Competition Theory of Risk Management Failures

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Abstract

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Keywords: Banks, Risk Management, Time Pressure, Coordination Failure, Global Games

JEL Classifications: G20, G32, G01

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There are three ways to make a living in this business: Be first, be smarter, or cheat. Well I don't cheat, and even though I like to think we have got some pretty smart people in this building, of the two remaining options it sure is a hell of a lot easier to just be first.

(*Margin Call*, J.C. Chandor, 2011)

1 Introduction

The role of risk management is to collect, aggregate, and analyze information about risk exposures and then to manage those risks. Most risk management theories focus on the second process, namely how a firm deals with *known* risk exposures. This literature shows that agency problems and financial constraints can lead to a constrained efficient lack of hedging (e.g., Smith and Stulz, 1985; Froot et al., 1993; Rampini and Vishwanathan, 2010).

A lack of risk management can also originate from the first process. **?** describes real-world cases that are symptomatic of communication or information deficiencies inside firms. In his classification of such risk management *failures*, five of six categories relate to communication or information, suggesting that often the failure concerns *learning* of critical risk exposures.[1] On this issue, it has been argued that risk-shifting incentives could also discourage investment in information (**?**) or that certain types of risks tend to be neglected due to their nature or behavioral biases (Shefrin, 2015).

In this paper, we argue that the information process of risk management may be subject to another distinct source of inefficiency when it is envisioned not only as the individual optimization problem of a single firm, but as an interrelated set of decisions by firms that compete in the same market: the net value of risk management to a financial firm depends on the dynamics of capital markets, which in turn is affected by financial firms' risk management choices. Through this loop arises the possibility that information choices across firms exhibits strategic complementarities, and hence that risk management deficiencies constitute the outcome of a *coordination* failure.

[1] The categories are (1) mismeasurement of known risks, (2) failure to take risks into account, (3) failure in communicating risks to top management, (4) failure in monitoring risks, (5) failure in managing risks, and (6) failure to use appropriate metrics.

The premise of our theory is that risk management introduces frictions in the operations of a financial institution that affect its ability to compete in capital markets. This is in turn based on two observations. First, managing risks requires an organization-wide effort to gather, transmit, aggregate, and analyze information about risk exposures, which is a particularly daunting task in firms where decentralized agents make risk-taking decisions. According to finance practitioners, risk management

> reduces to the basics of getting the right information, at the right time, to the right people, such that those people can make the most informed judgments possible... and that critical information flowing into and out of risk monitoring processes can be distilled and compiled in a coherent and timely manner and made available, not only to the risk managers, but to key business leaders across the institution and to top management.[2]

Second, the design of such information processes in financial firms cannot be decoupled from the requirements of a fast-paced competitive market environment. In a survey of risk management in the financial industry, the two most important challenges cited by top executives are the need to strike a "balance between a sales-driven front-office culture and a risk-focused culture" and to "achieve higher-quality and more timely reports" (**?**, 14). In a similar spirit, **?** argues that more granular monitoring processes may prevent the accumulation of large unmonitored pockets of risk, but also impedes traders' ability to react quickly to profitable market opportunities. In sum, there appear to be tensions between "sales" and risk management and between timeliness and accuracy of information. We believe these tensions may be related.

Together, these quotes portray risk management as an information process and suggest that deficiencies in it may be the outcome of organizational trade-offs. If this is the case, the design of risk management processes should reflect the costs and benefits of producing, communicating and using information about risks across an organization. This hypothesis raises a simple question as the entry point to our analysis: What cost of acquiring information about risks could plausibly

[2] This definition is from a report entitled "Containing Systemic Risk: The Road to Reform" (CRMPG III, 2008, 70) submitted to the US Treasury and the Financial Stability Board by a policy group composed of top executives and chief risk officers of leading global banks.

outweigh the value of that information even when the financial amounts at stake are substantial?[3] The answer we propose is particularly suitable for financial markets and hence for certain types of financial firms. The key assumption is that information processing "costs" *time*, which delays investment decisions. To firms that face short-lived investment opportunities, delays entail costs that never fade in importance. Quite the contrary, being opportunity costs, they inherently scale with the size or frequency of investments.

We construct a simple model of trading under time pressure to explore the implications of this premise: Competing firms search for scarce trading opportunities. Before beginning their search, each firm decides whether to activate a risk management system. An active system investigates any located opportunity on its "fit" with the firm's risk profile, which improves trading decisions but takes time. This creates a basic tension between trade execution and risk management.

Our analysis begins by characterizing the risk management choice of an individual firm as a function of time pressure. Time pressure renders all trading strategies less profitable. However, it harms slow strategies more severely for two reasons: the information benefit of risk management is contingent on trade execution, and the execution probability of slow strategies is more sensitive to available time. This in turn generates monotonic responses: the firm discards risk management (only) if time pressure exceeds a unique threshold, in which case prioritizing trade execution over risk management maximizes firm value (and is in the interest of all the firm's stakeholders), even though it provokes "trading debacles" – losses due to risks that would have been mitigated if the firm had known about them early enough.

While individually optimal, this can lead to a collectively inefficient outcome. The monotonic responses create strategic complementarity: Firms that abandon risk management to accelerate trading raise the time pressure on other firms, which then become more inclined to do the same. This in turn can generate equilibrium outcomes where competitive forces erode risk management incentives to the detriment of *all* firms – a race to the bottom. The root of this market failure is

[3] To put this question into perspective, it is useful to consider financial contexts in which investors explicitly pay for information to reduce uncertainty. Buyers in mergers and acquisitions hire advisors to conduct due diligence, often for several weeks, to detect potential issues before a deal is closed, and in 2012, paid on average .85% of the deal value for this information service (**?**). For a \$100 million acquisition (1.67% of the \$6 billion J.P. Morgan Chase lost in the 2012 London Whale scandal), this would amount to \$850,000.

that every firm, while optimizing its own time use, fails to internalize that its speed contributes to time pressure in the market. To examine under which conditions such failures are more likely to occur, we use a global game extension to eliminate the scope for multiple equilibria.

In terms of positive predictions, this theory is somewhat orthogonal to the existing literature. As a start, it only speaks to specific categories of risk management failure where (with hindsight) losses would have been avoided if information about the underlying risks, in principle available, had been duly processed. In addition, it implicates a distinct set of circumstances as the catalyst for such failures: they should be concentrated in firms (1) where collecting and aggregating risk information takes time, for example, because risk-taking decisions are decentralized, (2) which face a fast-paced competitive environment with transient investment opportunities, for example, due to preemption risk, and (3) during "hot markets" where investments have high *ex ante* values (even without risk management). This confluence of organizational traits, industry structure, and market conditions is distinct from the determinants of risk management in theories centered on risk shifting or financial constraints, such as leverage, bailout incentives, counterparty exposures, or collateral – which should be helpful in discriminating our theory empirically. While we discuss bits of circumstantial evidence, we are unaware of rigorous empirical findings that speak directly to our theory.

Another distinct feature of our theory is the connection between risk management and market quality. Due to the strategic complementarities, the firm-level tensions between risk management and trade execution aggregate into a market-wide trade-off between risk allocation and trading activity. In equilibrium, speed and volume of trading are *inversely* related to allocative efficiency. Moreover, the relationship runs both ways. Not only does an increase in trading activity lead to reductions in risk management, but conversely, lack of risk management boosts trading activity in two ways: First, firms with less risk management execute trades faster. Second, they discriminate less, executing trades that might otherwise have been blocked by risk management. Both higher speed and less caution increase the amount of trading per time unit. Thus, liquidity – in the sense of market immediacy and trading volume – is a *cause* and *byproduct* of real inefficiency in this setting.

REGULATION:

Risk management failures in this model are rooted not in the capital structures of financial firms but in the markets they operate in. Unlike risk shifting or black swans, they are impervious to capital and liquidity requirements. Some alternative policies have ambiguous effects as they deter valuable as well as excessive trades, but the following two-pronged approach appears reasonable: The first prong views deficient risk management as a governance problem, mandates and supervises standards of risk management, and holds *firms* liable for violations. The second prong views it as a public goods problem, subsidizes risk management information systems, and integrates risk controls into market processes and trading platforms to alleviate the coordination failure.

ROADMAP

Related literature

Our paper diverges from existing theories in two ways. First, as mentioned, risk management comprises two broad functions: measuring risks and choosing which to hedge. Previous theories focus on the latter function, analyzing whether and how firms should hedge *known* risk exposures (**???**).[4] To use risk management jargon, they study the firm's optimal "risk appetite." Our theory focuses on the information process, or "risk assessment," which looks for a priori *unknown* misalignments between a firm's actual risk exposure and risk appetite (which would prompt corrective action). Large losses due to overlooked misalignments is what we term risk management *failures*.

Second, the aforementioned theories focus on external financing frictions and agency problems as the source of inefficiency, and a lack of risk management in equilibrium is second-best efficient. In our model, the root friction is a coordination failure (or incomplete market) among competing firms, and the equilibrium outcome can be constrained inefficient. For this reason, our predictions

[4] In reduced form, the benefit of risk management is a private value (firm-specific benefit of hedging idiosyncratic risk) of entering a financial contract that is traded at a common value (market price of hedging contract). (In earlier work, **?** analyzes optimal hedging policies from the perspective of a risk-averse manager.) **?** refine this theory by subjecting hedging to the same frictions as financing. In their model, risk management incurs opportunity costs in that collateral committed to hedging contracts reduces a firm's capacity to finance current investment. Our paper shares the focus on the costs of risk management, but the resource that firms commit to risk management is time and opportunity costs of risk management derive from preemption risk in financial markets.

about risk management failures pertain to the confluence of particular market and firm structures, rather than contracting frictions, and discussing the possible scope for regulation is more salient.[5]

Technically, our framework resembles bank run models where the first-come-first-served rule embodies preemption (**?**).[6] But the similarity is not obvious, as risk management design does not coincide with the actual preemptive actions; it is a long-run organizational choice that precedes individual trades. Yet since we model trades as randomly staggered through time due to independent search processes, preemption motives pass via "time pressure" to risk management choices, which thus inherit the strategic complementarities known from bank runs. Because of this structural similarity, we can use global games methods developed for bank run equilibria (**?**) to refine risk management equilibria by dispersing expectations about time pressure.

Time-based competition is essential to the sizable literature on innovation and patent races. Most of this literature uses sequential games or real options models in which strategic choices coincide with the acts of preemption.[7] As mentioned earlier, the strategic choice in our model – whether to run risk management – is made *ex ante*. Our model is hence more similar to the one in **?** in which firms that compete on innovation choose ex ante between "mechanistic" and "organistic" organizational designs that differ in production efficiency and "time-to-market."

2 Risk management in equilibrium

2.1 Baseline model

A mass M of risk-neutral firms (traders), indexed by k, competes for trading opportunities. Time is continuous, and a generic trading opportunity takes the form of a mispricing $\pi > 0$ that appears in the market at $t = 0$. For example, demand shocks to agents in segmented markets can create price discrepancies between assets with correlated cash flows, as in **?** or **?**.

A friction interferes with the ability of traders to instantly take advantage of this mispricing.

[5]This is akin to the rationale for regulation in corporate governance models with externalities, which focus on pecuniary and information externalities in managerial labor markets (**?????**).

[6]See also **?**, **?**, **?**, **?**, **?**, **?**, **?**, and the survey by **?**.

[7]For work on real options in competitive environments, see, e.g., **?**, **?**, **?**, and **?**, who examine how strategic interactions affect firms' payoffs from exercising their options.

This friction can take two forms. First, discovery can take time: there can be delay after the mispricing appears until the time at which a trader becomes aware of it. Second, execution can take time: there can be a delay between a trader's decision to trade and its physical execution. Since these two frictions are equivalent in our framework, we model only the first one.[8] Specifically, traders discover the trading opportunity at random times that are identically and independently distributed according to an exponential distribution:

$$\tilde{t}_k \sim \mathrm{Exp}(\lambda^{-1}).$$

The traders' discount factors are normalized to 1.

Upon locating an opportunity, a trader can request a trade (of one unit). A trade pays the sum of the mispricing π, which is a common value across traders, and a private value α_k. We interpret α_k as the "fit" between the trade and the risk profile of that particular trader, desk, or firm. For example, the firm may prefer trades that hedge rather than amplify existing exposures.[9] α_k can also reflect the shadow cost of mobilizing collateral to guarantee positions (e.g., **?**), or frictions that amplify the impact of cash flow shocks on a firm, such as bankruptcy costs or financial constraints (e.g., **?**).

