983](#) and [Goldstein and Pauzner, 2005](#)) because of the common pool problem inherent with liquidity transformation. In the case of a market run, there is no common pool threatened by illiquidity. The seminal papers on market runs by [Bernardo and Welch \(2004\)](#) and [Morris and Shin \(2004\)](#) highlight how dealer constraints can create incentives to front-run the market by selling assets preemptively. [Bernardo and Welch \(2004\)](#) introduce the intertemporal tradeoff our model relies on, but their model does not feature strategic complementarities and therefore suffers from inherent multiplicity of equilibria. Our model with strategic complementarities can resolve the multiplicity with standard global game techniques which allows for continuous comparative statics in the analysis of flight-to-safety demand and policy implications. [Morris and Shin \(2004\)](#) consider a static model in which strategic complementarities arise because investors have “stop-loss rules” and will be forced to liquidate if prices fall sufficiently low. The preponderance of sales in March 2020 were from investors subject to liquidity shocks, suggesting that a stop-loss mechanism did not drive preemptive sales during this episode. [Allen, Morris, and Shin \(2006\)](#) show how higher order beliefs can generate “beauty contests” à la [Keynes \(1936\)](#) in asset markets with short-lived investors and imperfect information.

The literature on safe assets is large, see, e.g. [Gorton \(2017\)](#) for an overview. [Krishnamurthy and Vissing-Jørgensen \(2012\)](#) show that Treasuries are valued both for their safety and their liquidity by documenting yield spreads both with respect to assets similarly liquid but not safe and assets similarly safe but not liquid (see also [Duffee, 1998](#), [Longstaff, 2004](#), and [Greenwood and Vayanos, 2010, 2014](#)). [Caballero and Farhi \(2017\)](#) consider a model where the “specialness” of public debt is its safety during bad aggregate states and where safe assets have “negative beta,” as they tend to appreciate in times of aggregate market downturns, providing investors diversification against aggregate macroeconomic risks (see also [Maggiore, 2017](#), [Adrian, Crump, and Vogt, 2019](#), and [Brunnermeier, Merkel, and Sannikov, 2022](#)). Safe assets valued for their safety appear in a setting of limited participation and risk sharing in [Gomes and Michaelides \(2007\)](#) and through special investors who need safe assets to match liability cash flows in [Greenwood and Vayanos \(2010\)](#).

Safe assets’ liquidity is intimately linked to their safety: when payoffs are (nearly) riskless, assets are information-insensitive and thus easily traded “no questions asked” ([Gor-](#)

ton and Pennacchi, 1990, Holmström, 2015, Dang, Gorton, and Holmström, 2015). Holmström and Tirole (1998) model the use of safe assets as a store of value and as insurance against liquidity shocks. Safe assets valued for their liquidity appear in Vayanos and Vila (1999) and Rocheteau (2011) as well as the monetarist literature surveyed by Lagos, Rocheteau, and Wright (2017). The premium for moneyness has been studied empirically, e.g. by Greenwood, Hanson, and Stein (2015), Carlson et al. (2016), and Cipriani and La Spada (2021) (see also Nagel, 2016, and d’Avernas and Vandeweyer, 2021).

Gorton and Ordoñez (2022) study the interaction of public and private provision of safe assets used as store of value and as collateral (see also Holmström and Tirole, 2011, Stein, 2012, Gorton, Lewellen, and Metrick, 2012, Sunderam, 2014 and Krishnamurthy and Vissing-Jørgensen, 2015). Caballero and Krishnamurthy (2008) study flight to quality episodes triggered by uncertainty shocks. He, Krishnamurthy, and Milbradt (2019) study the roles of strategic complementarities and substitutes among investors in determining which asset becomes the safe asset via coordination (see also Farhi and Maggiori, 2017). For recent empirical analysis of safe assets both current and historical, see Chen et al. (2022) and Choi, Kirpalani, and Perez (2022).

The role of dealers and slow-moving capital more generally in short-term price dislocations is introduced, e.g. in Duffie (2010). Fontaine and Garcia (2012) and Hu, Pan, and Wang (2013) show the effects on liquidity in Treasury markets (see also Vayanos and Vila, 2021). Adrian, Boyarchenko, and Shachar (2017) specifically consider the effects of dealer balance sheet constraints on bond market liquidity. Goldberg and Nozawa (2021) show that dealer inventory capacity is a key driver of liquidity in corporate bond markets (see also Bruche and Kuong, 2021).

The market turmoil in the spring of 2020 and the effects of emergency facilities have been documented in detail, e.g. by Vissing-Jørgensen (2021) and He, Nagel, and Song (2022) for Treasuries and Haddad, Moreira, and Muir (2021) and Boyarchenko, Kovner, and Shachar (2022) for corporate bonds (see also D’Amico, Kurakula, and Lee, 2020, Fleming et al., 2021, Nozawa and Qiu, 2021, Aramonte, Schrimpf, and Shin, 2022, and Haughwout, Hyman, and Shachar, 2022). For detailed analysis of market liquidity conditions see Fleming and Ruela (2020), Kargar et al. (2021), O’Hara and Zhou (2021). The role of mutual funds in particular as large sellers of safe assets has been studied by Falato, Goldstein, and Hortaçsu (2021) and Ma, Xiao, and Zeng (2022). On the role of hedge funds, see e.g. Barth and Kahn (2021).

2 Model Setup

The model is set in two periods $t = 0, 1$ and has three types of agents and two types of assets, a safe asset and a risky asset. The safe asset, which is the focus of the analysis, has a fundamental value of 1 and is traded among the agents in both periods. Among the agents, there are risk averse investors who hold a portfolio of the safe asset and the risky asset (“safety investors”), risk neutral investors who hold the safe asset as protection against liquidity shocks (“liquidity investors”), and risk neutral dealers who participate in the safe asset market and are subject to balance sheet costs. All agents have a discount rate of zero and act competitively, and there is a measure one of each type. All asset prices are determined in equilibrium. We defer discussion of the safety investors until Section 5.

Liquidity Investors. Liquidity investors start out holding one unit of the safe asset and are subject to i.i.d. liquidity shocks in both periods. If a liquidity investor is hit by the shock, they need to consume immediately and sell their entire holding of the safe asset. The probability of a liquidity shock at date 0 is $s \in (0, 1)$ so, by the law of large numbers, a fraction s of liquidity investors are forced to sell at date 0 at price p_0 . Among the remaining fraction $1 - s$ each investor has to decide whether to also sell at date 0, receiving p_0 for sure, or to hold on to the safe asset and face liquidity risk at date 1, again with probability s .² Investors who hold and then suffer a liquidity shock at date 1 are forced to sell at price p_1 . Investors who don’t suffer a shock at either date receive a continuation value $v > 1$ that represents, e.g. future investment opportunities (Holmström and Tirole, 1998, 2001).

The liquidity shock probability s is drawn at the beginning of date 0 from a distribution F on $(0, 1)$. In order to apply global game techniques, we assume that there is imperfect information about s and each individual investor i observes an idiosyncratic signal $\hat{s}_i = s + \sigma_\varepsilon \varepsilon_i$ where the mean-zero signal noise ε_i is i.i.d. across all i with distribution G_ε and $\sigma_\varepsilon > 0$. We ultimately focus on the limit of vanishing signal noise, $\sigma_\varepsilon \rightarrow 0$ and therefore treat s as non-random in the exposition except when deriving the global game equilibrium.

As real-world liquidity investors we have in mind, e.g. foreign official agencies that may face sudden liquidity needs due to foreign exchange interventions or mutual funds that may face sudden liquidity needs due to investor withdrawals. Both were among the largest sellers of Treasuries in March 2020 and their sales were historically unprecedented (Figure 1, Panel A). While we focus on the strategic interaction among liquidity investors, there are potential additional layers of strategic interaction underlying the liquidity shocks

²We can also allow for different liquidity risk s_0 and s_1 at dates 0 and 1, respectively, but focus on the case of one common liquidity risk s for expositional clarity.

both in the foreign exchange context ([Morris and Shin, 1998](#)) and in the mutual fund context ([Chen, Goldstein, and Jiang, 2010](#)).

Dealers. Dealers value the safe asset at its fundamental value of 1 but face convex balance sheet costs for any inventory q given by cq^2 with $c > 0$. Dealers start out with no inventory and compete for sales such that they make zero profits. At date 0, the price p_0 at which dealers take on inventory q_0^D is therefore given by the indifference condition

$$(1 - p_0) q_0^D - c (q_0^D)^2 = 0,$$

which implies a demand from dealers given by

$$q_0^D = \frac{1}{c} (1 - p_0). \quad (1)$$

At date 1, dealers start with inventory q_0^D so the price p_1 at which they take on additional inventory q_1^D is given by the indifference condition

$$(1 - p_0) q_0^D + (1 - p_1) q_1^D - c (q_0^D + q_1^D)^2 = (1 - p_0) q_0^D - c (q_0^D)^2.$$

which results in demand

$$q_1^D = \frac{1}{c} (1 - p_1) - 2q_0^D. \quad (2)$$

Note that our framework does not restrict dealer demand at date 1 to be positive. If there is additional demand such as from an asset purchase facility discussed in [Section 6](#), we can have dealers sell part of their date-0 inventory such that $q_1^D < 0$. Since the quadratic balance sheet costs are symmetric around zero, we can also consider negative dealer demand at date 0, e.g. if they start with an initial endowment of inventory or if they are able to go short the safe asset.

We introduce balance sheet constraints in the spirit of the Supplementary Leverage Ratio (SLR), an unweighted capital requirement for banks that was introduced as part of the Basel III reforms after the GFC and became effective in 2014. Since the largest dealers in the U.S. are part of bank holding companies, the SLR constrains their activity, including in the Treasury market. Importantly, both the direct holdings of Treasuries and reverse repo positions take up dealers' balance sheet space and are subject to the SLR (for more details, see, e.g. [Duffie, 2018](#)). [Boyarchenko et al. \(2020\)](#) show that the constraints pass through to unregulated arbitrageurs who rely on the balance sheet of regulated dealers.

These constraints matter in markets for safe assets such as Treasuries as they rely heav-

ily on dealers for intermediating trades. [Brain et al. \(2019\)](#) document that Treasury market trading volume is split roughly evenly between dealer-to-client trades and inter-dealer trades; this suggests that, on average, a trade originating with one investor and ending with another investor passes through two dealers. The effects of balance sheet constraints are also quantitatively meaningful. For example, [He, Nagel, and Song \(2022\)](#) show that Treasury and repo spreads are significantly wider in the post-SLR period. In March 2020, the ability of dealers to provide liquidity in Treasuries was severely impaired as market depth dropped by a factor of more than 10 in the inter-dealer market ([Duffie, 2020](#)) while trading volume roughly doubled, reaching historically unprecedented levels ([Fleming and Ruela, 2020](#)). Furthermore, the SLR constraint was initially not alleviated by the Fed’s purchases of Treasuries because they were exchanged for reserves which, though perfectly liquid and safe, are treated the same under the SLR. Only on April 1 did the Fed temporarily exempt both Treasuries and reserves from the SLR rule. We return to these issues in our discussion of policy implications in Section 6.