There is uncertainty about the private values. At the time of discovery, k merely knows that

$$\tilde{\alpha}_k = \begin{cases} \alpha_+ & \text{with probability } \rho \\ \alpha_- & \text{with probability } 1-\rho. \end{cases}$$

The private values $\{\alpha_k\}_{k\in[0,M]}$ have a mean of zero and are independent across traders. We also assume $-\alpha_- > \pi > -\alpha_+$, that is, a trade is profitable if and only if $\alpha_k = \alpha_+$. We call "risk management" the process of producing information on α_k. Specifically, before $t = 0$, each firm simultaneously decides whether to activate a risk management technology. The technology

[8] More precisely, a specification of our framework in which all traders locate the trading opportunity immediately and execution introduces latency is isomorphic to one in which locating the opportunity introduces latency and execution is instantaneous.

[9] One of the most important operational risk management metrics are so-called concentration limits, the role of which is to ensure that the bank is not exposed too heavily to one particular idiosyncratic risk (**?**, 20).

investigates any requested trade and executes it only if $\alpha_k = \alpha_+$. However, investigation takes a deterministic time ι, and hence delays execution.

The way we model risk management infuses the private values with two more interpretations. First, the randomness of $\tilde{\alpha}_k$ implies *fundamental risk* that risk management cares about. Hence, mean-preserving spreads of the α_k-distribution could represent variation in this risk due to market or price volatilities. Second, the learning element implies that ex ante uncertainty about α_k also gauges the *need for collecting information*, or conversely, how much the risk is a priori unknown. (Indeed, the value of this information process in our model is a function of ρ and α_-.) In practice, this need is high(er) when risk-taking decisions are decentralized. Thus, the α_k-distribution also measures, in part, the degree to which the firm's organizational structure calls for internal "risk coordination." We will invoke these interpretations in our comparative statics analysis.

Finally, the mispricing is sensitive to trading pressure: it disappears once the mass of trades exploiting this opportunity reaches I. For example, I could be the net order flow that eliminates the difference between local demands across segmented markets, as in **?**.[10] The finite size of the trading opportunity creates preemptive competition among the traders, the intensity of which is captured by the ratio

$$i \equiv \frac{I}{M}.$$

The smaller this ratio, the more intense the competition. To focus on cases where the finite size of the trading opportunity generates concern about preemption, we restrict I to be strictly smaller than the mass of traders ρM for whom $\alpha_k = \alpha_+$, that is, $i < \rho$.[11] This restriction simplifies the exposition for now but is not essential. We will later endogenize M by adding an entry stage.

We conclude the description of this basic framework with three remarks on modeling choices.

First, risk management blocks trades that create unwanted risks. In practice, some risks can be hedged. Allowing for hedges does not change the gist of our results as long as identifying risks

[10]In Section **??**, we discuss model variants in which the mispricing decreases smoothly in the mass of trades, or is directly dependent on the time t since it appeared in the market.

[11]For $i < \rho$, the trading opportunity is exhausted in finite time in any equilibrium. The results are qualitatively the same if $\rho \leq i < 1$. For $i > 1$ time pressure disappears.

and implementing hedges still takes time. As a pre-trade process, it would delay trade execution, and as a post-trade process, it would leave firms vulnerable to risks in the interim.

Second, assuming a continuum of firms and i.i.d. random variables makes the model highly tractable: Every firm knows how many in total locate the opportunity over time and how many of those firms will have positive private values. In fact, the only aggregate uncertainty is strategic: To infer how many trades are *executed* over time, firms must form beliefs about everyone else's risk management. In Section **??**, we add exogenous aggregate uncertainty to eliminate equilibrium multiplicity and sharpen the predictions of the model.

Third, activating risk management is an ex ante decision by firms. The idea is that it requires organizational choices to collect and aggregate information from decentralized trading decisions.[12] In Section **??**, we discuss a model variant in which firms can make risk management choices "on the fly" as trading opportunities are discovered. And in a companion paper (Bouvard and Lee, 2017), we allow traders that operate within a firm's chosen risk management framework to manipulate the protocols.

2.2 Privately optimal risk management

Consider a trader who believes that trading opportunities stay alive for a period of length T, which we take as exogenous for the moment. Without risk management, his expected profit is π conditional on locating the opportunity before T, which happens with probability

$$p_h(T) \equiv 1 - e^{-T/\lambda}.$$

We will refer to this strategy as "hasty." This strategy is obviously irrelevant for $\pi < 0$. It is only when hasty trading is, on average, profitable that risk management has opportunity costs.

With risk management, his expected profit is $\rho(\pi + \alpha_+)$ conditional on locating the oppor-

[12]The Basel Committee uses the term risk management *framework* to describe systematic risk controls in firms.

tunity and identifying α_k before T, which happens with probability

$$p_d(T) \equiv \begin{cases} 0 & \text{if } T < \iota, \\ 1 - e^{-(T-\iota)/\lambda} & \text{otherwise.} \end{cases}$$

We will refer to this strategy as "deliberate." We also refer to either strategy as "implemented" once the trader has the possibility to execute the trade. For the hasty strategy, implementation amounts to locating the opportunity. For the deliberate strategy, it further requires identifying α_k, and does not entail execution if $\alpha_k = \alpha_-$.

The difference between the unconditional expected profits of the two strategies as a function of T is

$$\begin{aligned} \Delta(T) &\equiv p_d(T)\rho(\pi + \alpha_+) - p_h(T)\pi \\ &= p_h(T)(1-\rho)|\pi + \alpha_-| - [p_h(T) - p_d(T)]\rho|\pi + \alpha_+|. \end{aligned} \tag{1}$$

$\Delta(.)$ represents a firm's private net value of risk management. On the bottom line, the first term reflects the benefit of risk management: avoiding bad trades that would occur with probability $p_h(T)(1-\rho)$ under the hasty strategy. This benefit depends on the implementation probability $p_h(.)$, which means that the value of risk management is *contingent* on the option of executing the trade. The second term reflects the cost of risk management: failing to capture good trades with probability $[p_h(T) - p_d(T)]\rho$ that would be executed under the hasty strategy. This opportunity cost depends on the *difference* in the implementations probabilities, $p_h(T) - p_d(T)$, and hence the relative speeds of the two strategies.

Since both implementation probabilities $p_h(.)$ and $p_d(.)$ are increasing functions, time pressure affects both hasty and deliberate traders negatively. The slope of $\Delta(.)$ is thus a priori ambiguous. For $T < \iota$, time pressure affects only the hasty strategy: implementation probability is zero under the deliberate strategy, while it strictly increases with T under the hasty one. But for $T > \iota$, the deliberate strategy is more sensitive to time pressure than the hasty one for reasons related to both the benefit and the cost of risk management:

(i) *Value of information.* Conditional on implementation, the deliberate strategy pays off more than the hasty one. Hence, even if the implementation probabilities were to decrease equally, raising time pressure would lower the unconditional expected profit on the margin more under the deliberate strategy. The difference in conditional profits, $\rho(\pi + \alpha_+) - \pi = (1 - \rho)|\pi + \alpha_-| > 0$, is precisely the conditional benefit of risk management: avoiding bad trades. The unconditional value of this benefit shrinks as the probability of trade decreases with time pressure, reflecting that the information value of risk management is contingent on execution.

(ii) *Value of time.* The implementation probability is more sensitive to changes in the deadline under the deliberate strategy than under the hasty strategy: $p_d'(T) > p_h'(T)$. To implement her strategy, a hasty trader must find the opportunity before T, whereas a deliberate trader must find it before $T - \iota$. A trader who can search from 0 to T gains less from a marginal increase in search time than one who can search only from 0 to $T - \iota$. Intuitively, additional time matters more to those who have less to begin with. So, the difference $p_h(.) - p_d(.)$ and hence the opportunity cost of risk management increase with time pressure.

Thus, $\Delta(.)$ is U-shaped and reaches its minimum at $T = \iota$ (see Figure **??**).[13] Furthermore, $\Delta(.)$ goes to 0 as $T \to 0$, reflecting that no strategy can be implemented when there is no time. Conversely, when $T \to \infty$, $\Delta(T)$ converges to $(1-\rho)|\pi + \alpha_-| > 0$ as implementation is certain, so that the opportunity cost of risk management vanishes. In sum, these properties imply that there is a *unique* point $T^* > 0$ at which a trader is indifferent between the two strategies: $\Delta(T^*) = 0$. When time pressure is high, $T < T^*$, it is optimal for a trader to abandon risk management and prioritize execution, i.e., $\Delta(T) < 0$. By contrast, when time pressure is low, $T > T^*$, the benefit of informed decision-making under risk management outweighs the loss in execution speed, i.e., $\Delta(T) > 0$.

[13]The shape of $\Delta(.)$ does not depend on investigation time ι being deterministic. $\Delta(.)$ is similarly U-shaped when investigation time is exponentially distributed, as search time is. The non-monotonicity of $\Delta(.)$ will later complicate the global games refinement (Section **??**).

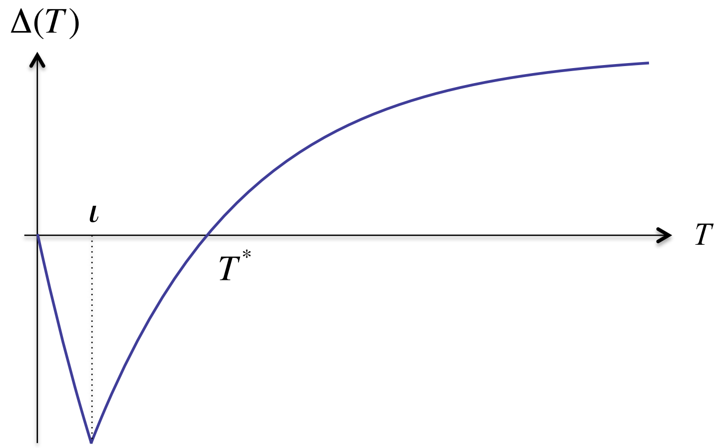

Figure 1: Time pressure and net private value of risk management.

T is the date at which the trading opportunity disappears, hence an inverse measure of time pressure. ι is the risk management delay. $\Delta(T)$ is the firm's expected profit from trading with risk management relative to trading without risk management.

Lemma 1. *The private value of risk management $\Delta(T)$ is strictly decreasing for $T < \iota$ and strictly increasing for $T > \iota$. Furthermore, there exists a unique threshold T^* such that firms activate risk management if and only if $T > T^*$, and T^* is an increasing function of π.*

This contrasts with theories of risk management deficiencies based on risk-shifting arguments. Here, a lack of risk management is not driven by differences in the financial claims held by various stakeholders (e.g., managers, shareholders, or debtholders), nor does it pit their interests against each other. On the contrary, a firm discards risk management in order to stay competitive under time pressure and to thereby *maximize firm value* for all stakeholders.

Lemma **??** also establishes that T^* increases in π, that is, risk management is less attractive when trading is ex ante more attractive. This is already visible in (**??**): When π increases, losses from bad trades, $|\pi+\alpha_-|$, shrink, while forgone profits from good trades, $[p_h(T)-p_d(T)]\rho(\pi+\alpha_+)$, grow. Thus, the benefit of risk management decreases, while its opportunity cost increases.

By Lemma **??**, a firm's best response to time pressure is given by

$$\Pr(h) = q(T) \equiv \begin{cases} 1 & \text{if } T < T^*(\pi) \\ [0,1] & \text{if } T = T^*(\pi) \\ 0 & \text{otherwise.} \end{cases}$$

Given a continuum of ex ante identical traders, q also denotes the fraction of hasty traders.

Notice that $q(T)$ is monotonic, which will be key to generating strategic complementarity. Also, T^* is independent of scale in the sense that multiplying the payoff $\pi + \tilde{\alpha}_k$ (with any positive scalar) does not change the sign of $\Delta(.)$ – the costs (and benefits) of risk management scale up with the size of the trading opportunity. Last, any and all interaction between firms goes through T but every firm, being infinitesimal, takes T as given.