For tractability, we model balance sheet constraints as a convex function of *net* dealer demand and abstract from bid-ask spreads. In reality, dealers can rarely net out offsetting trades instantaneously, and so sales or purchases that are not perfectly synchronized at the same dealer will increase balance sheet costs across the financial system, making the role of balance sheet constraints more pronounced. While we have modeled balance sheet costs as convex, in reality the SLR may at times impose hard quantity constraints with effectively infinite costs of expanding balance sheet further ([Duffie, 2020](#)). To the extent that regulatory constraints at times become totally binding, our results would be further strengthened. In sum, our modeling decisions bias the analysis toward less significant balance sheet costs.

3 Strategic Interaction of Liquidity Investors

Denote by $\alpha \in [0, 1]$ the fraction of strategic liquidity investors who decide to sell at date 0. Together with the non-strategic sales s from investors who receive a liquidity shock, total sales of safe assets at date 0 are

$$x_0 = s + (1 - s) \alpha.$$

At date 1, only the remaining strategic investors who receive a liquidity shock sell their safe assets, resulting in total sales

$$x_1 = s(1-s)(1-\alpha).$$

Denote by $p_0^e(\alpha)$ the price an investor expects to receive at date 0 if a fraction α of strategic investors sell early and by $p_1^e(\alpha)$ the price the investor expects to receive at date 1. Then the payoff gain from preemptively selling at date 0 is given by

$$\pi(\alpha) = p_0^e(\alpha) - (sp_1^e(\alpha) + (1-s)v).$$

Under complete information, there are three candidates for Bayesian Nash equilibria:

Hold equilibrium: If the incentive to sell is negative when no other strategic investors sell, that is $\pi(0) < 0$, then it is a pure-strategy equilibrium for no strategic investors to sell ($\alpha^* = 0$).

Run equilibrium: If the incentive to sell is positive when all other strategic investors sell, that is $\pi(1) > 0$, then it is a pure-strategy equilibrium for all strategic investors to sell ($\alpha^* = 1$).

Mixed equilibrium: If the incentive to sell is zero when a fraction of strategic investors sell, that is $\pi(\alpha^*) = 0$ for $\alpha^* \in (0, 1)$, then it is a mixed-strategy equilibrium for all strategic investors to sell with probability α^* .

In the hold equilibrium, the safe asset market is stable with only those investors selling who have a genuine need for liquidity. Their trades will naturally offset with safety investors reallocating into the safe asset and dealers will take residual supply into inventory. The hold equilibrium exists if

$$p_0^e(0) < sp_1^e(0) + (1-s)v.$$

Since liquidity investors' continuation value v is greater than 1 and prices are bounded above by the safe asset's fundamental value of 1, the hold equilibrium exists as long as, without any strategic sales, the price at date 1 is not considerably lower than the price at date 0 and liquidity risk at date 1 is sufficiently low.

In the run equilibrium, the safe asset market suffers a flood of sales, including sales by strategic investors who do not have a genuine need for liquidity at date 0. The run equilibrium exists and the safe asset market is fragile if

$$p_0^e(1) > sp_1^e(1) + (1-s)v,$$

that is if, with strategic sales, the price at date 1 is expected to be considerably lower than the price at date 0 and liquidity risk at date 1 is sufficiently high. In this case, strategic investors prefer to sell early rather than risk having to sell at a worse price in case they suffer a liquidity shock at date 1. The identifying feature of a run equilibrium are these preemptive sales by investors who do not face a genuine liquidity need and who therefore do not “consume” the proceeds of their sales. As noted in the introduction, the detailed analysis of Treasury markets in March 2020 by [Vissing-Jørgensen \(2021\)](#) provides suggestive evidence of such preemptive sales indicative of a run equilibrium: Among the largest sellers, foreign official agencies sold \$196 billion of Treasury bonds but “consumed” only 24% of the proceeds in the form of a \$48 billion reduction in their total U.S. Dollar assets.

There is the potential for both pure-strategy equilibria to exist if the incentive to sell $\pi(\alpha)$ is increasing in the fraction of strategic investors who sell. In such a situation of strategic complementarities, the safe asset market can break down due to self-fulfilling beliefs. Each individual strategic investor sells early only because they expect other strategic investors to sell early and the run on the safe asset market could be avoided if beliefs were coordinated instead on the hold equilibrium.

4 Equilibrium without Safety Investors

We first analyze the model without safety investors. This allows us to focus on the strategic interaction among liquidity investors and how it is affected by dealer balance sheet costs.

4.1 Market Clearing and Expected Prices

With only dealers available to buy assets, the demand at date 0 can be rewritten from (1) as

$$p_0(q_0) = 1 - cq_0. \quad (3)$$

Similar to [Morris and Shin \(2004\)](#), we assume that trades are executed sequentially and, for aggregate sales x_0 , each seller’s position in the queue is uniformly distributed on $[0, x_0]$. Each investor therefore expects to sell at the average in-run price $p_1^e = 1 - cx_0/2$.³ Substituting in total supply $x_0 = s + (1 - s)\alpha$, we have an expected payoff from selling at date 0 given by

$$p_0^e(\alpha) = 1 - \frac{c}{2} (s + (1 - s)\alpha). \quad (4)$$

³We show in [Appendix C](#) that our results maintain if all trades are pooled and executed jointly as long as balance sheet constraints are sufficiently tight.

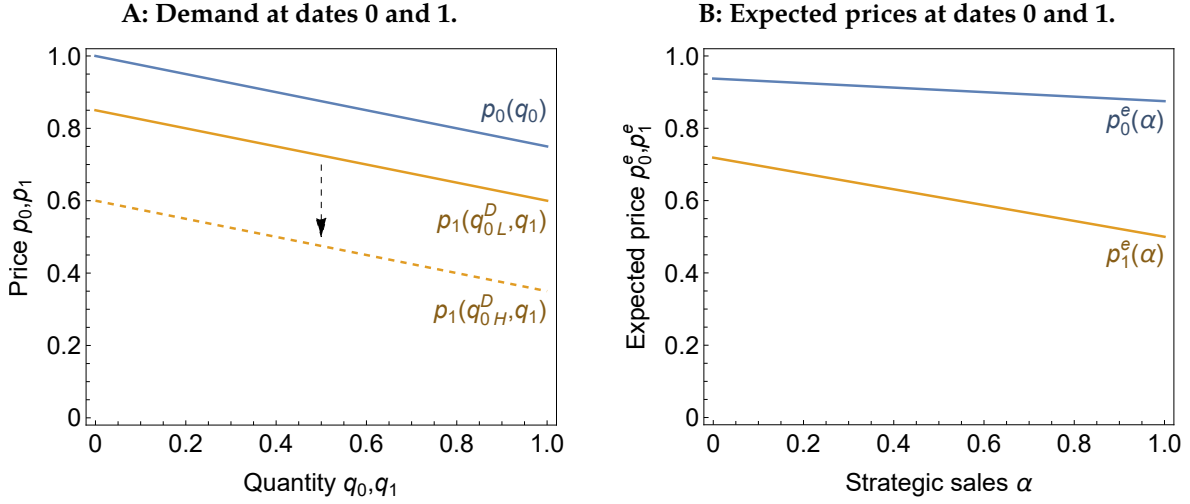


Figure 2: Demand and expected prices at date 0 and date 1. Panel A shows demand at date 0 and demand at date 1 for two levels of inventory $q_{0L}^D < q_{0H}^D$. Panel B shows expected prices at date 0 and date 1. Parameters: $c = 0.25$, $q_{0L}^D = 0.3$, $q_{0H}^D = 0.8$, $s = 0.5$.

The expected price at date 0 is decreasing in the strategic investors' sales α but also in the non-strategic sales s which directly reflect the severity of the liquidity risk at date 0.

At date 1, dealer demand from (2) can be rewritten as

$$p_1(q_0^D, q_1) = 1 - 2cq_0^D - cq_1, \quad (5)$$

and, for aggregate sales x_1 , each seller expects to receive the average price $p_1^e = 1 - 2cq_0^D - cx_1/2$. Substituting in total supply $x_1 = s(1-s)(1-\alpha)$ as well as dealer inventory which equals total date 0 supply x_0 , we have an expected payoff from selling at date 1 given by

$$p_1^e(\alpha) = 1 - 2c \underbrace{(s + (1-s)\alpha)}_{\text{date-0 inventory}} - \frac{c}{2} \underbrace{s(1-s)(1-\alpha)}_{\text{date-1 sales}}. \quad (6)$$

What is the effect of strategic sales α at date 0 on the price at date 1? First, α has a *positive* effect on p_1^e through sales at date 1 which come from the investors who didn't sell at date 0 and then receive a liquidity shock at date 1. If more strategic investors sell at date 0, then there are fewer left at date 1 who can suffer a liquidity shock and sell so the price will be higher. Second, strategic sale α at date 0 have a negative effect on the price at date 1 through dealer inventory. If dealers have to absorb more sales at date 0 then their residual demand at date 1 and therefore the equilibrium price will be lower.

Figure 2 illustrates demand at date 0 and date 1 and the resulting expected prices.

Panel A shows demand at date 0, $p_0(q_0)$ from equation (3), and demand at date 1, $p_1(q_0^D, q_1)$ from equation (5), for two different levels of inventory $q_{0L}^D < q_{0H}^D$. Given the simple structure of our model, demand at both dates is linear with the same slope of $1/c$ and inventory q_0^D results in a parallel shift of demand at date 1. Panel B shows the expected prices a strategic investor expects to receive at date 0 and at date 1, as a function of the fraction α of other strategic investors who sell at date 1, $p_0^e(\alpha)$ from equation (4) and $p_1^e(\alpha)$ from equation (6), respectively. In contrast to the demands Panel A, the expected prices in Panel B have different slopes as strategic sales α at date 0 have greater impact on the expected price at date 1 than at date 0.

Because strategic sales α move sales from date 1 to date 0 they have a direct negative effect on p_0^e with a coefficient $-\frac{1}{2}c(1-s)$ and direct positive effect on p_1^e with a coefficient $\frac{1}{2}c(1-s)s$. These direct effects are stabilizing since they make selling at date 0 less attractive and selling at date 1 more attractive. However, strategic sales α also affect p_1^e indirectly with a coefficient $-2c(1-s)$ through inventory on dealer balance sheets. This indirect effect is destabilizing since it makes selling at date 1 less attractive.