2.3 Collectively inefficient risk management

In equilibrium, the deadline T is endogenously determined. Let q denote the fraction of traders that play the hasty strategy. The time T by which the trading opportunity is exhausted satisfies

$$qp_h(T) + (1-q)\rho p_d(T) = i. \tag{2}$$

Let $T(q)$ denote the solution to (**??**). $T(q)$ is decreasing: the deadline shortens when the proportion of hasty traders is higher. The reason is twofold. First, hasty traders have a faster implementation because they avoid the risk management delay (execution speed). Second, conditional on locating the opportunity, rather than trading only when $\alpha = \alpha_+$, that is, with probability $\rho < 1$, hasty traders execute with probability 1 (indiscriminateness). As a result, the trading opportunity is depleted at a faster rate.

We let

$$T_h \equiv T(1) \qquad \text{and} \qquad T_d \equiv T(0)$$

denote, respectively, the shortest possible deadline (all traders are hasty), and the longest possible deadline (all traders are deliberate). T_h and T_d bound the range of deadlines that can arise in the market.

These bounds can be used to identify parameter regions in which strategic dominance arises. We know from Lemma **??** that the threshold T^* below which the private value of risk management is negative increases with π. For high enough π, there may be an equilibrium in which all traders are hasty (hereafter, hasty equilibrium). Indeed, let $\overline{\pi}$ be defined by $T^*(\overline{\pi}) = T_d$. If $\pi > \overline{\pi}$, then $T_d < T^*(\pi)$: Even if everyone else were to be deliberate, T_d would be lower than the threshold T^* below which the hasty strategy is the best response, making it strictly dominant for any trader to be hasty. An analogous argument applies to low π. If $\pi < \underline{\pi}$, where $T^*(\underline{\pi}) = T_h$ if $T_h > \iota$ or else $\underline{\pi} = 0$, being deliberate is strictly dominant for all traders (hereafter, deliberate equilibrium).

When π is in the intermediate region $(\underline{\pi}, \overline{\pi})$, the equilibrium prediction is ambiguous: $q(T)$ and $T(q)$ intersect at three (fixed) points. Suppose a trader believes everyone else is hasty. The implied deadline T_h is then smaller than $T^*(\pi)$ so that his best response is also to be hasty. Thus, a hasty equilibrium exists. If the trader instead believes that everyone else is deliberate, the implied deadline T_d is larger than $T^*(\pi)$ and supports a deliberate equilibrium. In the third equilibrium, the fraction of hasty traders q is precisely such that the implied deadline renders everyone indifferent between the two strategies, i.e., $T(q) = T^*(\pi)$ or $\Delta(T(q)) = 0$. The different equilibrium configurations are illustrated in Figure **??**.

Proposition 1. *There exists a unique interval $[\underline{\pi}, \overline{\pi}] \neq \emptyset$ such that the hasty equilibrium exists for all $\pi \geq \underline{\pi}$, the deliberate equilibrium exists for all $\pi \leq \overline{\pi}$, and one equilibrium in which both strategies are used exists for all $\pi \in (\underline{\pi}, \overline{\pi})$.*

The source of equilibrium multiplicity is the positive feedback loop created by $T(q)$ and $q(T)$ being both decreasing, which makes risk management choices strategic complements: When more traders are deliberate, the trading opportunity is depleted at a slower pace as risk management delays execution and blocks executions whenever $\alpha_k = \alpha_-$. This lowers the time pressure on others, making them more inclined to be deliberate as well. Conversely, more hastiness raises

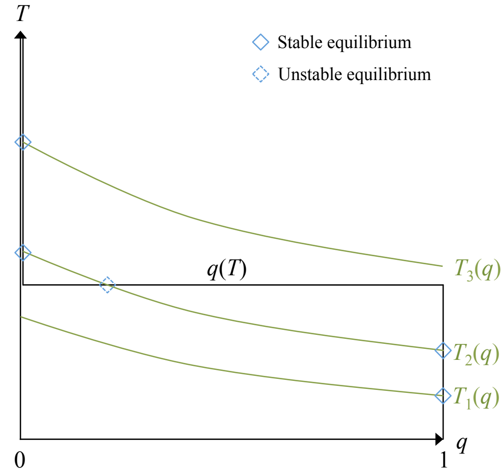

Figure 2: Strategic complementarities in risk management.

The step function $q(T)$ depicts the firms' optimal risk management choice as a function of time pressure, while $T_{\cdot}(q)$ depicts how time pressure depends on the firms' risk management choices for various levels of the common value π (i.e., the ex ante value of a trade). Lower $T_{\cdot}(q)$ correspond to higher values of π. Intersections between $q(T)$ and $T_{\cdot}(q)$ constitute equilibria.

time pressure, which begets more hastiness.[14]

The strategic complementarity also makes the interior equilibrium unstable: Any shock that causes $T(q)$ to deviate from T^* breaks the indifference condition and pushes all traders to the same strategy.

Corollary 1. *Only corner equilibria are stable.*

In every equilibrium, payoffs are symmetric across traders. Since aggregate payoffs decrease in the mass of executed trades with $\alpha_k = \alpha_-$, we obtain a simple Pareto ranking:

Corollary 2. *Everyone being deliberate strictly Pareto-dominates any non-deliberate equilibrium.*

Any non-deliberate equilibrium is thus a coordination failure – a "race to the bottom." The reason traders can be trapped in the hasty equilibrium is that their individual objective functions fail to internalize the social value of risk management. Consider trader k's net gain from deviating

[14]Compared with bank runs or currency attacks, the strategic complementarities in our model operate through time pressure and learning incentives as opposed to direct payoff externalities: by choosing to be hasty, each trader increases the opportunity cost of acquiring information for every other trader.

to the deliberate strategy when everyone else is hasty:

$$\Delta(T_h) = p_d(T_h)(1-\rho)|\pi + \alpha_-| - [p_h(T_h) - p_d(T_h)]\pi. \tag{3}$$

The second term captures the preemption motive: By switching to the deliberate strategy, the trader becomes less likely to capture the common value π. This private loss to k is not a social one, since another trader will capture the common value in lieu of k. The first term corresponds to the private benefit of risk management: Under the deliberate strategy, k can avoid a loss of $|\pi + \alpha_-|$. But the social benefit of risk management in this event further depends on the private value of the (hasty) trader k' who then executes in lieu of k: The social gain is zero if $\alpha_{k'} = \alpha_-$ but otherwise $\alpha_+ - \alpha_-$, which happens with probability ρ. Since $\rho(\alpha_+ - \alpha_-) > |\pi + \alpha_-|$, trader k does not fully internalize the allocative efficiency gain of risk management.

Proposition **??** and its corollaries are noteworthy for two main reasons: Most theories of risk management *problems* focus on the moral hazard of agents who do not fully bear potential losses. By contrast, such externalization of losses does not drive our results. Hence, as positive theory, the key predictions about risk management incentives do not pertain to executive compensation, capital structure, bailout policies, financial contagion, or other sources of risk-shifting incentives. Rather, our analysis implicates factors such as competition, market structure and conditions, or speed of information processing as important determinants of risk management quality – thereby pointing to a different, novel set of potentially testable empirical relationships.

From a normative perspective, it is worth noting that a lack of risk management in our model does not constitute a second-best outcome. Instead, any non-deliberate equilibrium is constrained Pareto-inefficient, being due to coordination failure, and thus creates scope for Pareto-improving regulation. What is more, such regulation may have to target (some of) the determinants of risk management quality mentioned above, or impose penalties on firms for risk management failures – even if none of a firm's financial losses are externalized. This is because, here, the externalities of risk management choices operate through competitive market pressure.

3 Determinants and correlates of risk management failures

While equilibrium multiplicity highlights strategic complementarity, it generates ambiguity about the influence of structural parameters on firms' risk management choices. In this section we use global games techniques to resolve this indeterminacy (**??**), and for the resulting unique equilibrium, explore how parameter changes affect the level of risk management. The purpose of these comparative statics is to characterize, first, the set of circumstances under which risk management failures are likely to be observed, and second, the equilibrium relationship between financial market characteristics and risk management quality.

3.1 Global Games treatment

Standard global games techniques are applicable in settings with *global* strategic complementarity (see, e.g., **?**). In our model, this would require that increasing the fraction of deliberate traders always raises the private value of risk management. But this is not the case: While T is monotonically increasing in the fraction of deliberate traders, $\Delta(.)$ is not monotonic in T. However, our model does satisfy a weaker form of strategic complementarity: By Lemma **??**, $\Delta(.)$ crosses 0 once, and is monotonic when positive. These properties define *one-sided* strategic complementarity, as in **?**, whose method we use to obtain equilibrium uniqueness in our setting.

To this end, we add aggregate uncertainty to the model by assuming that the common value π, instead of being a fixed parameter, is a random variable uniformly distributed over $(\overline{\pi}-\delta, \overline{\pi}+\delta)$, about the realization of which traders have dispersed information.[15] Specifically, before deciding whether to activate risk management, each privately observes a noisy signal, $s_k \equiv \pi + \xi_k$, where $\{\xi_k\}_{k\in[0,1]}$ are uniformly and independently distributed on $[-\varepsilon, +\varepsilon]$. This information structure keeps traders from precisely knowing what others know and thereby from perfectly coordinating on one strategy.

The equilibrium derivation is (more involved?) but very similar to **?** and relegated to the Online Appendix. Equilibrium strategies take the threshold form typical of global games: Every

[15]As is usual in global games, we assume that δ is large enough to guarantee the existence of lower- and higher-dominance regions, i.e., $\delta > \max\{\overline{\pi}+\alpha_+, \alpha_- - \overline{\pi}\}$

trader is hasty if his signal s_k lies below a unique common threshold s^*, and deliberate otherwise. Since the signals are heterogenous, hasty and deliberate traders generically coexist. However, a characteristic property of global games is to preserve equilibrium uniqueness even in information structures arbitrarily close to common knowledge of π. That is, even as the signal noise vanishes, $\varepsilon \to 0$, the equilibrium remains unique although everyone converges on the same strategy:

Proposition 2. *For all $\varepsilon > 0$, a unique equilibrium exists. For $\varepsilon \to 0$, the equilibrium converges to: All traders play the hasty strategy if $\pi > \pi^*$ and the deliberate strategy if $\pi < \pi^*$, where π^* is strictly positive and satisfies*

$$\int_0^1 \Delta[T(q), \pi^*]dq = 0. \tag{4}$$

Proposition **??** is the counterpart of Proposition **??** in the richer environment of global games.[16] To understand equation (**??**), start with the non-limit case where ε is bounded away from 0. The marginal trader who receives the threshold signal s^* conjectures that π is uniformly distributed in $[s^* - \varepsilon, s^* + \varepsilon]$. Given that all traders apply the threshold s^* and their signal errors are i.i.d., every $\pi \in [s^* - \varepsilon, s^* + \varepsilon]$ maps one-to-one into a fraction q of traders playing the hasty strategy. Accordingly, the marginal trader can transform his posterior on π into a posterior on q, and this posterior distribution on q, in turn, implies a distribution of deadlines $T(q)$ by way of equation (**??**). Such a distribution, or noisy posterior, emerges from a given s^* even for ε arbitrarily small. Conversely, the equilibrium threshold s^* must satisfy the condition that the trader who receives it is indifferent between the hasty and the deliberate strategy (i.e., is marginal) under the implied distribution of deadlines. The limit of this indifference condition as ε tends to 0 is (**??**). **Consider Removing/Shortening?**

3.2 Codeterminants of risk-management failures

The main benefit of equilibrium uniqueness is to deliver shaper predictions on the link between the aggregate level of risk management and firms' trading environment. We start with a set of comparative statics.

[16] In equation (**??**), $\Delta(.,.)$ is defined as in (**??**), with the addition of a second argument explicitly recognizing the dependence on the common value π.

First, the structure of the risk traders become exposed to if they execute bears a natural relationship to their incentives to engage in risk management. This risk has a mean that depends on the realization of π, and higher-order moments that depend on the distribution of private values $\tilde{\alpha}_k$. To capture these moments, we now define $\alpha_+ \equiv \frac{\sigma}{\rho}$ and $\alpha_- \equiv \frac{-\sigma}{1-\rho}$ with $\sigma > 0$. This preserves the zero mean $E(\tilde{\alpha}_k) = \rho\frac{\sigma}{\rho} + (1-\rho)\frac{-\sigma}{1-\rho} = 0$ for any values of σ and ρ, but yields a simple parametrization of variance $\rho\left(\frac{\sigma}{\rho}\right)^2 + (1-\rho)\left(\frac{-\sigma}{1-\rho}\right)^2 = \sigma^2$ and skewness $\rho\left(\frac{1}{\rho}\right)^3 + (1-\rho)\left(\frac{-1}{1-\rho}\right)^3 = \rho^2 - (1-\rho)^2 = 2\rho - 1$. That is, π, σ and ρ, respectively, pin down mean, variance and skewness while each preserving the other moments. The next result is then a direct consequence of Proposition **??**.