Why is the destabilizing indirect effect of strategic sales so much stronger than the stabilizing direct effect, at a ratio of 2 to 1/2? For two reasons: First, existing inventory q_0^D has twice the price impact on dealer demand at date 1 than new inventory q_1 . Second, while investors anticipate the full effect of existing inventory in case they have to sell at date 1, they internalize only half the effect of sales on price at date 0 since they expect to sell at the average in-run price. We show in Appendix C that our results maintain if all trades are pooled and executed jointly as long as balance sheet constraints are sufficiently tight.

4.2 Incentive to Sell Preemptively

Using the expressions for p_0^e and p_1^e , we can derive the payoff gain $\pi(\alpha)$ which captures the incentive of an individual strategic liquidity investors to sell at date 0 if a fraction α of other strategic investors sells:

$$\pi(\alpha) = \overbrace{1 - \frac{c}{2}(s + (1-s)\alpha)}^{p_0^e(\alpha)} - \underbrace{s\left(1 - 2c(s + (1-s)\alpha) - \frac{c}{2}s(1-s)(1-\alpha)\right)}_{p_1^e(\alpha)} - (1-s)v. \quad (7)$$

As discussed in Section 3, the level and slope of the payoff gain determine the equilibrium (or equilibria) of the strategic interaction among liquidity investors.

Proposition 1 (Strategic liquidity investors' incentive to preemptively sell at date 0).

- There are strategic complementarities if and only if liquidity risk is sufficiently high:

$$\begin{aligned}\pi'(\alpha) > 0 &\Leftrightarrow (4 - s)s > 1 \\ &\Leftrightarrow s > \tilde{s} \equiv 2 - \sqrt{3} \approx 0.27.\end{aligned}$$

- Higher liquidity risk uniformly increases the incentive to sell, $\partial\pi/\partial s > 0$.
- Greater dealer balance sheet costs increase the incentive to sell if there are strategic complementarities, $\pi'(\alpha) > 0 \Rightarrow \partial\pi/\partial c > 0$.
- A greater continuation value uniformly decreases the incentive to sell, $\partial\pi/\partial v < 0$.

Proof. See Appendix B. □

The key determinant of the strategic interaction among liquidity investors is the effect of other strategic investors' sales α on an individual investor's selling incentive π . The safe asset market is fragile if there are strategic complementarities $\pi'(\alpha) > 0$, that is if an individual investor has a greater incentive to sell if more of the other investors are selling.

As discussed in Section 4.1, strategic sales α have a stabilizing direct effect that decreases p_0^e and increases p_1^e , and a destabilizing indirect effect through dealer balance sheets that decreases p_1^e — the latter effect considerably stronger with a ratio of 2 to 1/2. When evaluating the effects on the incentive to sell π , we have to account for the fact that effects on p_1^e are discounted by the liquidity shock probability s since they are only relevant if the investor actually suffers a liquidity shock at date 1. We therefore have a destabilizing indirect effect of α on the incentive to sell π with a coefficient

$$2c(1 - s)s,$$

and a stabilizing total direct effect with a coefficient (in absolute value)

$$\frac{1}{2}c(1 - s)(1 + s^2),$$

resulting in a ratio of

$$\frac{2s}{\frac{1}{2}(1 + s^2)}.$$

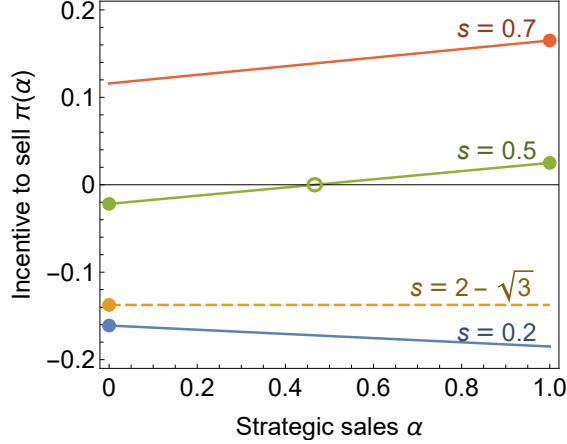


Figure 3: Incentive to sell and equilibria. The figure shows the payoff gain $\pi(\alpha)$ for different values of liquidity risk s . Circles indicate equilibria of the game under complete information. Parameters: $c = 0.25$, $v = 1.2$.

Consider the relative strength of the two effects and how they depend on the magnitude of liquidity risk s . The stabilizing effect in the denominator is present whether or not there is liquidity risk, i.e. the coefficient is non-zero even for $s = 0$ and then increases slowly with liquidity risk as it is quadratic in s — combining the individual investor’s date-1 liquidity risk and the aggregate date-1 liquidity risk. In contrast, the destabilizing effect through dealer balance sheets is linear in s — reflecting only the individual investor’s risk of facing the constrained dealers — and it increases faster due to the stronger effect of strategic sales on p_1^e than on p_0^e . For sufficiently high s , the destabilizing effect dominates, resulting in strategic complementarities.

Besides the slope $\pi'(\alpha)$, higher liquidity risk also increases the level of the incentive to sell. This is intuitive as, for given α , higher s means additional non-strategic sales as well as strategic sales at which load up dealer balance sheets at date 0 and destabilize the market. Consistent with the important role dealer balance sheets play for market fragility, they tend to increase the incentive to sell preemptively and do so for sure if strategic complementarities are present. In sum, the incentive to sell at date 0 and therefore the potential for market fragility is increasing in how much liquidity safety investors face and in the balance sheet constraints faced by dealers who absorb sales at both dates.

Figure 3 illustrates the incentive to sell and the resulting equilibria of the complete information game for different levels of liquidity risk. For low s , $\pi(\alpha)$ is uniformly negative and decreasing, and the unique equilibrium is the hold equilibrium ($\alpha^* = 0$). As s increases, the level and slope of $\pi(\alpha)$ increase, until it first becomes flat at $s = \tilde{s}$ and then intersects the horizontal axis, at which point the game has multiple equilibria (hold, sell

and mixed). For sufficiently high s , $\pi(\alpha)$ is uniformly positive and the unique equilibrium is for everyone to sell ($\alpha^* = 1$). Note that Figure 3 shows strategic complementarities arising at a point where the payoff gain is negative, that is

$$\pi(\alpha \mid s = \tilde{s}) = \frac{c}{2}\tilde{s}^2 - (1 - \tilde{s})(v - 1) < 0,$$

so the dashed horizontal line is below the horizontal axis. In the following, we will focus on this case by imposing the following assumption on c and v .

Assumption 1. *We assume that $\frac{c}{2}\tilde{s}^2 - (1 - \tilde{s})(v - 1) < 0$.*

Consistent with the comparative statics in Proposition 1, the point at which the payoff gain π changes from decreasing to increasing is more likely to be below the horizontal axis if v is larger or c is smaller. What happens if Assumption 1 is not satisfied? In that case, the unique equilibrium is still to hold for sufficiently small s and to sell for sufficiently large s . However, since the payoff gain crosses the horizontal axis with negative slope, the unique equilibrium is the mixed strategy equilibrium for an intermediate range of s , similar to the case of endogenous liquidity shocks from margin constraints in [Bernardo and Welch \(2004\)](#). Since our focus is on the potential for fragility, we focus the analysis on the case where multiple pure-strategy equilibria arise (Assumption 1).

4.3 Global Game and Unique Equilibrium

Under complete information, there can be multiple equilibria in the strategic interaction among liquidity investors — a hold equilibrium and a run equilibrium (and a mixed equilibrium). We now introduce noise into investors' payoffs to break the common knowledge underpinning the multiplicity and use global game techniques to derive a unique equilibrium. In particular, we assume that investor i does not observe the degree of liquidity risk s perfectly, instead receiving a signal $\hat{s}_i = s + \sigma_\varepsilon \varepsilon_i$ with ε_i i.i.d. across all i and σ_ε positive but arbitrarily small. As a result, a strategic investor faces fundamental uncertainty about the likelihood of a liquidity shock, s , as well as strategic uncertainty about the fraction of other strategic investors who sell preemptively, α .

We can write the payoff gain explicitly as a function of the fundamental s as well as the fraction of strategic investors who sell, $\pi(\alpha, s)$. Making use of standard global game results (e.g. [Morris and Shin, 2003](#)), we can derive a unique Bayesian Nash equilibrium for the game among strategic investors.

Proposition 2 (Unique global game equilibrium). *For signal noise $\sigma_\varepsilon \rightarrow 0$, the unique Bayesian Nash equilibrium among strategic investors is in switching strategies around a threshold s^* defined by*

$$\int_0^1 \pi(\alpha, s^*) d\alpha = 0.$$

For liquidity risk below the threshold, $s < s^$, all strategic investors hold on to their safe assets and the market is stable. For liquidity risk above the threshold, $s > s^*$, all strategic investors sell their safe assets and the market suffers a run.*

Proof. See Appendix B. □

While Appendix B contains the full proof, we provide the following outline for intuition. An investor who receives a signal exactly equal to the switching point has to be indifferent between holding and selling,

$$E[\pi(\alpha, s) \mid \hat{s}_i = s^*] = 0, \quad (8)$$

where the expectation is with respect to both α and s . Note from equation (7) that $\pi(\alpha, s)$ is linear in α and cubic in s . We have $E[s \mid \hat{s}_i = s^*] = s^*$, and, in the limit $\sigma_\varepsilon \rightarrow 0$, we have $E[s^2 \mid \hat{s}_i = s^*] \rightarrow (s^*)^2$ and $E[s^3 \mid \hat{s}_i = s^*] \rightarrow (s^*)^3$, so fundamental uncertainty vanishes, and strategic uncertainty in the form of the distribution of α becomes uniform on $[0, 1]$. We therefore have

$$\lim_{\sigma_\varepsilon \rightarrow 0} E[\pi(\alpha, s) \mid \hat{s}_i = s^*] = \int_0^1 \pi(\alpha, s^*) d\alpha,$$

where $\int_0^1 \pi(\alpha, s) d\alpha$ is a cubic polynomial in s . We show in the proof of Proposition 2 that $\frac{\partial}{\partial s} \int_0^1 \pi(\alpha, s) d\alpha > 0$ with $\int_0^1 \pi(\alpha, 0) d\alpha < 0$ and $\int_0^1 \pi(\alpha, 1) d\alpha > 0$ so there is a unique threshold s^* that satisfies the indifference condition $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$.

Since the equilibrium and related variables such as the equilibrium price p_0 switch discontinuously around s^* , the threshold is a measure of market stability and we can refer to a market with higher s^* as more stable.