Proposition 3 (Risk moments)**.** *Risk management quality, ceteris paribus,*

a. decreases in the mean π (common value).

b. increases in the volatility σ and skewness ρ (private value).

From part b. in Proposition **??**, traders partly internalize the benefit of risk management. In the model, active risk management creates downwards protection by blocking trades with a negative private value. Therefore, like a put option, risk management is more valuable to firms when volatility or the probability of tail realizations increases. In that dimension, private incentives align with social surplus: risk management creates a social surplus equal to $\rho(\alpha_+ - \alpha_-) = \frac{\sigma}{1-\rho}$, which also increases in σ and ρ, and captures the benefit of firms acquiring information. However, this surplus is independent from the realization of π because the preemption game between traders is zero-sum in the common value dimension. Hence, part a. encapsulates the coordination failure across traders. When the common value π is higher, the opportunity cost of missing on the trading opportunity rises. Since traders compete in speed for this common value, higher realizations of π exacerbate preemption motives, which may then dominate risk considerations. Then, when giving up risk management, traders do not internalize that the resulting increase in time pressure raises the opportunity cost of risk management for all other traders.

Proposition **??** suggests that periods of high (common value) trading profits are more likely to be associated with lax risk management. Note that a positive shock to the distribution of

π has ambiguous effects on traders' overall welfare. To see this, note that a trader's expected payoff given a competition intensite $i = \frac{I}{\rho M}$ is

$$\begin{aligned} & \Pr[\pi \geq \pi^*(i)] i \mathbb{E}[\pi | \pi \geq \pi^*(i)] + \Pr[\pi < \pi^*(i)] i \mathbb{E}\left[\pi + \frac{\sigma}{\rho} | \pi < \pi^*(i)\right] \\ = \ & i \left[\mathbb{E}(\pi) + \Pr(\pi < \pi^*) \frac{\sigma}{\rho}\right] \end{aligned} \tag{5}$$

Now, consider a uniform increase in the common value π.[17] This increase has the direct effect of raising trading profit $\mathbb{E}(\pi)$ and the indirect effect of lowering the ex-ante probability $\Pr(\pi < \pi^*)$ that risk management takes place. As is apparent from (**??**), if $\frac{\sigma}{\rho}$ is high enough, i.e., if the private value spread or skewness is high, this increase in π lowers traders' overall payoff: The equilibrium impact of π on the likelihood of a coordination failure dominates the direct increase in profitability.

The strength of the externality that traders exert on each other is directly linked to the intensity of time competition. Proposition **??** also allows us to confirm the intuition that factors which exacerbate time competition increase the chances of a coordination failure.

Proposition 4 (Time pressure)**.** *Risk management quality, ceteris paribus,*

a. decreases when external speed increases relative to internal speed, i.e., when ι/λ increases.

b. decreases when competition intensifies, i.e., when i decreases.

First, Proposition **??** shows that *relative* speed matters (part a.). To see this, consider how an increase in search speed impacts the marginal trader: On one hand, it raises the probability that he discovers the trading opportunity before any given deadline $T(q)$; on the other hand, all other traders also locate the opportunity faster, which shortens the deadlines $\{T(q)\}_{q \in [0,1]}$. These two effects offset each other such that, under hasty strategies, no trader gains or loses any advantage. That is, higher search speed does not advantage search *per se.* It does, however, increase the opportunity cost of risk management: A trading opportunity becomes more likely to vanish between time $\tilde{t}_k$ at which a trader discovers it and time $\tilde{t}_k + \iota$ at which he can trade

[17] I.e., let $\pi' = \pi + \delta$ where δ is a constant such that the support of π' still satisfies the conditions in Section **??**. Note that this change does not affect the threshold π^*.

on it under the deliberate strategy. As the implementation probability of the deliberate strategy decreases relative to that of the hasty one, so must π^* for indifference condition (**??**) to hold. Key to this results is thus the latency risk management imposes relative to the time it takes traders to discover opportunities.

Changes in speed can be related to technological innovations that allow processing larger et more complex sets of data at a faster rate. Proposition **??** suggests the impacts of gains in processing speed on risk management and trading need to be jointly analyzed. Even in a world in which information systems steadily become faster at identifying risks, the overall quality of risk management may not improve because firms are locked in a race where fast trading also becomes increasingly critical. In other words, progresses in data processing are a double-edge sword. In addition, internal speed is not only related to raw computing power or modelling sophistication but also to the size and scope of the organization the trader belongs to. Reconciling risks across lines of business is more time-consuming when organizational complexity increases. By contrast, external speed, that is, the ability to identify mispricings in one particular market, does not necessarily depend on the overall risk structure of a firm. This suggests a link between the size and organizational complexity of financial institutions and the equilibrium level of risk management, which we discuss further in the next section.

Proposition **??** also establishes a direct relationship between competition intensity and equilibrium risk-management: π^* decreases when competition intensifies, i.e., when i decreases. As explained earlier, the marginal trader, the one receiving the signal $s^* = \pi^*$, forms posterior beliefs about the distribution of deadlines $T(q)$, which spans $[T_h(i), T_d(i)]$ and includes T^*. By (**??**), when i decreases, $T(q)$ shifts down for all q, that is, the deadline shortens for every realization of q. This in turn shifts more probability mass into the region below T^* where the marginal trader prefers being hasty (i.e., $\Delta[T(q), \pi^*] < 0$), so that the integral in (**??**) turns negative and π^* must decrease for the indifference condition to remain satisfied.[18]

One benefit of being able to link competition intensity to equilibrium strategies, hence to equilibrium profits, is that we can take one more step and endogenize i. Specifically, suppose

[18]The fact that $\Delta(\pi^*, .)$ is negative below T^* and positive otherwise drives the monotonicity of $\pi^*(i)$. However, the proof cannot rely solely on this observation because $\Delta(\pi^*, .)$ is non-monotonic below T^* (see Appendix).

that traders face a fixed cost χ of entering the market. Then, in equilibrium, the intensity of competition i must satisfy the zero-profit condition

$$i\{\mathbb{E}(\pi) + \Pr[\pi < \pi^*(i)]\alpha_+\} = \chi. \tag{6}$$

In that case, lower barriers to entry raise immediacy, but may cause a deterioration of risk management.

Corollary 3. *A decrease in the cost of entry χ increases the mass of traders, decreases the expected deadline, and makes risk management less likely.*

Lower entry costs mechanically raise market immediacy: The larger the mass of active traders, the more trades occur in any time interval. In addition, there is an equilibrium effect: The rise in time pressure lowers the threshold for π above which traders abandon risk management, which further accelerates the market as fewer trades are delayed or blocked. Thus, market immediacy is not only *inversely* related to allocative efficiency but, due to this positive feedback loop, both *cause* and *consequence* of misallocation. We discuss this tension between immediacy and risk management further in Section **??** below. Corollary **??** also shows that traders' failure to coordinate on the dominant equilibrium can subsist in an environment where traders make zero-profit ex ante.

Finally, the equilibrium in Proposition **??** also has predictions for the interaction between risk moments and time pressure.

Proposition 5 (Interaction)**.** *An increase in the speed ratio ξ or competition intensity $\frac{1}{i}$ weakens the impact of volatility σ and skewness ρ on risk management quality. That is,*

$$\frac{\partial \pi^*}{\partial \sigma \partial i} > 0,\ \frac{\partial \pi^*}{\partial \sigma \partial \xi} > 0,\ \frac{\partial \pi^*}{\partial \rho \partial i} > 0 \text{ and } \frac{\partial \pi^*}{\partial \rho \partial \xi} > 0.$$

From proposition **??**, an increase in external (market) speed relative internal (risk-management) speed, or an increase in competition intensity not only has the direct effect on risk management described in Proposition **??**, it also makes traders less responsive to a change in the riskiness of their trades. That is, in an environment where time pressure is high, an increase in private value spread or skewness is less likely to trigger a switch from a hasty equilibrium strategy to a deliberate one. This interactions suggest that equilibria with low level of risk management can result from multiple factors acting in concert and reinforcing each others. In the next section, we try to tie these factors to concrete features of the financial system and instances in which risk management seems to have failed.

3.3 Discussion: risk-management failures and financial crises

The previous section identifies a constellation of precursors for risk management failures. Some of them can be related to structural evolutions to the competitive structure of financial markets due to regulation or technical changes (see, e.g., Kroszner and Strahan, 1999; Rajan, 2005).

In the U.S., the deregulation of the banking industry that started in the 1970s has progressively allowed banks once confined to state limits to compete across states, effectively lowering the cost of entry into local markets (Black and Strahan, 2002). At the same time, progress in information and communication technologies have made it easier for banks to operate in markets farther from their base (Petersen and Rajan, 2002, Alessandrini et al., 2009). Informational barriers to entry sustained by banks' superior information about their local market have declined as both information availability and processing capacity improved, leading banks to rely increasingly on hard quantifiable information (Rajan et al. 2015). In the context of our model, this can be interpreted as a decline in the cost of entering new markets (captured by χ in Corollary **??**).

These regulatory and technical changes have also spurred the expansion of some of the most successful players. These banks not only hold a disproportionate amount of total banking assets, but also have a more intricate organizational structure (Black and Strahan, 2002; Cetorelli et al., 2014). In addition, the shift of banking towards an originate-and-distribute model has induced banks to retain risks on their balance sheet that are harder to evaluate and more difficult to hedge (Rajan 2005; Acharya et al. 2013). Demsetz and Strahan (1997) show that larger banking organizations which should benefit from a diversified set of activities to lower their aggregate risk have in fact more volatile earnings than smaller, less diversified banks. A 2008 report from the division of Banking Supervision and Regulation of the Fed Board opens as follows: *"In recent years, banking organizations have greatly expanded the scope, complexity, and global nature of their business activities.[...] As a result, organizations have confronted significant risk management and corporate governance challenges, particularly with respect to compliance risks that transcend business lines, legal entities, and jurisdictions of operation."* Organizational scope and product complexity raise the analytical and computational demands placed on risk management, effectively slowing it down. A 2013 survey by Ernst and Young of major U.S. banks indicate that conducting group-wide stress tests takes several months and that the slow results are a barrier to using the tests as an effective management tool.[19] In the context of our model, this would make risk management more time-consuming, and counteract the effect of technological progress on internal speed ι.

At the same time, technological progress has increased the speed at which banks can identify trading opportunities (Frame and White, 2004). In a 2009 speech on financial innovation, Ben Bernanke highlights that the emergence of models of credit scoring has led to the *"ever-faster evaluation of creditworthiness, identification of prospective borrowers, and management of existing accounts."* Zhu (2018) provides direct evidence of the link between the availability of new technologies (high-resolution satellite imaging coupled with recognition algorythms) and the speed at which information about future earnings is incorporated into asset prices.

Overall, this structural transformation of the U.S. banking industry features two of the factors that predict a low risk-management equilibrium outcome in our model: increased competition for trading opportunities due to lower entry costs, combined with a faster progression of external (trading) speed relative to internal (risk-management) speed. Note that, from Proposition **??**, these two factors are not only directly favouring hasty strategies, but also making the low risk-management equilibrium outcome less responsive to changes in their risk environment. That is, firms are less likely to strengthen their risk-management protocols in response to factors that inflate their private-value volatility or skewness. For instance, leverage magnifies the impact of

[19] Similarly, a 2012 McKinsey survey on major U.S. banks reports that the time needed to run a value at risk on a single typical trading portfolio ranges between two and fifteen hours and can be much longer in stressed environments.

risk exposures on the balance-sheet of a financial institution, which would be captured by σ in our model. Higher reliance on short-term funding (e.g., repos) amplifies the effect of downside risk by creating scope for panic-based liquidity shortages and runs following negative shocks. This would correspond to higher skewness, ρ. Our theory predicts that the intensification of time competition could lead financial institutions such as broker-dealers which, before 2008, faced lighter constrains on leverage than commercial banks, and relied on overnight short-term funding much less stable than deposits, to set up risk-management protocols that may not be commensurate to the risks their capital structure implied.