Corollary 1. *Market stability as measured by the global game threshold s^* is decreasing in dealer balance sheet costs, $\partial s^* / \partial c < 0$ and increasing in liquidity investors' continuation value, $\partial s^* / \partial v > 0$.*

Proof. See Appendix B. □

Market stability naturally inherits the properties of the incentive to sell listed π in Proposition 1. Consider the effect of dealer balance sheet costs c on market stability s^*

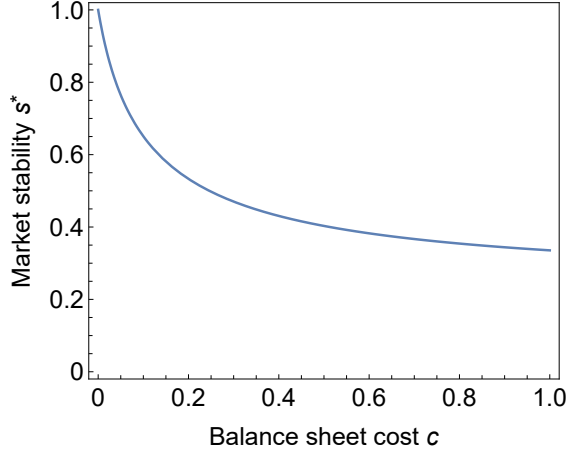


Figure 4: Effect of balance sheet costs on market stability. The figure shows market stability measured by the equilibrium threshold s^* as a function of the dealer balance sheet cost c with $v = 1.2$.

illustrated in Figure 4. If dealers faced no balance sheet costs ($c = 0$), the market would be perfectly stable ($s^* = 1$) and strategic investors would never sell preemptively, even for very high liquidity risk s . However, as balance sheet costs c increase from zero, market stability s^* decreases rapidly and then levels off at higher values of c .

The threshold equilibrium implies that the behavior of strategic liquidity investors and therefore the equilibrium price changes discontinuously around the threshold s^* . In particular, total supply at date 0 is s for $s < s^*$ and one for $s > s^*$ so the equilibrium price from equation (3) becomes

$$p_0^*(s) = \begin{cases} 1 - cs & \text{for } s < s^*, \\ 1 - c & \text{for } s > s^*. \end{cases} \quad (9)$$

Figure 5 illustrates the equilibrium price p_0^* . When liquidity risk is very low, all strategic investors hold on to their safe assets and only investors who receive a liquidity shock sell — the equilibrium price is therefore steadily decreasing in s , representing the sales of non-strategic investors. However, once liquidity risk crosses the threshold s^* , all strategic investors preemptively sell their safe assets — the market is flooded and the equilibrium price drops discontinuously. Figure 5 further illustrates the equilibrium price for two different levels of dealer balance sheet costs c . As balance sheet costs increase, the threshold s^* and therefore market stability decreases (Corollary 1). In addition, the drop in market prices at the discontinuity is much larger for higher balance sheet costs. This is due to the fact that the drop in equation (9) is given by $c(1 - s^*)$ where c and s^* interact multiplica-

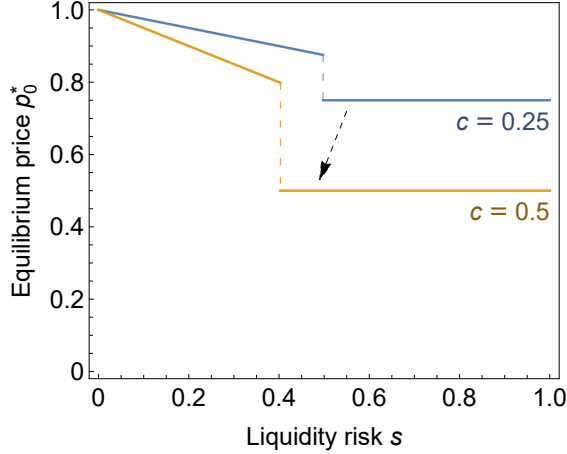


Figure 5: Effect of dealer balance sheet costs on equilibrium price. The figure shows the equilibrium price at date 0 p_0^* as a function of liquidity risk s for different values of dealer balance sheet cost c with $v = 1.2$.

tively.

4.4 Investor Welfare and Inefficient Runs

Because liquidity investors value the safe asset at $v > 1$ when held to maturity, selling the asset without a genuine liquidity need is generally inefficient. As a result, our model features panic-based run equilibria in which liquidity investors would be better off if they could coordinate to hold instead. However, the welfare-consequences of the hold and run equilibria are somewhat subtle because investors who would have suffered a liquidity shock at date 1 can be better off if they sell in a panic-based run equilibrium at date 0. Nonetheless, our model predicts that robustly the market will feature run equilibria at times when investors would be better off if all investors could coordinate to hold.

If all strategic investors sell at date 0, they (and the non-strategic investors) receive an expected payoff $p_0^e(\alpha = 1) = 1 - c/2$. Expected payoffs if all strategic investors hold are more complicated: investors with a liquidity shock at date 0 receive $p_0^e(\alpha = 0) = 1 - (c/2)s$; investors with a liquidity shock at date 1 receive $p_1^e(\alpha = 0) = 1 - 2cs - (c/2)s(1 - s)$; and investors that do not receive a liquidity shock at either date receive v . Altogether, the difference in investor welfare between the hold allocation and the run allocation is a function of liquidity risk s and given by

$$\Delta(s) \equiv s \left(1 - \frac{c}{2}s\right) + (1 - s) s \left(1 - 2cs - \frac{c}{2}s(1 - s)\right) + (1 - s)^2 v - \left(1 - \frac{c}{2}\right). \quad (10)$$

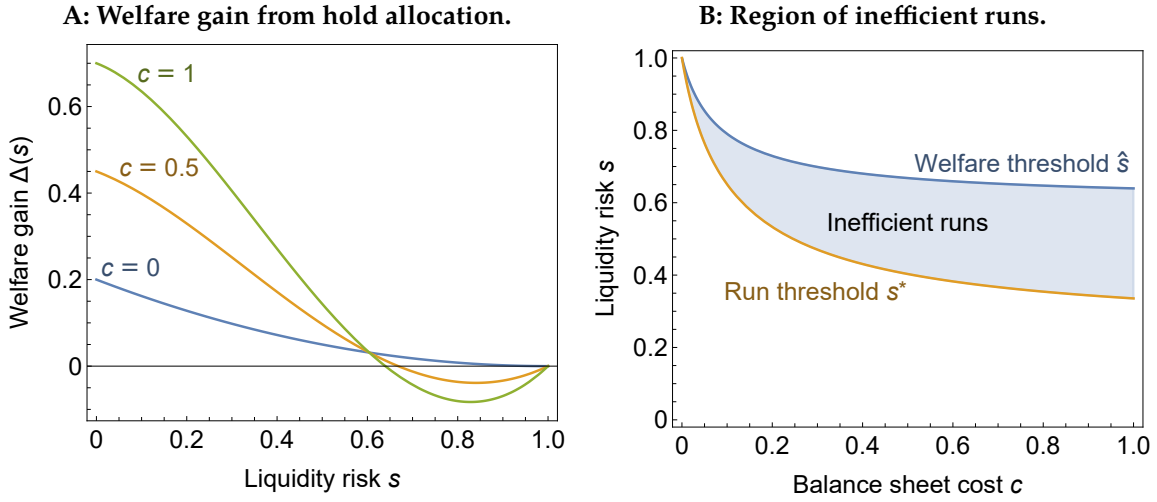


Figure 6: Investor welfare and inefficient runs. Panel A shows the difference in welfare between the hold and run allocations as a function of liquidity risk s for different values of dealer balance sheet cost c . Panel B shows the welfare threshold \hat{s} and the equilibrium threshold s^* as a function of dealer balance sheet cost c . The shaded region indicates the “panic region”: the values of liquidity risk s such that the global game features a run equilibrium but the hold equilibrium leads to higher welfare. Parameters: $v = 1.2$.

The first three terms are the payoffs in the hold allocation ($\alpha = 0$) and the last term is the payoff in the run allocation ($\alpha = 1$).

With no liquidity shocks we have $\Delta(0) = v - 1 + c/2 > 0$, which includes the elevated value of the asset plus the saved balance sheet cost. With guaranteed liquidity shocks we have $\Delta(1) = 0$ since all investors are forced to sell early — there is no one who could hold. However, $\Delta(s)$ is a polynomial of degree 4 and not necessarily strictly positive for $s \in [0, 1]$. Figure 6A plots $\Delta(s)$ for different values of the balance sheet cost c and illustrates that $\Delta(s)$ has a root $\hat{s} \in (0, 1)$ for $c > 0$ so there is a range of s near 1 where $\Delta(s) < 0$, i.e. where welfare is higher in the run allocation.

How can the run allocation welfare-dominate if liquidity investors value the safe asset at $v > 1$ and the price they sell at is strictly less than 1? The issue is precisely the main feature of our model: investors’ fear of being forced to liquidate at date 1 at depressed prices. In a hold allocation, a fraction $(1 - s)s$ of investors will be forced to sell at date 1, after a fraction s have already sold at date 0. We have already noted in Proposition 1 that for high s investors would prefer to sell early, guaranteeing p_0^e , even if the current price is depressed by strategic sales from other investors — and this is all the more so in a hold allocation with no strategic sales. Thus, with sufficient liquidity risk, agents are better off

selling early, when prices are high, rather than in the future, when dealers' balance sheets are bloated.

While the welfare difference $\Delta(s)$ compares the hold and run allocations, only one of the two is an equilibrium for any level of s : hold for s below the global game threshold s^* and sell for s above s^* . An important question therefore is whether our model features inefficient run equilibria, with investors selling strategically when the hold allocation would have yielded higher welfare. This amounts to determining whether the welfare difference $\Delta(s)$ is positive for s at or above the threshold s^* or equivalently, whether $s^* < \hat{s}$.

Proposition 3 (Inefficient Runs). *The model features inefficient run equilibria in which investors would be better off coordinating on the hold allocation. In particular, we have $s^* < \hat{s}$ and therefore $\Delta(s) > 0$ for $s \in (s^*, \hat{s})$.*

Proof. See Appendix B. □

Figure 6B illustrates the result. The figure plots the equilibrium threshold s^* and the welfare cutoff \hat{s} as functions of the dealer balance sheet cost c . The shaded region plots the “panic region”: the values of liquidity risk s in which the global game features a run equilibrium but the hold allocation would lead to higher welfare. Outside the shaded region, agents coordinate on the equilibrium that leads to highest welfare. Our results imply that there is scope for policy in order to shrink the inefficient (shaded) region by increasing s^* . By decreasing the frequency of the run equilibrium, policy could tilt outcomes in favor of higher welfare (the hold equilibrium) whenever liquidity risk is not too high.

5 Equilibrium with Safety Investors

We now introduce a second type of investors who are risk averse and hold a portfolio of the safe asset and the risky asset. These “safety investors” are subject to aggregate shocks to the expected payoff of the risky asset which lead them to shift their portfolio composition. We are interested in the situation where, in a bad state of the world, safety investors increase their holdings of the safe asset, potentially offsetting the flow of sales from liquidity investors.

Our modeling of safety investors is deliberately simple in order to integrate them into the model of strategic interaction among liquidity investors. In principle, safety investors could be active both at date 0 and at date 1. Additional safe asset demand at date 1 unambiguously increases the price at date 1 which reduces the incentive to sell preemptively and has a stabilizing effect on the strategic interaction at date 0. In contrast, additional

demand at date 0 increases both the price at date 0 as well as the price at date 1 — by reducing dealer inventory — with an ambiguous overall effect on market stability at date 0. We therefore restrict attention to the case where safety investors are active only at date 0. Appendix D discusses the general case.