In addition to structural factors, Proposition **??** suggests that banks' business cycle impact the equilibrium level of risk management. The idea that firms are more likely to compromise on risk management in favorable market conditions is consistent with a survey of chief risk officers (**?**, 18). More than half of the respondents cite market conditions as a determinant of the leniency of risk governance: They indicate that risk appetite is often reined in during difficult times and expanded when markets pick up. For instance, origination of mortgage-based securities (MBS) by the top 15 underwriters in the U.S. doubled from 2004 to 2006.[20] Coval Jurek and Stafford (2009) argue the growth of this market was fuelled by a mispricing that allowed originators to sell debt tranches at yields that did not correctly reflect the underlying risk. Our model predicts that the magnitude of this mispricing raises the opportunity cost for financial institutions to engage in risk management and lose business to their competitors. At the top of the league tables for MBS underwriting from 2004 to 2007 lied Bear Sterns and Lehman Brothers.

Now, our model does not speak to the supply and demand imbalances at the source of these financial booms (e.g., international capital flows, saving glut) or to the the type of assets these booms may affect (e.g., real estate). However, it provides a rationale for why financial institutions may fail to contain the risks associated to these new opportunities, which may eventually lead to a systemic crisis. Our notion of systemic risk is distinct from the concern that the financial system may be overly exposed to a handful of large institutions deemed "too-big-to-fail." While size can play a role in making risk-management more complex hence slower, as explained earlier,

[20]cite JMP case study

the systemic nature of risk-management failures in our model stems from all participants in the same market being subject to time pressure and reinforcing it by weakening risk controls. That is, risk is systemic because common market forces shape the response of all traders and lead to a suboptimal allocation of risks across participants.

**************Sam's notes, to be incorporated above?**************************

Financial crisis: This is not so much about why the failure of individual institutions escalated into the financial crisis, i.e., the amplification mechanisms. Also not about the supply and demand factors (savings glut, international capital flow), i.e., the macroeconomic forces that set the stage for the crisis. Also, not about the origins of the housing market bubble. It is, however, about the question why the risk management in those institutions may have failed to avert the institutional failures, which in turn triggered the crisis. Interconnectedness of banks. Systemically important institutions.

Multiple factors are important. Multiple checks must fail. One particular failure is: risk management inside banks. Important to the extent that the failure of these institutions was instrumental in triggering the crisis...if risk management in these institutions (who acted as crucial conduits) would have averted their failure, that might have averted the crisis.

Difference between knowingly taking the risks, and being ex post surprised about the outcome, would have averted failure if in full possession of ex ante available information.

- Originated in a boom market: housing market bubble, MBS
- MBS were highly profitable for Lehmann and Bear Stearns, huge trading volume in preceding years, growing
- Securitization was an exploding business that banks were desperate to get into because the traditional banking business was suffering from competition (money market funds)
- Large complex organizations, cross-exposures
- Short-term leverage, fragility, runs, high alpha spread
- Skewness: low probability (historically), high loss event (systemic nature)

- Speed ratio: Internal time was an issue, historical vs Monte Carlo simulations, greeks vs full analysis

4 Extensions

We examine here the robustness of our model and conclusions, both in terms of predictions and welfare implications, to alternative interpretations and specifications.

4.1 Social value of speed

Until now we have focused on coordination failures *among* traders, that is, we have shown that when the hasty strategy is played in equilibrium, it produces a welfare loss $\rho(\alpha_+ - \alpha_-)$ which corresponds to a misallocation of the asset. Now, equilibrium strategies also affect the lifetime T of the trading opportunity π. The speed at which this correction happens may also have welfare implications, which depend on the interpretation of this trading opportunity.

First, π can be interpreted as a mispricing in the informational sense, that is, a discrepancy between the market price of an asset and its fundamental value based on information about future cash-flows. In that scenario, traders are agents with superior information who collectively make a profit at the expense of other (unmodelled) agents. The transaction between informed traders and their uninformed counterpart is therefore a pure transfer (a zero-sum game) and if we restrict attention to this set of agents, the only aggregate welfare loss is indeed the one caused by the coordination failure among informed traders. However, the informational content of asset prices can have broader effects when they affect real economic decisions(e.g., investment, regulation **cite Bond Goldstein Guembel)**. In that case, the speed at which private information about fundamental values is incorporated into prices matters for welfare. Our model then suggests a tension between allocative efficiency among traders and informational efficiency.

Alternatively, π can be the product of gains from trade. For instance, traders could be intermediaries who provide liquidity to an agent and are compensated for the risk they take in the process. In that case, speed might be directly valuable insofar as agents with a demand for liquidity have a need for immediacy as, for instance, in Glosten and Milgrom (1988). This would be consistent with a market design that rewards speed by incorporating some degree of time priority when processing trades. There again, our model suggests a tension: equilibria that provide the highest degree of immediacy also generate a misallocation of risks among intermediaries.

BY SETTING PRICE, AGENT CAN DETERMINE π AND THEREBY IMMEDIACY. OPTIMIZES TRADE-OFF BETWEEN PRICE AND TIME. IF SHE OPTIMIZES ON PRICE, THEN RM IS GOOD. IF SHE OPTIMIZES ON TIME, THEN RM IS BAD.

A parsimonious way to explicitly introduce this tension in the model is to assume that the lifetime of a trading opportunity can be directly dependent on the time since it appeared in the market, in addition to trading pressure. For instance, an agent with a liquidity need may have to leave the market if its demand is not fulfilled quickly enough. This can be done by introducing some constant probability that the trading opportunity disappears in any small interval of time dt before it is exhausted (see Online Appendix). In this setup, it is no longer true that risk management is necessarily Pareto-optimal for traders, as they internalize the social benefit of fast execution, that is, being more likely to seize the common value π before it disappears from the market. However, coordination failure remains a problem: A hasty equilibrium can still coexist with a deliberate one, and whenever this is the case, the former is Pareto-dominated.

This extension also delivers volume implications. In expectation, there is more trading in a hasty equilibrium than in a deliberate one, implying an ambiguous relationship between trading volume and allocative efficiency: A higher trading volume reflects both the social benefit of fast execution (liquidity) as well as the social cost of less risk management.

4.2 Sources of strategic complementarities

In the model, coordination failures are driven by strategic complementarities in risk management. These complementarities arise through a loop: Lower aggregate risk management raises time pressure, which in turn raises the opportunity cost of delaying execution to manage risk. Now, suppose risk management does not create latency ($\iota = 0$), but firms need to pay a fixed cost k in order to set up or maintain a risk management system. Then a firm chooses to do risk management if and only if

$$p_h(T)\rho(\pi + \alpha_+) - k > p_h(T)\pi \tag{7}$$

Indeed, since risk management is instantaneous, the implementation probability is now $p_h(T)$ irrespective of the strategy. Note that (**??**) can be rewritten as

$$-p_h(T)(1-\rho)(\pi+\alpha_-) > k,$$

which, since $p_h(.)$ is strictly increasing and $\pi + \alpha_- < 0$, implies that whether (**??**) holds may depend on T. This, intuitively, is a scale effect: If T shrinks and the deadline is tight, then the benefit of risk management which only materializes if the firm gets to trade is too small relative to k. Interestingly, T still depends on equilibrium choices of risk management, even if $\iota = 0$, i.e., despite the absence of risk-management latency, $T_h < T_l$. As is apparent from equation (**??**), this is because firms that are deliberate trade less often, so that the trading opportunity is depleted at a slower pace in a deliberate equilibrium. This property closes the loop and allows to sustain the same type of equilibrium multiplicity and coordination failure as in the original model.

This variant of the model highlights that the key to generating the externality that leads to a coordination failure is that a trader who gives up risk management increases time pressure for every other trader in the market. That higher time pressure in turn makes risk management less beneficial can operate through different channels: an opportunity cost, as in the original specification, a fixed cost, as discussed above, or any combination of both.[21] Note however, that these two types of cost have different properties. A fixed cost operate through a scale effect: If trading has a low probability because time pressure is high, then firms cannot recoup the cost of setting up a system that investigates trades. That argument however loses some bite if fixed risk-management costs can be spread over many trades within the firm and over time, or if the size of the trade is large. It becomes then more likely that firms would coordinate on the deliberate strategy. On the contrary, to firms that face short-lived investment opportunities, delays entail costs that never dwindle in importance. Quite the contrary, these opportunity costs inherently scale up with the size or frequency of investments.

[21] Another channel is agency costs: if time pressure makes traders more eager to bypass risk management in order to trade more, then the cost of incentivizing them to monitor risk rises.

4.3 Strategic substituability and welfare

Up to now, we have interpreted the misallocation of the asset to a trader with a low private value as a loss of surplus. That is, the mismatch $\alpha_+ - \alpha_-$ is not only a loss to traders, but a social loss, rather than a transfer to other agents in the economy. This is consistent with canonical models of risk management in corporate finance (**?**) that ground risk management in financial frictions: In a capital market with imperfections, a negative cash-flow shock may prevent firms from funding positive-NPV projects, or even trigger a costly bankruptcy. There, failing to manage risk leads to a reduction in total surplus.

An alternative is that the lack of risk-management generates losses that benefit other agents, typically competitors. In that case, risk management affects the allocation of surplus, but not necessarily its aggregate size. For instance, Acharya and Yorulmazer (2008) argue that banks have incentives to hold liquidity to buy assets a fire-sale prices when competitors become distressed. We argue here that the private or social nature of risk-management losses maps into different types of strategic interactions: When the lack of risk-management destroys surplus, risk management choices tend to be strategic complements, while they tend to be strategic substitute when risk-management failures only generates transfers across traders.

We formalize this point with a simple extension of the model. Suppose traders play a twice-repeated version of the original game in which traders make a risk management decisions at the beginning of every period $t \in \{1, 2\}$. π_t denotes the common-value trading profit in period t, and there is no (exogenously specified) private value α. However, as earlier, every firm has a probability $1 - \rho$ to be ill-suited to bear the risk involved in the trade. In that case, if it trades nevertheless, it drops from the market at the end of the period. While this is immaterial in the second (final) period, bankruptcy matters in period 1 because it deprives the firm from period-2 profits. Hence, in period 1, the private value α, instead of being exogenously specified reflects a continuation value. Finally, in every period, the trader or its firm derives a profit B_t from non-trading activities. These activities cannot be taken over by other firms and represent lines of business where relationships and soft information are instrumental to generating profit.[22] This

[22] A milder version is that these activities can be taken over by other firms either at some cost, or only with

assumption makes bankruptcy costly, in the social sense: if a firm goes bankrupt in period 1, some surplus destroyed as B_2 is never be realized. In keeping with the baseline version of the model, $\{\pi_t\}_{t\in\{1,2\}}$ is common knowledge from start, the game starts in period 1 with a mass M_1 of traders and there is no entry throughout. $i_1 = \frac{I}{M_1}$ measures competition intensity at the beginning of period 1.

In the absence of (exogenous) private value α, it is individually and socially optimal for traders to be hasty in period 2. The expected trading profit in that period is $i_2\pi_2$, where $i_2 = \frac{I}{M_2}$ captures competition intensity in period 2. Total profit in period 2 is

$$\Pi_2 \equiv i_2\pi_2 + B_2. \tag{8}$$

Consider now the *net* benefit of trading (rather than not trading) in period 1. If the trader can sustain the trade risk (probability ρ), then the net payoff from trading is simply π_1. If, on the other hand, trading leads to bankruptcy (probability $1-\rho$), the net payoff from trading is $\pi_1 - \Pi_2$.

To see how this extension relates to our initial setup, suppose first that $\pi_2 = 0$ and therefore the continuation value $\Pi_2 = B_2$ only captures surplus that is destroyed in a bankruptcy. In that case, the net benefit of risk management is the period-1 is

$$\Delta(T) = p_d(T)\rho\pi_1 - p_h(T)[\pi_1 - (1-\rho)B_2],$$

and the analysis is identical to the one in the original setup. That is, this extension nests our initial setup in the case where the private-value loss to the firm is a social loss.

This suggests that for strategic substituabilities to arise, some of value lost by firms that do not implement risk management need to be recouped by other firms. To make this salient, consider the polar opposite case where $\pi_2 > 0$ but $B_2 = 0$. The net benefit of risk management is now

$$\Delta(T, q) = p_d(T)\rho\pi_1 - p_h(T)[\pi_1 - (1-\rho)i_2(q)\pi_2],$$

some probability.

where $i_2 = \frac{i_1}{1-q(1-\rho)}$ increases with the fraction of hasty traders in period 1, q. That is, through competition intensity i_2, continuation payoffs depend on period-1 decisions: If more traders give up risk management in period 1, then more of them fail and the ratio of the size of the trading opportunity to the mass of surviving trader rises in period 2. This creates a source of strategic substitutability between risk-management choices that co-exists with the original strategic complementarities. Indeed the marginal impact of a change in the fraction of hasty traders q on the net benefit of risk management now writes

$$\frac{\partial}{\partial q}\Delta[T(q), q] = \frac{\partial \Delta}{\partial T}[T(q), q]\frac{\partial T}{\partial q} + \frac{\partial \Delta}{\partial q}[T(q), q]. \tag{9}$$

From the analysis of the original model, the first term in (**??**) is negative if $T > \iota$: If fewer traders are deliberate, time pressure increases which increases the opportunity cost of risk-management latency. The second term, however, is positive, equal to $p_h(T)(1-\rho)i_2'(q)\pi_2$: If fewer traders are deliberate, more of them go bankrupt at the end of the period, which raises the profit of surviving traders in period 2, hence the marginal benefit of risk management. To see how these strategic substituabilities can affect the equilibrium outcome, suppose

$$\pi_1 - i_1\pi_2 > 0 > \pi_1 - \frac{i_1}{\rho}\pi_2. \tag{10}$$

From the left-hand-side inequality, if a trader anticipates that all other traders are deliberate, the best response is to give up risk management. If, on the contrary, the trader anticipates that all other traders are hasty, the right-hand-side inequality implies that the best response is to do risk management provided the risk management delay ι is not too large. In that configuration, any equilibrium features a mix of traders with and without active risk management, which reflects the substituability between risk-management decisions.

Overall, this extension highlights that strategic complementarities between risk-management decisions are more likely to arise when risk-management failures involve a deadweight loss. If, on the contrary, risk-management losses involve transfers to other traders, a drop in aggregate risk management increases the size of these transfers, and may in turn increase the payoff from risk management. Note however that even in the extreme case where risk-management losses are a mere reallocation of future business, i.e., $B_2 = 0$, strategic complementarities coexist with strategic substituabilities, as is apparent from (**??**), and could still sustain multiple equilibria. Now, as argued above, it seems reasonable that deficiencies in risk-management failures destroy surplus: any friction that makes the reallocation of assets from distressed firms to healthy ones costly would generate these social losses. In fact, it is *only* to the extent that risk-management losses are socially costly that risk-management decisions matter in the first place: if $B_2 = 0$, that is, if risk-management losses are pure transfers, then traders' expected payoff is the same ex ante in any equilibrium and is equal to their payoff if traders could commit to all do risk management, or to all not do it. In other words, while coordination might still be a strategic concern, there is no coordination *failure* in the absence of a deadweight loss from risk management deficiencies.

4.4 Alternative modeling of trading.

Our model of trading is stylized. For instance, firms cannot choose how many units to trade, nor can they reverse previous trades. While these assumptions may seem restrictive, they are not crucial for our results. Allowing firms to trade more units tends to reinforce the threat of preemption and hence the fragility of the deliberate equilibrium under time pressure. (This is true even when a firm's willingness to trade more units increases with active risk management.) Furthermore, our results are robust to re-trading as long as trades are *partly* irreversible, for example, due to (a duplication of) transaction costs. In fact, the effect of partial reversibility is ambiguous: By allowing efficient *re*-allocations, it also lowers the private value of ex ante risk management and makes hasty trading more likely to begin with.

The way in which trading pressure affects the magnitude of the trading opportunity could also be modeled differently. In particular, the common value π could continuously decrease as more traders execute the trade, reflecting a price-sensitive demand for liquidity as in **?**. This has two countervailing effects on the strategic complementarities between traders. On one hand, when more traders are hasty, the expected common value at which a trader can execute the trade is lower, which makes risk management more desirable. On the other hand, when more traders are hasty, the common value shrinks at a faster rate, which heightens the preemption motive and thus makes risk management less desirable. One can show that when π decreases linearly with the mass of (traders who) executed trades, the second effect dominates the first one, thereby reinforcing strategic complementarities.

4.5 Endogenous alphas, fixed costs, endogenous speeds

5 Risk management regulation

Practitioners commonly note that financial firms must balance "business needs and risk appetite" (**?**, 12). While this is true for each firm in our model, our analysis also suggests that if all firms freely strike their own balance, the market can be constrained inefficient. This creates scope for regulation to curb excessive trading and to improve the risk allocation. Below we discuss regulatory approaches from this perspective, some used in practice and others so far only debated.

Capital and liquidity requirements. Leverage or maturity play no explicit role in our model. Rather, any impact they might have is implicit in the private value $\tilde{\alpha}_k$. There are two possible interpretations: First, management acts in the interest of all investors, and $\tilde{\alpha}_k$ reflects potential *deadweight* losses from undesirable risks given the firm's capital structure. In this case, $|\tilde{\alpha}_k|$ may increase with leverage (e.g., due to bankruptcy costs). Second, management is biased toward specific investors (e.g., shareholders), whose vulnerability alone is represented by $\tilde{\alpha}_k$, in which case $|\tilde{\alpha}_k|$ may decrease with leverage (e.g., due to risk shifting).[23] Constrained inefficiencies in our model are *conditional* on $\tilde{\alpha}_k$, irrespective of *whose* "need" for risk management it reflects. Thus, capital structure regulation in our model would modify the need for risk management, but not correct any inefficiencies conditional on that need.

Pigouvian approaches. In the constrained inefficient outcome of our model, firms trade "too much" in that trades are not selective enough. One countermeasure is hence to levy a tax τ on

[23]**?** show that a management with risk-shifting incentives, being less concerned about uncertainty, may underinvest in information. Correcting management incentives would in this case resolve the lack of information acquisition. The converse is not true: Better information per se would not curb risk-shifting. Quite the contrary, it would enable management to shift risks more effectively.

every trade.[24] This decreases the value of a trading opportunity to $\hat{\pi} = \pi - \tau$, which has two effects: On one hand, it lowers the opportunity cost of risk management. On the other hand, it makes trades with $\hat{\pi} + \alpha_+ < 0$ unprofitable. The tax can thus deter excessive as well as valuable trade.

Given the role of the external-internal speed ratio $\frac{\iota}{\lambda}$, one could also "tax" speed investments.[25] Discouraging external speed (increasing λ) is also a double-edged sword: The decrease in time pressure promotes risk management, but lowers market immediacy and trading volume for valuable trades. By contrast, subsidizing internal speed (decreasing ι) helps risk management, and conditional thereon, also raises speed. Technological investment into information processes inside banks is currently a risk management priority (**?**, 68f):

> Systems and data vied for the top spot on the challenges to internal transparency... and, indeed, have been raised as among the top challenges throughout this report. "There is a huge effort underway to redo all the plumbing, data aggregation, accuracy, quality of information," one executive said. "That's the framework in which a lot of our future-state risk systems will be addressed... a huge, multiyear, gazillion-dollar effort."

In our model, such investments in internal speed, in practice often only made to meet regulatory requirements, contribute to a "public good" by decreasing the likelihood of coordination failure (Section **??**).

Governance regulation. To be effective against both of the mutually reinforcing externalities in our model, opportunity costs and agency rents, regulation must address risk management in conjunction with incentive compensation. This resonates with the view taken by the Fed in its *Guidance on Sound Incentive Compensation Policies* (see footnote **??**):

> [S]trong and effective risk-management and internal control functions are critical to the safety and soundness of banking organizations. However,... poorly designed or

[24]**?** proposed transaction taxes based on the argument that excess currency speculation undermines the allocative role of exchange rates for hedging purposes, i.e., risk allocation.

[25]**?** provide examples of such arms races between trading firms.

> managed incentive compensation arrangements can themselves be a source of risk to banking organizations and undermine the controls in place. Unbalanced incentive compensation arrangements can place substantial strain on the risk-management and internal control functions of even well-managed organizations... [and] encourage employees to take affirmative actions to weaken the organization's risk-management or internal control functions. (36401)

The guidelines recommend supervising compensation practices (e.g., deferred pay and clawbacks) and associated risk control and governance processes together (36397).[26] Similarly, a qualitative inspection of risk management is now part of regulatory assessments of bank capital adequacy. For instance, in 2014, the Fed rejected the capital plans of four large financial institutions on grounds of qualitative deficiencies in their risk management processes.[27]

Our model supports deferred pay and clawbacks but provides a more nuanced view on "bonus cultures." In particular, it suggests that an exclusive reliance on bonuses in trader compensation need not imply weak compliance incentives, provided the bonuses are deferred and can be clawed back. In fact, high-powered contracts can be efficient when a firm's risk controls are strong, risk management is not a major concern, or time pressure is low. A blanket requirement to use lower-powered contracts would then impose unnecessary agency costs on those trading activities with unintended side effects (such as discouraging the activity or investment in other risk controls). Instead, our analysis suggests confining regulatory intervention to "problem areas" that display high-powered compensation in conjunction with other characteristics, such as a high degree of time pressure, reliance on soft information, slow pre-trade controls, and weak post-trade controls (see Figure **??**).

Still, ex ante restrictions may be problematic. For one, whether risk controls are (too) slow

[26] See also SR letter 12-17, "Consolidated Supervision Framework for Large Financial Institutions," released by the Fed in 2012.

[27] The banks are Citibank, HSBC, RBS Citizens, and Santander. In the case of Citibank, the capital plan was rejected because of concerns about its ability to properly aggregate risk information across its business units, or more precisely, its "ability to project revenue and losses under a stressful scenario for material parts of the firm's global operations, and its ability to develop scenarios for its internal stress testing that adequately reflect and stress its full range of business activities and exposures" (Federal Reserve Board, Comprehensive Capital Analysis and Review 2014: Assessment Framework and Results, 7).

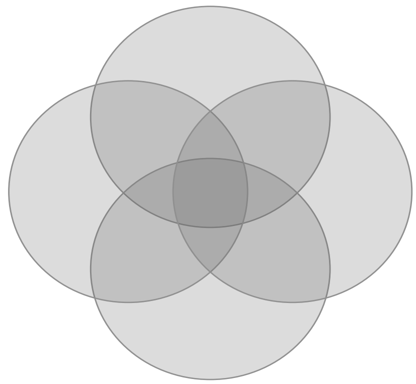

Figure 3: Problem areas.

Darker areas are where risk management is more likely (constrained) inefficient and, for example, high-powered contracts may indicate such inefficiency.

or weak can be hard to assess, and is often discernible only after the fact. Moreover, since agency rents may constrain risk management even in the constrained efficient equilibrium, compensation regulation may face the dilemma that lax rules provoke weak risk management while mandating sufficiently low-powered compensation renders the trading activity unprofitable for firms.

It may be more effective to enforce standards or duties through *ex post* liability, in which case the question arises whether institutions or individuals should be held liable for risk management failures. According to our model, the answer is both. On one hand, individual liability fails to address the "opportunity cost effect" that firms may (tacitly) tolerate or even want lax controls and non-compliance. For instance, in the London Whale scandal, J.P. Morgan Chase was fined nearly $1 billion for unsound risk protocols (**?**):

> The internal controls – the key fraud prevention device inside the company – were a joke. The Chief Investment Office in London had a Valuation Control Group (VCG) that was supposed to act as a check on mis-marking or other violations. But it had only one employee for a large trading desk. And the employee would get price quotes from the traders themselves, like asking the fox for statistics on the hen house...

> This was a license to cheat, and the VCG guidelines could only have come from the risk management officers at the bank. Traders "took full advantage" of the VCG's laissez-faire approach to valuations,... and would lobby successfully for even more leeway. Essentially, there was no risk management at the Chief Investment Office, and senior executives were all too happy to not be apprised of the details.

Afterwards, the bank substantially expanded its valuation control group and pledged to impose stricter discipline on valuations as well as "check traders' valuations more frequently than its previous practice of once a month" (**?**).[28]

At the same time, institutional liability fails to address the "agency cost effect." Here individual liability helps: it relaxes incentive constraints, making it cheaper for firms to simultaneously provide search and compliance incentives. In cases where compliance is high even without regulation, this is of no consequence. But where agency rents constrain risk management, it helps firms mitigate the multi-task conflict that drives the inefficiencies in both the constrained inefficient and second-best equilibria of our model.