5.1 Safety Investors' Safe Asset Demand

Safety investors' utility is linear in consumption at date 0 and quadratic in future wealth,

$$u(c_0, w) = c_0 + w - \frac{1}{2}\kappa w^2,$$

where the curvature parameter $\kappa > 0$ commingles risk aversion and intertemporal substitution and we assume $w < 1/\kappa$. In addition to the safe asset with future payoff 1, there is a risky asset with future payoff z distributed according to H_z where we denote the expected payoff as $\mu_z = \int z dH_z(z)$ and the variance as $\sigma_z^2 = \int z^2 dH_z(z) - \mu_z^2$.

Given initial wealth w_0 , safety investors choose consumption c_0 and a portfolio with holdings q_0^S of the safe asset and q_z of the risky asset subject to the budget constraint $c_0 + p_0 q_0^S + p_z q_z \leq w_0$ to maximize $E[u(c_0, w)]$ where future wealth is given by $w = q_0 + zq_z$. After substituting in for c_0 using the budget constraint, we have first-order conditions for q_0 and q_z given by

$$\begin{aligned} 0 &= E[1 - \kappa(q_0 + zq_z)] - p_0 \\ &= 1 - \kappa(q_0 + zq_z) - p_0, \end{aligned}$$

and

$$\begin{aligned} 0 &= E[z - \kappa(q_0 + zq_z)z] - p_z \\ &= \mu_z - \kappa(\mu_z q_0 + (\mu_z^2 + \sigma_z^2)q_z) - p_z, \end{aligned}$$

which are both linear in q_0 and q_z . Solving, we arrive at safety investors' demand for the safe asset and the risky asset given by

$$\begin{aligned} q_0 &= \frac{1}{\kappa\sigma_z^2} \left(\sigma_z^2 + \mu_z p_z - (\mu_z^2 + \sigma_z^2) p_0 \right) \\ q_z &= \frac{1}{\kappa\sigma_z^2} (\mu_z p_0 - p_z), \end{aligned}$$

while their consumption at date 0 is given as the residual $c_0 = w_0 - (p_z q_z + p_0 q_0)$.

To close the model, we assume that safety investors have to hold the entire supply $Z > 0$ of the risky asset, i.e. $q_z = Z$. In this case, the risky asset price is $p_z = \mu_z p_0 - \kappa \sigma_z^2 Z$ and, substituting in, safety investors' demand for the safe asset simplifies to

$$q_0^S = \frac{1}{\kappa} (1 - \kappa \mu_z Z - p_0), \quad (11)$$

which is linear in p_0 and has a similar structure to dealers' demand in equation (1). For ease of exposition, we write safety investors' demand as

$$q_0^S = a - b p_0,$$

with $a = 1/\kappa - \mu_z Z$ and $b = 1/\kappa$. We are interested in shocks to the risky asset's expected payoff μ_z which enter safety investors' safe asset demand only through the intercept a . A decrease in μ_z then is equivalent to an increase in a .

5.2 Effect of Safety Investors on Market Stability

Combining the demand from dealers, $q_0^D = \frac{1}{c} (1 - p_0)$, with the demand from safety investors, $q_0^S = a - b p_0$, total demand for safe assets at date 0 can be written as

$$p_0(q_0) = \frac{1 + ac}{1 + bc} - \frac{c}{1 + bc} q_0. \quad (12)$$

With total supply of $x_0 = s + (1 - s) \alpha$, a liquidity investor who sells at date 0 expects to receive

$$p_0^e(\alpha) = \frac{1 + ac}{1 + bc} - \frac{1}{2} \frac{c}{1 + bc} (s + (1 - s) \alpha).$$

An increase in the additional demand from safety investors (higher a) uniformly increases the expected price.

At date 1, only dealers demand the safe asset so demand is unchanged from equation (5) in Section 4. However, dealer inventory is no longer the entire date-0 supply x_0 as some of these sales have been absorbed by safety investors rebalancing their portfolios. Specifically, dealer inventory is given by

$$q_0^D = \frac{1}{c} (1 - p_0(x_0)) = \frac{\frac{1}{c} x_0 - \frac{b}{c} (1 - \frac{a}{b})}{\frac{1}{c} + b},$$

while safety investors absorb

$$q_0^S = b \left(\frac{a}{b} - p_0(x_0) \right) = \frac{bx_0 + \frac{b}{c} \left(1 - \frac{a}{b}\right)}{\frac{1}{c} + b}.$$

Comparing the expressions for q_0^D and q_0^S , we see that total supply x_0 is split among dealers and safety investors, first, proportional to their respective price sensitivities $1/c$ and b and, second, based on the difference in their respective baseline valuations of 1 and a/b .

Combining dealer demand at date 1 from equation (5) with inventory q_0^D and date-1 supply $x_1 = s(1-s)(1-\alpha)$, a liquidity investor who sells at date 1 expects to receive

$$p_1^e(\alpha) = 1 - 2c \underbrace{\frac{s + (1-s)\alpha + b - a}{1 + bc}}_{\text{date-0 inventory}} - \frac{c}{2} \underbrace{s(1-s)(1-\alpha)}_{\text{date-1 sales}}.$$

As in the case without safety investors in Section 4, strategic sales α at date 0 have both a direct positive effect on the expected price at date 1 — by reducing the mass of liquidity investors left at date 1 who can suffer a liquidity shock and sell — as well as an indirect negative effect through dealer inventory.

Our focus now is how changes in additional sales a affect the two expected prices and the strategic interaction of liquidity investors captured by the payoff gain:

$$\begin{aligned} \pi(\alpha, s) = & \overbrace{\frac{1+ac}{1+bc} - \frac{1}{2} \frac{c}{1+bc} (s + (1-s)\alpha)}^{p_0^e(\alpha)} \\ & - s \underbrace{\left(1 - 2c \frac{s + (1-s)\alpha + b - a}{1 + bc} - \frac{c}{2} s(1-s)(1-\alpha) \right)}_{p_1^e(\alpha)} - (1-s)v. \end{aligned}$$

The question is if (or when) additional demand from safety investors is stabilizing, i.e. decreases π .

Proposition 4. *Additional demand at date 0 decreases the incentive to sell preemptively if and only if liquidity risk is sufficiently high, $d\pi/da < 0 \Leftrightarrow s > 1/2$. The effect of additional demand is monotonic in liquidity risk, $d^2\pi/(dsda) < 0$.*

Proof. See Appendix B. □

Where does the ambiguous effect of a on π originate? Similar to strategic sales by liquidity investors, demand from safety investors has a direct effect and an indirect effect on

the payoff gain π . The direct effect of an increase in demand a is an increase in the date-0 price p_0^e and therefore an increase in the payoff gain π with a coefficient

$$\frac{c}{1 + bc}.$$

This effect is destabilizing since a higher price at date 0 incentivizes strategic investors to sell preemptively.

The indirect effect works through relaxing dealer balance sheet constraints which increases the date-1 price p_1^e and therefore reduces the payoff gain π with a coefficient (in absolute value)

$$s \frac{2c}{1 + bc}.$$

This stabilizing effect on p_1^e is twice as high as the destabilizing effect on p_0^e because of the larger effect of existing date-0 inventory on dealer demand than of new date-1 inventory. However, the effect on p_1^e is discounted by the liquidity shock probability s since it is only relevant if the investor actually suffers a liquidity shock at date 1. For the stabilizing effect to dominate, such that additional demand from safety investors increases market stability, liquidity risk has to be sufficiently high, i.e. greater than $1/2$.

The payoff gain with safety investor demand retains the standard global game conditions of [Morris and Shin \(2003\)](#) so, for vanishing signal noise, the unique equilibrium remains in switching strategies around a threshold s^* defined by the indifference condition $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$. In particular, recall that π is increasing in s so an exogenous decrease in π leads to a higher threshold s^* , capturing higher market stability. The ambiguous effect of safety investor demand on the payoff gain π ([Proposition 4](#)) therefore translate into an analogous effect on market stability.

Corollary 2. *Additional demand at date 0 is stabilizing if the market is relatively stable and destabilizing if the market is relatively unstable, $ds^*/da > 0 \Leftrightarrow s^* > 1/2$.*

Proof. See [Appendix B](#). □

[Figure 7](#) illustrates the ambiguous effect of safety investor demand on market stability by plotting the equilibrium run threshold s^* as a function of a for different levels of the dealer balance sheet cost c . When balance sheet costs are low, the market is relatively stable: the threshold s^* where the price drops discontinuously is above $1/2$. In this case, the run threshold is increasing in safety demand a , so that runs become less likely as safety demand increases. When balance sheet costs are high, the market is relatively unstable with the threshold s^* below $1/2$. In this case the run threshold is decreasing in a so higher

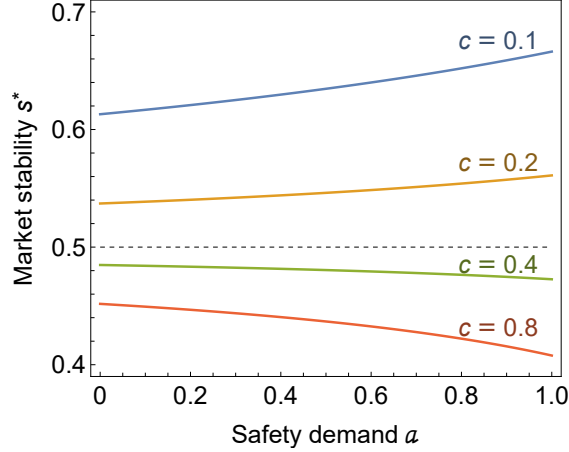


Figure 7: Effect of safety investor demand on equilibrium market stability. The figure shows market stability measured by the equilibrium threshold s^* as a function of safety investor demand a for different levels of dealer balance sheet cost c . Parameters: $v = 1.2$, $b = 1$.

safety demand is destabilizing — the market is “fragile”: For a given level of liquidity risk that is close to but below the run threshold, an increase in demand for the safe asset can reduce the threshold sufficiently to tilt the market into a run equilibrium.

The interaction of liquidity investors and safety investors therefore results in a feedback effect in market stability. If the market is resilient to begin with then liquidity investors and safety investors interact symbiotically: In times of stress, the additional demand for safe assets from safety investors has a stabilizing effect on the strategic interaction of liquidity investors and attenuates the risk of market breakdown. However, if the market is fundamentally fragile, e.g. due to an increase in dealer balance sheet costs, the relationship reverses: Additional demand from safety investors in times of stress further destabilizes the strategic interaction of liquidity investors, increasing their incentive to sell preemptively and thereby increasing the risk of market breakdown.