Market design. Regulators may also want to reconsider market processes. For one, the coordination failure in our model is driven by preemptive competition, which is a result of time priority in market rules or interactions. Moreover, as markets speed up further, algorithmic trading becomes increasingly attractive, making traditional notions of internal governance obsolete; machines are fast and demand no agency rents. Regulators would have to assess to what extent an algorithmic strategy or computer code sidesteps risk controls, which may prove difficult.

? caution that the gap between "machine speed" and "human speed" created by algorithmic trading may aggravate the lack of risk management; and suggest that a growing focus on speed and machines may necessitate *systemwide* risk management regulation "translated into computer code and executed by automated systems" with "safeguards at multiple levels of the system." In other words, interventions into market processes may become integral. Among measures currently debated are proposals (i) to discretize trading time to eliminate preemptive competition

[28]Following the scandal and the regulatory fine, J.P. Morgan Chase invested close to $1 billion in 2013 on strengthening internal controls and assigned more than 5,000 employees to compliance.

at very short intervals and (ii) to build safeguards, such as trade limits and pre-trade protocols, into the system at the level of intermediaries or central counterparties, such as dealer-brokers, clearing houses, or exchanges (see, e.g, **???**).[29]

To place the case for market design interventions in context, consider **?**'s framework in which *equilibrium market structure* is the outcome of the tradeoff between the costs (to intermediaries) of maintaining a continuous presence in a market and the benefits (to traders) of being able to transact as immediately as possible. In their setting, there is no over-provision of immediacy.[30] In our setting, immediacy can invoke a race to the bottom with respect to risk management by traders, which is why interventions in market design to reduce immediacy can be Pareto-improving.

Regulatory competition. When competing firms belong to different jurisdictions, regulators inherit the race-to-the-bottom incentives identified in our model insofar as they care about the competitiveness of "their" firms. Concerns about such regulatory competition indeed exist (**?**, 4):

> Issues related to risk management of these technology-dependent trading systems are numerous and complex and cannot be addressed in isolation within domestic financial markets. For example, placing limits on high-frequency algorithmic trading or restricting unfiltered sponsored access and co-location within one jurisdiction might only drive trading firms to another jurisdiction where controls are less stringent.

Similar concerns are voiced in the aforementioned *Guidance on Sound Incentive Compensation Policies* (36399).

[29]In a survey on the risks of high-frequency trading, proprietary trading firms – when asked what they would change for "the betterment of the markets" – mention inter alia that (i) "requiring trading venues to uniformly apply pre-trade risk checks for all market participants would consistently apply latency to and level the playing field for all trading firms" and that (ii) "every trading venue should have limits on maximum positions, quantity per order, and credit... [and] on number of messages that can be sent to the trading venue within a specified period of time... per product/customer" (**?**, 13f).

[30]In **?**, immediacy is determined by technological investments of the exchanges on which investors trade, and the exchanges' choices, which shape market structure in their model, are driven by differentiation incentives. In aggregate, these investments can be too high relative to the welfare optimum since they not only accelerate trading but also (are meant to) relax competition between the exchanges.

6 Related literature

? and ? were first to formalize why and how firms should hedge exposures to idiosyncratic risk in the presence of external financing frictions.[31] ? refine this theory qualifying when risk management is optimal if hedging is subject to the same frictions as financing. In their model, risk management incurs opportunity costs in that collateral committed to hedging contracts reduces a firm's capacity to finance current investment. While our paper shares a focus on the costs of risk management, there are two main differences. First, Rampini and Viswanathan consider a firm's problem of whether or how to insure known risks. By contrast, we focus on firms' decisions to set up systems to monitor the take-up of, if unmonitored, unknown risks. Second, in our model, the resource that firms commit to risk management is time and opportunity costs of risk management arise from preemption in financial markets.

Preemption is similar to the first-come-first-served rule in bank run models (??), from which our model departs in two noteworthy ways.[32] First, risk management design is the outcome of long-run decisions that do not coincide with on-the-spot preemptive actions: such organizational choices precede individual trades. Yet since we model trade as randomly staggered through time as a result of independent search processes, preemption motives pass via "time pressure" to risk management choices, which through this medium inherit the strategic complementarities known from bank runs. Because of this structural similarity, we can also adapt global games techniques used to refine bank run equilibria (?) to risk management equilibria by dispersing firms' expectations of time pressure.

Second, since risk management choices and traders' actions are distinct, we can further introduce agency problems that firms must address to implement their chosen risk management framework. This allows us to study the *interaction* of agency problems across firms subject to "bank run" externalities. Costly monitoring theories are common in financial intermediation, internal capital markets, and corporate governance (e.g., ????). We are, however, unaware of

[31] In reduced form, the benefit of risk management is a private value (firm-specific benefit of hedging idiosyncratic risk) of entering a financial contract that is traded at a common value (market price of hedging contract). In earlier work, ? analyzes optimal hedging policies from the perspective of a risk-averse manager (employee).

[32] See also ?, ?, ?, ?, ?, ?, and additional references in the survey by ?.

existing work where the cost of monitoring is time, or depends on competition or on others' monitoring choices.

Our theory provides a rationale for risk management regulation – as distinct from capital or liquidity regulation – similar to theories that justify corporate governance regulation based on externalities. This literature has focused on pecuniary externalities (**??**) and learning externalities (Nielsen, 2006; **???**) in the context of managerial labor markets.

Links between competition and risk taking have been studied in the banking literature with a focus on the effect of competition on bank franchise values (**????**) and the returns to screening (**??**).[33] The key mechanism in our paper is that competition raises the (opportunity and agency) *costs* of screening. Our analysis of agency is reminiscent of **?** who examine a multi-task conflict between screening and loan "prospecting," which – despite lacking an explicit time dimension – bears similarity to preemptive competition.

A literature in industrial organization studies more broadly how competition interacts with agency and has identified a variety of effects operating through information revelation, marginal returns to managerial effort, and total firm income.[34] The overall effect is generally ambiguous, qualifying the "Hicks conjecture" that product market competition curbs managerial slack. These papers typically study one-dimensional moral hazard in oligopolistic models. Our results rely on multi-dimensional moral hazard, and in this respect, are closer to **?** who study how labor market competition skews contractual incentives across different types of tasks.

Time-based competition is essential to the sizable literature on innovation and patent races. Most of this literature uses sequential games or real options models in which strategic choices coincide with the acts of preemption.[35] As mentioned earlier, the strategic choice in our model – whether to run risk management – is made *ex ante*. Our model is hence more similar to the one in **?** in which firms that compete on innovation choose ex ante between "mechanistic" and "organistic" organizational designs that differ in production efficiency and "time-to-market."

[33] A different perspective is taken in **?** where lenders to the same borrower exert negative externalities on each other by raising the borrower's overall default incentives.

[34] See, e.g., **???????**.

[35] For work on real options in competitive environments, see, e.g., **?**, **?**, **?**, and **?**, who examine how strategic interactions affect firms' payoffs from exercising their options.

Recently, time-based competition has become the focus of research on high-frequency (low-latency) trading in financial markets. Apart from showing that the race to reduce latency spurs overinvestment in technology, these papers trace out the impact on market liquidity, asset prices, and trading volume (**???**).[36] Our analysis is not specific to high-frequency trading but shares a similar view, and adds to the list of concerns that competing on speed may impair the *risk allocation* in financial markets by undermining governance processes inside firms.

This connects our paper to the literature on the allocative role of secondary capital markets. Most existing results in this literature revolve around (efficient) prices as a source of information that can destroy risk-sharing opportunities, guide investment decisions, enhance incentive contracts, and frustrate takeovers.[37] In our model, allocation is driven not by information revealed through market prices but by processes inside firms, which are, however, affected by the market's speed.

Our focus on a risk management link between markets and organizations combines the perspectives of two recent papers. **?** study the role of risk management protocols in creating liquidity feedback loops in the market, whereas **?** focus on the "dissent" function of risk management inside an organization and when this function may be compromised. In our model, market interactions and organizational choices are jointly determined by a trade-off between immediacy in the market and "dissent" in organizations.

7 Conclusion

The implementation of risk management requires monitoring and information processes to collect the relevant information inside firms. These processes take time and can delay investment decisions, which represents an opportunity cost that scales up with the size of the firms' investment opportunities when those opportunities are *short-lived*. Based on this premise, this paper has presented a theory to explain why risk management failures occur and also why there may be

[36] A notable exception is **?** who, instead of focusing on preemption among traders, study the incentives of securities exchanges to offer trading platforms of different speed to heterogenous traders.

[37] See, e.g., **?** for a survey of this literature.

scope for risk management regulation not warranted by the capital structure of financial firms but rather the type of markets they compete in.

Financial markets are a natural context for the speed-information trade-off in our model, and there are several avenues we have left unexplored. Providing a micro-foundation for the private value of risk management in multi-divisional firms could link questions about the boundaries of the firm to the degree of preemptive competition. Furthermore, while this paper has focused on risk management, it would be of interest to study how the strategic complementarities in our framework affect learning about the common value of traded assets and information aggregation. Finally, one could explore the speed-information trade-off from the perspective of managers that disclose information or learn from prices, or securities exchanges that affect the speed at which trading unfolds.

Our framework could also be extended to other contexts. First, our formalization of "time pressure" lends itself to the analysis of strategic complementarities akin to those in bank runs or financial panics without the connotation of frenzy. It may be useful in modeling long-term organizational choices in a variety of settings with time-based competition, thereby expanding the applicability of the theoretical apparatus that has been developed for models of panics.

Second, costly monitoring or state verification models are a workhorse in principal-agent theory. The notion that the relevant cost of such information processes is time, and that this may determine optimal contracts in environments where time is of the essence, is more generally applicable beyond risk management. In particular, as we have shown, it naturally creates a tension between monitoring (by the principal) and initiative (by the agent), akin to those analyzed in the literature on delegation, but dependent on time pressure.

Appendix A: Proofs of results in Section ?? (Baseline Model)

Proof of Lemma ??

See Online Appendix.

Proof of Proposition ??

We derive the equilibrium of the general case in which ε can be bounded away from 0. The proof is in several steps, and we only show here the existence of a unique equilibrium *in threshold strategies*. The proof that any equilibrium is in threshold strategies follows **?** and is in the Online Appendix.

For a given realization of π, the proportion of hasty traders under a threshold strategy $\hat{s}$ is

$$q(\pi,\hat{s}) \equiv \begin{cases} 0 & \text{if } \pi \leq \hat{s}-\varepsilon, \\ \dfrac{\pi+\varepsilon-\hat{s}}{2\varepsilon} & \text{if } \hat{s}-\varepsilon < \pi < \hat{s}+\varepsilon, \\ 1 & \text{if } \pi \geq \hat{s}+\varepsilon \end{cases} \tag{11}$$

For a proportion q of hasty traders, the mass of trade executed by time T is

$$m(q,T) \equiv q p_h(T) + (1-q)\rho p_d(T),$$

Hence the time at which the trading opportunity is exhausted, $\tau(\pi,\hat{s})$, is solution to $m[q(\pi,\hat{s}),\tau] = i$. Finally, the net expected benefit of a deliberate strategy given a signal s_k and a threshold $\hat{s}$ is

$$u(s_k,\hat{s}) \equiv \mathbb{E}_\pi\{\Delta[\pi,\tau(\pi,\hat{s})]|s_k\} = \frac{1}{2\varepsilon}\int_{s_k-\varepsilon}^{s_k+\varepsilon} \Delta[\pi,\tau(\pi,\hat{s})]d\pi, \tag{12}$$

Step 1: Existence of a unique threshold equilibrium.

Claim 1. *$\tau(\pi,\hat{s})$ is decreasing in π and increasing in $\hat{s}$. Furthermore, $\tau(\pi+a,\hat{s}+a) = \tau(\pi,\hat{s})$.*

Proof. $q(\pi,\hat{s})$ is increasing in π and decreasing in $\hat{s}$. Furthermore, $m(q,T)$ is increasing in T, and since $p_h(T) > \rho p_d(T)$, increasing in q. Therefore, $\tau(\pi,\hat{s})$ is decreasing in π and increasing in $\hat{s}$. Finally, from (**??**), $q(\pi+a,\hat{s}+a) = q(\pi,\hat{s})$, which in turn implies $\tau(\pi+a,\hat{s}+a) = \tau(\pi,\hat{s})$. □

Claim 2. *There exists a unique s^* such that $u(s^*,s^*) = 0$.*

Proof. We first show the existence of s^* using upper- and lower-dominance regions. Suppose that $s < \underline{\pi} - \varepsilon$, then of any $\pi \in [s-\varepsilon, s+\varepsilon]$, $T^*(\pi) < T_h \leq \tau(\pi, s)$, therefore $\Delta[\pi, \tau(\pi, s)] > 0$ and hence $u(s,s) > 0$. Similarly, if $s > \overline{\pi} + \varepsilon$, then $u(s,s) < 0$. The continuity of $u(.,.)$ then implies the existence of s^*, which proves existence.