5.3 Correlated Liquidity and Safety Shocks

We consider the risks faced by liquidity investors and safety investors to be correlated. In times of stress, liquidity investors face a higher risk of suffering a liquidity shock, i.e. s is high, and safety investors face a low payoff of the risky asset, i.e. μ_z is low and therefore a is high. To understand the net effect of increases in s and a on the safe asset market, we can derive the equilibrium price at date 0 as a function of s and a . As before, total supply in the global game equilibrium is s for $s < s^*$ (all strategic investors hold) and 1 for $s > s^*$ (all strategic investors sell). Substituting into the price with demand from safety investors

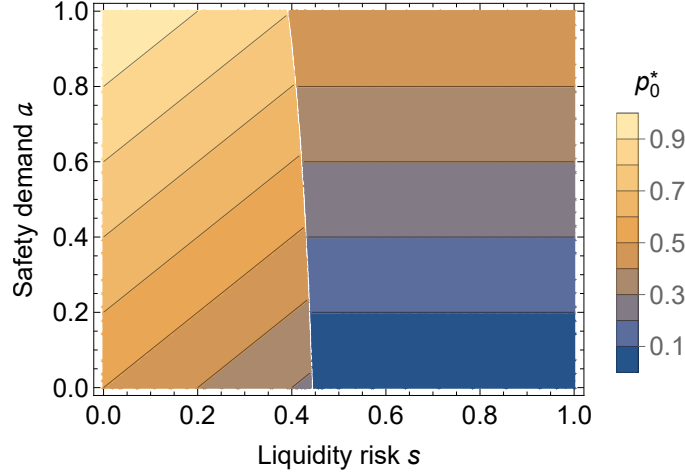


Figure 8: Equilibrium price for combinations of liquidity and safety shocks. The figure shows a contour plot of the equilibrium price p_0^* as a function of liquidity risk s and safety demand a . Parameters: $v = 1.2$, $b = 1$, $c = 1$.

in equation (12), the equilibrium price becomes

$$p_0^*(s, a) = \begin{cases} \frac{1}{1+bc} (1 - c(s - a)) & \text{for } s < s^*(a), \\ \frac{1}{1+bc} (1 - c(1 - a)) & \text{for } s > s^*(a). \end{cases} \quad (13)$$

Figure 8 illustrates the equilibrium price for combinations of s and a with a contour plot. The figure plots a case where the market is relatively fragile: The threshold s^* is always below $1/2$ so the cliff where the price drops as the equilibrium switches from hold to run is decreasing in (s, a) -space: for liquidity risk s close to s^* , an increase in safety investor demand a can push the market over the cliff and trigger a price crash. In the hold equilibrium, i.e. for $s < s^*$, the expression in equation (13) shows that equal-sized increases in s and a exactly offset each other and leave the price unchanged so the contour lines in Figure 8 have a slope of one. This implies that whenever safety demand a increases more than 1:1 with liquidity risk s and liquidity risk remains below the threshold s^* , we observe a classic flight to safety with p_0^* increasing, i.e. safe assets appreciating. This corresponds to the period from mid-February to early March 2020 where stock prices decreased and Treasury prices increased (Figure 1, Panel A). However, if the balance shifts and the increase in liquidity risk s outweighs the increase in safety demand a , the price p_0^* can decrease and suddenly drop as s crosses the threshold s^* and the equilibrium shifts to a dash for cash. This corresponds to the period in mid-March 2020 where Treasury prices reverse their increase and drop together with stock prices.

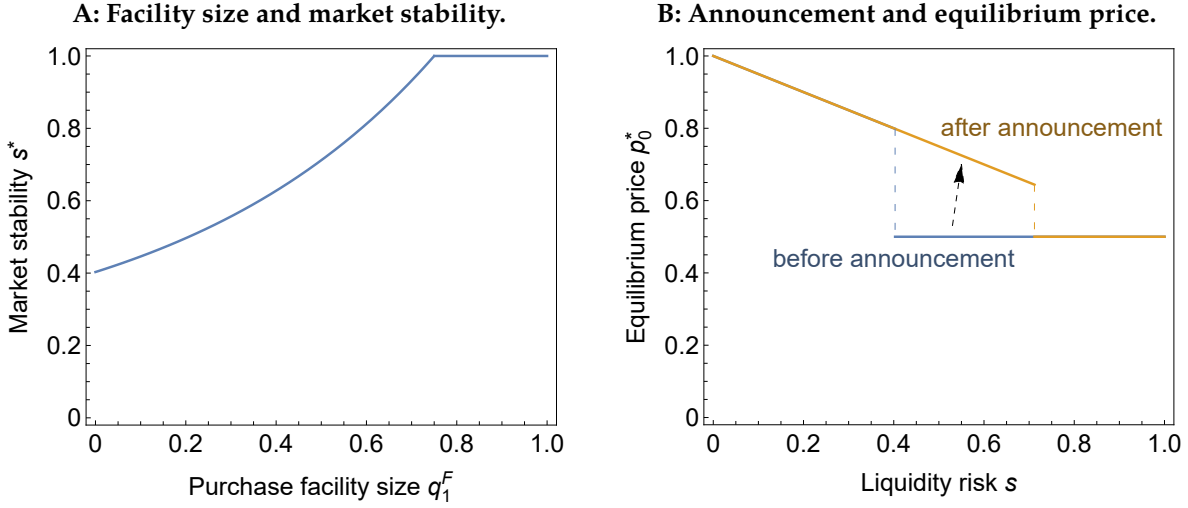


Figure 9: Effects of date-1 purchase facility announced at date 0. Panel A shows the effect of the facility size q_1^F on date-0 market stability as measured by the equilibrium threshold s^* . Panel B shows the effect of the announcement of a facility with $q_1^F = 0.5$ on the equilibrium price at date 0. Parameters: $v = 1.2$, $c = 0.5$.

6 Policy Implications

We consider several policy implications that follow from our model, focusing on asset purchase facilities, dealer balance sheet costs, and market structure.

Asset Purchase Facilities. Suppose the policy maker announces at date 0 an asset purchase facility that will purchase a quantity q_1^F of the safe asset at date 1. This leaves demand at date 0 unchanged but adds to dealer demand at date 1, such that the payoff gain becomes

$$\begin{aligned} \pi(\alpha) = & 1 - \frac{c}{2} (s + (1-s)\alpha) \\ & - s \underbrace{\left(cq_1^F + 1 - 2c(s + (1-s)\alpha) - \frac{c}{2}s(1-s)(1-\alpha) \right)}_{p_1^e \text{ affected by } q_1^F} - (1-s)v. \end{aligned}$$

The payoff gain is uniformly decreasing in the size of the facility q_1^F and this stabilizing effect, given by $\partial\pi/\partial q_1^F = -sc$, is larger (in absolute value) for both higher degrees of liquidity risk s and higher dealer balance sheet costs c . Figure 9 illustrates the effects of the purchase facility. Panel A shows the effect of the facility size q_1^F on market stability at date 0 as measured by the equilibrium threshold s^* . Consistent with the stabilizing effect of q_1^F being increasing in liquidity risk s , we see that market stability is increasing and

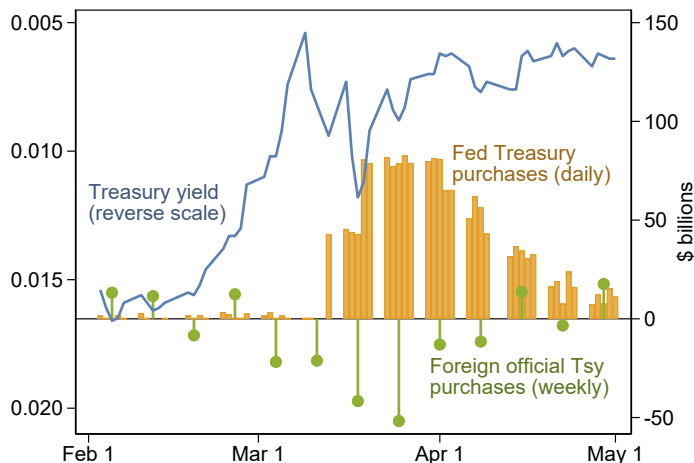


Figure 10: Federal Reserve purchases and foreign official sales of Treasuries. The figure shows the market yield on 10-year Treasuries as well as Federal Reserve Treasury purchases and foreign official agencies’ net Treasury purchases inferred from changes in custody holdings. For details on the data see Appendix A.

convex in q_1^F until s^* reaches one and the market is perfectly stable. Panel B of Figure 9 shows the announcement effect of a facility on the date-0 price p_0^* . Upon announcement, the equilibrium threshold s^* increases from the value without a facility, s_{pre}^* , to the value with a facility, $s_{post}^* > s_{pre}^*$. For intermediate levels of liquidity risk, $s \in [s_{pre}^*, s_{post}^*]$, the announcement leads to a switch from the run equilibrium to the hold equilibrium and therefore a discrete jump in the date-0 price as indicated by the arrow in the figure.

Our theoretical results in this simple two-period model suggest that what matters for stabilizing a fragile market is the announcement more than the purchases directly. However, this result should be interpreted with some care especially when there is little time between the announcement and execution of purchases as was the case for the Treasury market in March 2020 (Vissing-Jørgensen, 2021). In this case, the purchases can be interpreted as falling into period 0 or into period 1 with potentially opposite effects as official sector purchases in period 0 can be destabilizing and trigger strategic sales in the same way that purchases from safety investors can (Section 5).

Figure 10 shows purchases of Treasuries by the Federal Reserve (Fed) as well as net purchases of foreign official agencies, among the largest sellers of Treasuries in 2020q1 (Figure 1, Panel C). In early March, foreign net purchases started turning moderately negative for two weeks just as Treasury prices peaked, consistent with only non-strategic sales from investors with genuine liquidity needs. Then prices dropped and foreign sales accelerated as the Fed started purchasing Treasuries, consistent with switching to the run equi-

librium where strategic investors without genuine liquidity needs preemptively sell and potentially amplified by the initially moderate Fed purchases. Only after the Fed roughly doubled its daily purchases on March 19 and committed to maintaining them as long as necessary on March 23 did prices recover and foreign sales subside.⁴ This is consistent with switching back to the hold equilibrium once investors were confident that they would not face worse prices in case they suffer a liquidity shock in the future.

The corporate bond market provides a clean illustration of the announcement effects implied by our model. While corporate bonds are not considered as safe (or liquid) as Treasuries, highly rated ones are on a spectrum of relative safety slightly below agency MBS (He and Song, 2022) and also feature flight to safety (Baele et al., 2019). Haddad, Moreira, and Muir (2021) document that, in March 2020, prices of corporate bonds suffered a crash similar to that in Treasuries. Surprisingly, the dislocations *worse* for bonds considered safer which is consistent with safe asset fragility as shown in our model. Further, Haddad, Moreira, and Muir (2021) show in detail that the Fed's purchase facilities for corporate bonds had large positive effect on prices *at the time they were announced* in March even though purchases would not start until June (see also Boyarchenko, Kovner, and Shachar, 2022).

Dealer Balance Sheet Costs. Dealer balance sheet costs play a crucial role in the strategic interaction of liquidity investors since dealer inventory is the key link between the price at date 0 and the price at date 1. Considering just the interaction of liquidity investors, higher dealer balance sheet costs result in a more fragile safe asset market, i.e. a market that is more prone to runs and sudden price crashes (Figure 5). Also taking into account the effect of additional demand from safety investors, an increase in dealer balance sheet cost can tip the market from a stable regime where risk agents have a stabilizing effect to a fragile regime where risk agents have a destabilizing effect (Figure 7). However, a policy that aims to relax dealer balance sheet constraints in times of stress has to be designed with care due to the subtleties of the strategic interaction. For example, if the policy relaxes dealer constraints only at date 0 (or relatively more at date 0) then it can increase the incentive to sell preemptively at date 0. If the market is in a run equilibrium, such a policy will appear to not have an effect and if it is in the hold equilibrium then a short-run relaxation of constraints can precipitate a run. In addition, policy has to target the constrain that is

⁴The statement by the Fed's Federal Open Market Committee (FOMC) on March 23 reads "The Federal Reserve will continue to purchase Treasury securities and agency mortgage-backed securities in the amounts needed to support smooth market functioning and effective transmission of monetary policy to broader financial conditions." Available at <https://www.federalreserve.gov/newsevents/pressreleases/monetary20200323a.htm>.

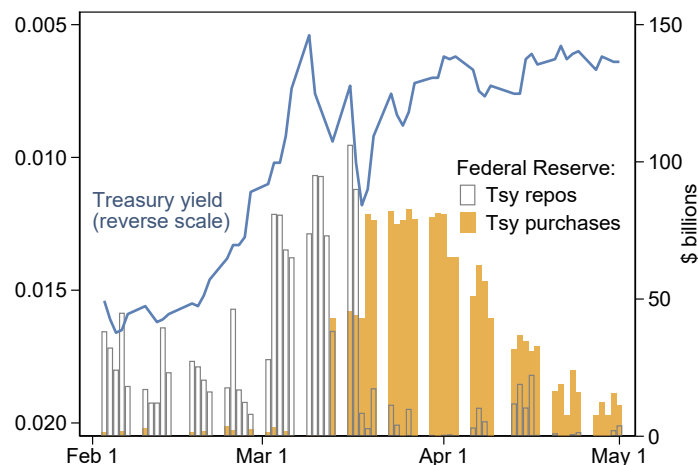


Figure 11: Federal Reserve interventions in Treasury markets. The figure shows the market yield on 10-year Treasuries and two types of Federal Reserve interventions: Treasury repos (lending against Treasury securities) and outright Treasury purchases. For details on the data see Appendix A.

actually binding.

Figure 11 illustrates these subtleties with the sequence of Fed interventions aimed at the Treasury market in the spring of 2020. Going into March, the Fed was conducting limited Treasury repo operations (lending against Treasuries) as part of its regular monetary policy implementation and was actually shrinking the offering size of these operations.⁵ As conditions deteriorated starting March 9, repo offering sizes were increased to over \$1 trillion by March 12 but, as shown in Figure 11, take-up by dealers was only moderate at around \$100 billion and the liquidity provision through repos was not effective against the drop in Treasury prices. This is consistent with the SLR being the binding constraint on dealers as the SLR is not relaxed by funding a Treasury position with a loan from the Fed (Duffie, 2020). Figure 11 shows that the recovery in Treasury prices in mid-March coincided with a switch by the Fed from lending against Treasuries to purchasing them outright and that the Fed was able to scale back purchases once Treasuries were exempted from the SLR on April 1.

This sequence of events is consistent with our model’s predictions on the effects of policy relieving current and future balance sheet constraints. Assets had to be purchased to

⁵On February 4 the New York Fed’s Open Market Trading Desk decreased term repo operation offering size from \$35 billion to \$30 billion and again on February 13 from \$30 billion to \$25 billion, concurrent with a reduction in overnight repo from \$120 billion to \$100 billion, as reported in the New York Fed’s report “Open Market Operations during 2020” available at <https://www.newyorkfed.org/medialibrary/media/markets/omo/omo2020-pdf.pdf>.

effectively relax the binding constraint and, to ensure that dealer balance sheets remained unconstrained going forward, purchases had to be sufficiently sustained and Treasuries had to be exempted from the SLR.

Market Structure. Our framework generates market fragility through a combination of two factors since a strategic investor (i) expects to receive the average in-run price when selling preemptively at date 0 but (ii) bears the full impact of dealer inventory from date 0 when being forced to sell at date 1. Both of these factors are inherently tied to the structure of the safe asset markets where trading occurs in a decentralized, sequential way and dealers play a large role intermediating flow imbalances over time. Changes to market structure that lead to more pooling of trades and that reduce the role of dealers as a bottleneck for flow can therefore reduce the fragility of safe asset markets (Duffie, 2020).

As already noted, these issues are almost surely only going to get worse over time as the federal deficit grows and Treasury supply increases. So long as dealers' balance sheet capacity grows more slowly than the stock of Treasuries, the market will have insufficient ability to intermediate trades (Duffie, 2020). Our model implies that this will exacerbate preemptive selling and increase the frequency of dash for cash episodes.

7 Conclusion

We focus on three key features of safe asset markets: investors who value the assets' safety, investors who value the assets' liquidity, and dealers who face balance sheet constraints. Combining these features, we show that safe asset markets are fragile, susceptible to sudden price crashes due to coordination effects among the investors valuing liquidity that are amplified by the investors valuing safety.

Our model helps understand the unprecedented events in the U.S. Treasury market at the onset of the Covid-19 pandemic in March 2020 as a "perfect storm" of the three features: First, financial regulation in the wake of the financial crisis of 2007–2009 had significantly tightened dealer balance sheet constraints, increasing the inherent fragility of the market. Second, the pandemic threatened a global economic slowdown leading to a powerful flight-to-safety demand, further destabilizing the market. Third, lockdowns created unprecedented liquidity needs among consumers and official agencies. The result according to our model was a market run that featured indiscriminate sales by liquidity investors, including those without genuine liquidity needs who feared having to sell at even worse conditions in the future.

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Appendix

A Data

Treasury yield: The market yield on U.S. Treasury securities at 10-year constant maturity, daily frequency, from the Federal Reserve’s H.15 via FRED series DGS10.

S&P 500: The S&P 500 index, daily frequency, from Standard & Poors via FRED series SP500.

Fed holdings of Treasuries: Federal Reserve outright holdings of Treasury notes and bonds (both nominal and TIPS), weekly frequency as of Wednesday, from the Federal Reserve’s H.4.1 via FRED series WSHONBNL and WSHONBILL.

Dealer net positions of Treasuries: Primary Dealers’ net position in Treasuries (both nominal and TIPS) from the New York Fed’s Primary Dealer statistics available at <https://www.newyorkfed.org/markets/counterparties/primary-dealers-statistics>.

Dealer reverse repo against Treasuries: Primary Dealers’ gross reverse repurchase agreements against Treasuries (both nominal and TIPS) from the New York Fed’s Primary Dealer statistics available at <https://www.newyorkfed.org/markets/counterparties/primary-dealers-statistics>.

Net purchases of Treasuries: Net purchases of Treasuries (all types), quarterly frequency (not seasonally adjusted), from the Federal Reserve’s Financial Accounts Table FU.210 available in the CSV files at <https://www.federalreserve.gov/releases/z1>. The label “foreign investors” refers to the sector “rest of the world” in the original table.

Fed Treasury Purchases: Federal Reserve Treasury purchases (all types), daily frequency, from the New York Fed’s Treasury securities operations, available at <https://www.newyorkfed.org/markets/desk-operations/treasury-securities>.

Foreign Official Treasury Purchases: Net Treasury purchases inferred from changes in Treasury securities held in custody for foreign officials and international accounts, weekly frequency as of Wednesday, from the Federal Reserve’s H.4.1 via FRED series WMTSECL1.

Fed Treasury Repos: Federal Reserve Treasury repurchase agreements (overnight and term) in temporary open market operations, daily frequency, from the New York Fed via FRED series RPTSXD.

B Proofs

Proof of Proposition 1. We can rewrite the payoff gain $\pi(\alpha)$ as

$$\pi(\alpha) = \frac{c}{2}s^2 + \frac{c}{2}s(s(4-s) - 1) - (1-s)(v-1) + \frac{c}{2}(1-s)(s(4-s) - 1)\alpha,$$

and differentiate with respect to α to get

$$\pi'(\alpha) = \frac{c}{2}(1-s)(s(4-s) - 1),$$

with $c > 0, s \in (0, 1), v > 1$, and $\alpha \in [0, 1]$, which imply the following comparative statics:

- We have $\pi'(\alpha) > 0$ if and only if $s(4-s) - 1 > 0$ which has one root in the unit interval given by $\tilde{s} \equiv 2 - \sqrt{3}$.
- Differentiating π with respect to s , we have

$$\frac{\partial \pi}{\partial s} = \frac{3c}{2} \left(\frac{10}{3} - s \right) (1-\alpha)s + \frac{c}{2}(5\alpha - 1) + v - 1,$$

which is positive.

- Differentiating π with respect to c , we have

$$\frac{\partial \pi}{\partial c} = \frac{1}{2}s^2 + \frac{1}{2}(s(4-s) - 1)(s + (1-s)\alpha),$$

which is positive if $s(4-s) - 1 > 0$.