Furthermore,

$$\begin{aligned} u(s,s) &= \frac{1}{2\varepsilon}\int_{s-\varepsilon}^{s+\varepsilon} \Delta[\pi, \tau(\pi, s)]d\pi \\ &= \frac{1}{2\varepsilon}\int_{s-\varepsilon}^{s+\varepsilon} \Delta[\pi, \tau(\pi + a, s+a)]d\pi \\ &= \frac{1}{2\varepsilon}\int_{s+a-\varepsilon}^{s+a+\varepsilon} \Delta[\pi - a, \tau(\pi, s+a)]d\pi \\ &< \frac{1}{2\varepsilon}\int_{s+a-\varepsilon}^{s+a+\varepsilon} \Delta[\pi, \tau(\pi, s+a)]d\pi = u(s+a, s+a), \end{aligned}$$

where the second equality follows from Claim **??** and the last inequality follows from $\frac{\partial \Delta}{\partial \pi} < 0$. Hence, $u(s,s)$ is strictly decreasing in s, which proves uniqueness. □

Finally, to complete the proof we show the following result.

Claim 3. *$u(s, s^*) > 0$ for $s < s^*$ and $u(s, s^*) < 0$ for $s > s^*$.*

Proof. From (**??**), $u(s^*, s^*) = 0$ implies that $\Delta[., \tau(., s^*)]$ changes sign on $[s^* - \varepsilon, s^* + \varepsilon]$. Therefore, by continuity, there exists $\hat{\pi} \in [s^* - \varepsilon, s^* + \varepsilon]$ such that $\Delta[\hat{\pi}, \tau(\hat{\pi}, s^*)] = 0$, and hence, $\tau(\hat{\pi}, s^*) = T^*(\hat{\pi}) > 0$.[38] Suppose $\pi < \hat{\pi}$, then $\tau(\pi, s^*) \geq T^*(\hat{\pi})$, and therefore using the single crossing property (Lemma **??**), $\Delta[\hat{\pi}, \tau(\pi, \hat{s})] \geq 0$. Furthermore, since $\frac{\partial \Delta}{\partial \pi} < 0$, $\Delta[\pi, \tau(\pi, \hat{s})] > \Delta[\hat{\pi}, \tau(\pi, \hat{s})] \geq 0$. Similarly, if $\pi > \hat{\pi}$, then $\Delta[\pi, \tau(\pi, \hat{s})] < 0$. This also shows that $\hat{\pi}$ is uniquely defined.

Suppose $s < s^*$. If $s < \hat{\pi} - \varepsilon$, for any $\pi \in [s - \varepsilon, s + \varepsilon]$, $\Delta[\pi, \tau(\pi, s^*)] > 0$, and thus $u(s, s^*) > 0$. If $\hat{\pi} - \varepsilon \leq s < s^*$,

$$\begin{aligned} u(s, s^*) - u(s^*, s^*) &= \frac{1}{2\varepsilon}\int_{s-\varepsilon}^{s+\varepsilon} \Delta[\pi, \tau(\pi, s^*)]d\pi - \frac{1}{2\varepsilon}\int_{s^*-\varepsilon}^{s^*+\varepsilon} \Delta[\pi, \tau(\pi, s^*)]d\pi \\ &= \frac{1}{2\varepsilon}\int_{s-\varepsilon}^{s^*-\varepsilon} \Delta[\pi, \tau(\pi, s^*)]d\pi - \frac{1}{2\varepsilon}\int_{s+\varepsilon}^{s^*+\varepsilon} \Delta[\pi, \tau(\pi, s^*)]d\pi. \end{aligned}$$

$\pi < s^* - \varepsilon$ implies $\pi < \hat{\pi}$, and therefore $\Delta[\pi, \tau(\pi, s^*)] > 0$. Thus, $\int_{s-\varepsilon}^{s^*-\varepsilon} \Delta[\pi, \tau(\pi, \hat{s})]d\pi > 0$. $\pi \geq s + \varepsilon$ implies $\pi \geq \hat{\pi}$ and therefore $\Delta[\pi, \tau(\pi, s^*)] < 0$. Hence, $\int_{s+\varepsilon}^{s^*+\varepsilon} \Delta[T(\pi, s^*)]d\pi < 0$. Therefore $u(s, s^*) - u(s^*, s^*) = u(s, s^*) > 0$. Symmetrically, if $s > s^*$, $u(s, s^*) < 0$. □

[38] If $T^*(\hat{\pi}) = 0$, then $\hat{\pi} \leq 0$ and $\Delta[\hat{\pi}, T] > 0$ for any $T > 0$, a contradiction.

Step 2: Any equilibrium is a threshold equilibrium.

See Online Appendix.

Proof of Proposition ??

We show here that π^* is an increasing function of i, which together with the discussion in the main text, proves Proposition **??**.

Let $T(q,i)$ be defined as in (**??**), with the addition of the second argument explicitly recognizing its dependence on i. Let

$$U(\pi) \equiv \int_0^1 \Delta[\pi, T(q,i)]dq.$$

Note that π^* solves $U(\pi) = 0$. Note also that $U'(.) < 0$, and from (**??**), $T(q,i)$ is increasing in i. Consider two cases,

(a) $T_h(i) \geq \iota$

Then, for any $q \in [0,1)$, $T(q,i) > \iota$, and therefore $\frac{\partial \Delta}{\partial T}[\pi^*, T(q,i)] > 0$. This, in turn, implies

$$\frac{\partial U}{\partial i}(\pi^*) = \int_0^1 \frac{\partial \Delta}{\partial T}[\pi^*, T(q,i)] \frac{\partial T}{\partial i}(q,i)dq > 0,$$

and finally, by the implicit function theorem,

$$\frac{\partial \pi^*}{\partial i} = -\frac{\frac{\partial U}{\partial i}(\pi^*)}{U'(\pi^*)} > 0.$$

(b) $T_h(i) < \iota$

Let

$$\hat{q}(i) \equiv \frac{i}{p_h(\iota)}. \tag{13}$$

$$\begin{aligned} U(\pi^*) &= \int_0^{\hat{q}(i)} \{\rho(\pi^* + \alpha_+)p_d[T(q,i)] - \pi^* p_h[T(q,i)]\}dq - \int_{\hat{q}(i)}^1 \pi^* p_h[T(q,i)]dq \\ &= \hat{q}(i)[\rho(\pi^* + \alpha_+) - \pi^*] - \int_0^{\hat{q}(i)} \{\rho(\pi^* + \alpha_+)[1 - p_d[T(q,i)]] - \pi^*[1 - p_h[T(q,i)]]\}dq \\ &\quad + \int_{\hat{q}(i)}^1 \pi^*[1 - p_h[T(q,i)]]dq \end{aligned} \tag{14}$$

If $q < \hat{q}(i)$, then $1 - p_d[T(q,i)] = e^{\iota/\lambda}[1 - p_h[T(q,i)]]$. Using $qp_h[T(q,i)] + (1-q)\rho p_d[T(q,i)] = i$, we get

$$1 - p_d[T(q,i)] = e^{\iota/\lambda}[1 - p_h[T(q,i)]] = e^{\iota/\lambda} \frac{q + (1-q)\rho - i}{q + (1-q)\rho e^{\iota/\lambda}}. \tag{15}$$

Hence, the first integral in (**??**) becomes

$$[\rho e^{\iota/\lambda}(\pi^* + \alpha_+) - \pi^*] \int_0^{\hat{q}(i)} \frac{q + (1-q)\rho - i}{q + (1-q)\rho e^{\iota/\lambda}} dq. \tag{16}$$

If $q > \hat{q}(i)$, then $p_d[T(q,i)] = 0$. Using this in $qp_h[T(q,i)] + (1-q)\rho p_d[T(q,i)] = i$, we get $1 - p_h[T(q,i)] = \frac{q-i}{q}$. Hence, the second integral in (**??**) becomes

$$\pi^* \int_{\hat{q}(i)}^1 \frac{q-i}{q} dq \tag{17}$$

Consider the first line of equation (**??**). $U(\pi^*)$ depends on i both through the boundaries of the integrals (via $\hat{q}(i)$) and through the integrands (via $T(q,i)$). However, since $p_d[T(\hat{q}(i)), i] = 0$, the effect of a marginal change in i that goes through $\hat{q}(i)$ cancels out. Hence, using (**??**) and (**??**) to substitute into the second line of (**??**), we obtain

$$\frac{\partial U}{\partial i}(\pi^*) = [\rho e^{\iota/\lambda}(\pi^* + \alpha_+) - \pi^*] \int_0^{\hat{q}(i)} \frac{1}{q + (1-q)\rho e^{\iota/\lambda}} dq - \pi^* \int_{\hat{q}(i)}^1 \frac{1}{q} dq. \tag{18}$$

Now, if $q > \hat{q}(i)$,

$$\frac{1}{q} = \frac{p_h[(T(q)]}{i}, \tag{19}$$

In addition, rearranging (**??**),

$$p_d[T(q)] = \frac{q(1-e^{\iota/\lambda}) + e^{\iota/\lambda} i}{q + (1-q)\rho e^{\iota/\lambda}} \text{ and } p_h[T(q)] = \frac{(1-q)\rho(e^{\iota/\lambda} - 1) + i}{q + (1-q)\rho e^{\iota/\lambda}},$$

which, since $e^{\iota/\lambda} > 1$, implies

$$\frac{p_d[T(q)]}{e^{\iota/\lambda} i} < \frac{1}{q + (1-q)\rho e^{\iota/\lambda}} < \frac{p_h[T(q)]}{i}. \tag{20}$$

Finally, using (**??**), (**??**) and (**??**),

$$i \frac{\partial U}{\partial i}(\pi^*) > \rho(\pi^* + \alpha_+) \int_0^{\hat{q}(i)} p_d[T(q)] dq - \pi^* \int_0^1 p_h[T(q)] dq$$

The RHS of this last inequality is $U(\pi^*) = 0$, and using again the implicit function theorem concludes the proof. □

Proof of Proposition ??

We show here that π^* is a decreasing function of $\frac{\iota}{\lambda}$, which together with the discussion in the main text, proves Proposition **??**.

As in (**??**), let

$$\hat{q}(\iota/\lambda) \equiv \frac{i}{1 - e^{-\iota/\lambda}}.$$

We have

$$U(\pi^*) = \int_0^{\min\{\hat{q}(\iota/\lambda),1\}} \{\rho(\pi^* + \alpha_+)p_d[T(q)] - \pi^* p_h[T(q)]\}dq - \int_{\min\{\hat{q}(\iota/\lambda),1\}}^1 \pi^* p_h[T(q)]dq$$

Note that $U(\pi^*)$ depends on λ and ι both through the boundaries of the integrals and, implicitly, through the functions $p_d(.)$ and $p_h(.)$, that is, the probabilities of execution under each strategy. However, $p_d[T(\hat{q}(\iota/\lambda))] = 0$, and hence, the effect of a marginal change in λ or in ι on the integral boundaries cancels out. As a result, differentiating $U(\pi^*)$ with respect to λ or ι only requires differentiating the integrands.

Let $x \equiv e^{\iota/\lambda}$. Using equations (**??**), (**??**) and (**??**), one obtains

$$\frac{\partial U(\pi^*)}{\partial x} = -\frac{\partial}{\partial x}\left\{[\rho x(\pi^* + \alpha_+) - \pi^*]\int_0^{\min\{\hat{q}(\iota/\lambda),1\}} \frac{q + (1-q)\rho - i}{q + (1-q)\rho x} dq\right\}. \tag{21}$$

It is easy to check that the expression between brackets is increasing in x. Therefore

$$\frac{\partial \pi^*}{\partial x} = -\frac{\frac{\partial U}{\partial x}(\pi^*)}{U'(\pi^*)} < 0.$$

This, in turn, implies that π^* is decreasing in ι and increasing in λ. □

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