- Differentiating π with respect to v , we have

$$\frac{\partial \pi}{\partial v} = -(1-s) < 0$$

which is negative. □

Proof of Proposition 2. In order to apply the standard global game result that there is a unique equilibrium and that it is in switching strategies, we have to show that the payoff gain $\pi(\alpha, s)$ satisfies certain properties (Morris and Shin, 2003). Proposition 1 establishes State Monotonicity and Action Monotonicity, that is $\pi(\alpha, s)$ is increasing in s and increasing in α for $s > \tilde{s}$ which is satisfied if there are multiple equilibria of the complete-information game. The payoff gain satisfies Strict Laplacian State Monotonicity since we

have

$$\int_0^1 \pi(\alpha, s) d\alpha = \frac{c}{2}s^2 + \frac{c}{2}s(s(4-s) - 1) - (1-s)(v-1) + \frac{c}{4}(1-s)(s(4-s) - 1), \quad (14)$$

which satisfies

$$\int_0^1 \pi(\alpha, 0) d\alpha = -(v-1) - \frac{c}{4} < 0,$$

and

$$\int_0^1 \pi(\alpha, 1) d\alpha = \frac{3c}{2} > 0,$$

as well as

$$\frac{\partial}{\partial s} \int_0^1 \pi(\alpha, s) d\alpha = cs + \frac{c}{4}((s(4-s) - 1) + (1+s)(4-2s)) + (v-1) > 0,$$

for $s > \tilde{s}$ and therefore a unique $s^* \in (\tilde{s}, 1)$ solves $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$. Finally, $\pi(\alpha, s)$ satisfies Uniform Limit Dominance since we have

$$\pi(\alpha, 0) = -(v-1) - \frac{c}{2}\alpha < 0,$$

and

$$\pi(\alpha, 1) = \frac{3c}{2} > 0.$$

Under these properties, [Morris and Shin \(2003\)](#) show that, in the limit $\sigma_\varepsilon \rightarrow 0$, the global game has a unique equilibrium and that the equilibrium is in switching strategies around a threshold s^* defined by the indifference condition $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$ where distribution of α conditional on signal $\hat{s}_i = s^*$ is uniform on $[0, 1]$. \square

Proof of Corollary 1. Implicit differentiation of the equilibrium condition $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$ using (14) yields

$$\frac{ds^*}{dc} = -\frac{\frac{1}{2}(s^*)^2 + \frac{1}{2}s^*(s^*(4-s^*) - 1) + \frac{1}{4}(1-s^*)(s^*(4-s^*) - 1)}{cs^* + \frac{c}{4}((s^*(4-s^*) - 1) + (1+s^*)(4-2s^*)) + (v-1)} < 0$$

and

$$\frac{ds^*}{dv} = \frac{1-s^*}{cs^* + \frac{c}{4}((s^*(4-s^*) - 1) + (1+s^*)(4-2s^*)) + (v-1)} > 0$$

as stated in the corollary. \square

Proof of Proposition 3 First, the equilibrium threshold s^* satisfies $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$. We can rewrite equation (14) as

$$\int_0^1 \pi(\alpha, s) d\alpha = \frac{c}{4} \left(-s^3 + 5s^2 + 3s - 1 \right) - (1-s)(v-1). \quad (15)$$

Second, we can rewrite the difference between welfare in the hold and run allocation in equation (10) as

$$\Delta(s) = (1-s) \left(\frac{c}{2} \left(s^3 - 5s^2 + s + 1 \right) + (1-s)(v-1) \right), \quad (16)$$

which satisfies $\Delta(0) > 0$ and $\Delta(1) = 0$, and has one root in $(0, 1)$ for $c > 0$ which we denote \hat{s} .

We want to show that $\Delta(s^*) > 0$, which means that $s^* < \hat{s}$ and therefore the hold allocation is better than the run allocation and yet investors play the run equilibrium in the global game for $s \in (s^*, \hat{s})$. From equation (15), the equilibrium threshold s^* satisfies (writing s without the star for simplicity)

$$\frac{c}{4} \left(-s^3 + 5s^2 + 3s - 1 \right) = (1-s)(v-1).$$

Substituting this into (16), we can calculate $\Delta(s^*)$ and we have (writing s without the star for simplicity)

$$\begin{aligned} \Delta(s^*) &\propto (1-s) \left(\frac{c}{2} \left(s^3 - 5s^2 + s + 1 \right) + \frac{c}{4} \left(-s^3 + 5s^2 + 3s - 1 \right) \right), \\ &\propto s^3 - 5s^2 + 5s + 1, \\ &= (1-s) \left(-s^2 + 4s - 1 \right) + 2. \end{aligned}$$

The first term has one root in $(0, 1)$ given by $2 - \sqrt{3} \equiv \tilde{s}$ and is strictly positive for $s \in (\tilde{s}, 1)$. We have $s^* > \tilde{s}$ from the proof of Proposition 2 and thus $\Delta(s^*) > 0$ and therefore $\Delta(s) > 0$ for all $s \in (s^*, \hat{s})$. Thus, we have an inefficient region. \square

Proof of Proposition 4. We can rewrite the payoff gain with additional demand as

$$\pi(\alpha) = \frac{c}{2}s^2 + \frac{c(a-b)}{1+bc} (1-2s) - (1-s)(v-1) + \frac{c}{2} \left(\frac{1}{1+bc} (4s-1) - s^2 \right) (s + (1-s)\alpha),$$

and differentiate with respect to a to obtain

$$\frac{d\pi}{da} = \frac{c}{1+bc} (1-2s),$$

and

$$\frac{d^2\pi}{dsda} = -\frac{2c}{1+bc}.$$

We therefore have $d\pi/da > 0$ if and only if $s < 1/2$ as well as $d^2\pi/(dsda) < 0$. \square

Proof of Corollary 2. The global game threshold is defined by $\int_0^1 \pi(\alpha, s^*) d\alpha = 0$ and implicit differentiation yields

$$\frac{ds^*}{da} = -\frac{\int_0^1 \frac{d}{da} \pi(\alpha, s^*) d\alpha}{\int_0^1 \frac{d}{ds^*} \pi(\alpha, s^*) d\alpha},$$

and therefore $ds^*/da > 0$ if and only if $s^* > 1/2$. \square

C Pooled Trade Execution and Cubic Balance Sheet Costs

Suppose that instead of the quadratic balance sheet costs of the main text, we consider cubic balance sheet costs cq^3 . At date 0, the price p_0 at which dealers take on inventory q_0^D is given by the indifference condition

$$(1-p_0)q_0^D - c(q_0^D)^3 = 0,$$

which implies a demand given by

$$p_0(q_0) = 1 - c(q_0)^2.$$

With inventory q_0^D the indifference condition at date 1 is given by

$$(1-p_0)q_0^D + (1-p_1)q_1^D - c(q_0^D + q_1^D)^3 = (1-p_0)q_0^D - c(q_0^D)^3.$$

which results in demand

$$p_1(q_0^D, q_1) = 1 - c(3(q_0^D)^2 + 3q_0^D q_1 + (q_1)^2).$$

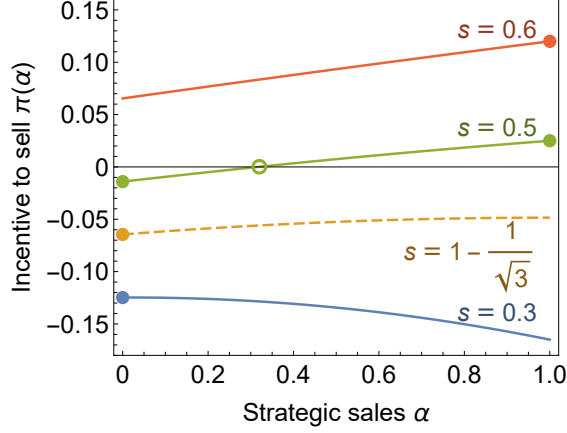


Figure 12: Pooled trade execution and cubic balance sheet costs. The figure shows the payoff gain $\pi(\alpha)$ for different values of liquidity risk s . Circles indicate equilibria of the game under complete information. Parameters: $v = 1.2$, $c = 0.25$.

With pooled trade execution, the expected price does not have the factor $1/2$ of the average in-run price of the main text. Substituting in date-0 supply $x_0 = s + (1 - s)\alpha$ and date-1 supply $x_1 = s(1 - s)(1 - \alpha)$, we have expected prices

$$p_0^e(\alpha) = 1 - c(s + (1 - s)\alpha)^2$$

$$p_1^e(\alpha) = 1 - c\left(3(s + (1 - s)\alpha)^2 + 3(s + (1 - s)\alpha)(s(1 - s)(1 - \alpha)) + (s(1 - s)(1 - \alpha))^2\right).$$

The payoff gain then is, as before

$$\pi(\alpha) = p_0^e(\alpha) - sp_1^e(\alpha) - (1 - s)v$$

with derivatives given by

$$\pi'(\alpha) = c(1 - s)\left(2s^4 - 8s^3 + 9s^2 - 2s - 2(1 - s)^4\alpha\right)$$

$$\pi''(\alpha) = -2c(1 - s)^5$$

Since $\pi''(\alpha) < 0$ we have $\pi'(\alpha) > 0$ for all α if $\pi'(1) > 0$. With

$$\pi'(1) = c(1 - s)\left(-3s^2 + 6s - 2\right),$$

we have $\pi'(1) > 0$ iff $s > 1 - 1/\sqrt{3} \approx 0.42$.

In sum, with pooled trade execution and cubic balance sheet costs, we have strategic complementarities for $s > 1 - 1/\sqrt{3}$, i.e. a threshold slightly higher than the threshold $\tilde{s} =$

$2 - \sqrt{3}$ in the main text. Figure 12 illustrates the payoff gain and the resulting equilibria of the complete information game for different levels of liquidity risk (analogous to Figure 3 in the main text).

D Case with Safety Investors Active at Both Dates

Suppose we have additional demand $q_0^S = a_0 - b_0 p_0$ at date 0 and $q_1^S = a_1 - b_1 p_1$ at date 1. Things are unchanged at date 0 with expected price

$$p_0^e(\alpha) = \frac{1 + a_0 c}{1 + b_0 c} - \frac{1}{2} \frac{c}{1 + b_0 c} (s + (1 - s) \alpha).$$

At date 1, dealers demand $q_1^D = \frac{1}{c} (1 - p_1) - 2q_0^D$ with inventory q_0^D as in the main text. With additional demand, total demand at date 1 can be written as

$$p_1(q_1) = \frac{1 + a_1 c - 2c q_0^D}{1 + b_1 c} - \frac{c}{1 + b_1 c} q_1.$$

With total supply $x_1 = s(1 - s)(1 - \alpha)$ substituting in dealer inventory

$$q_0^D = \frac{s + (1 - s) \alpha + b_0 - a_0}{1 + b_0 c}$$

we have an expected price

$$p_1^e(\alpha) = \frac{1 + a_1 c - 2c \left(\frac{s + (1 - s) \alpha}{1 + b_0 c} - \frac{a_0 - b_0}{1 + b_0 c} \right)}{1 + b_1 c} - \frac{1}{2} \frac{c}{1 + b_1 c} s(1 - s)(1 - \alpha)$$

Collecting terms, we have expected prices given by

$$p_0^e(\alpha) = \frac{1 + \left(a_0 - \frac{1}{2} s \right) c}{1 + b_0 c} - \frac{1}{2} \frac{c}{1 + b_0 c} (1 - s) \alpha$$

$$p_1^e(\alpha) = \frac{1 + \left(a_1 - \frac{1}{2} s (1 - s) \right) c}{1 + b_1 c} + \frac{2c(a_0 - b_0 - s)}{(1 + b_1 c)(1 + b_0 c)} - \frac{1}{1 + b_1 c} \left(\frac{2c}{1 + b_0 c} - \frac{c}{2} s \right) (1 - s) \alpha$$

As before, a_0 has twice the effect on p_1^e than on p_0^e but p_1^e is discounted by s so for a_0 to be stabilizing, we need $s > 1/2$. In contrast, a_1 only affects p_1^e so it is always stabilizing.