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Deposit Clustering

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Abstract

We study the impact of deposit clustering on the likelihood of a bank run. In our model, a bank's continuum of depositors partition into K communities. Depositors in the same community observe almost-identical information about the bank. Clustering makes depositors more inclined to run, and more so with greater clustering into fewer communities. Yet, joining a community is privately optimal for an individual depositor. Our findings point to the risks of deposit clustering, as seen in the 2023 bank runs. We show that diversification of the depositor base, via the mechanism different from asset diversification, can mitigate the bank run risk and requires regulatory effort.

Keywords: Global games, bank runs.

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1 Introduction

The banks that suffered runs in early 2023 exhibited one salient feature: Their depositors were in close-knit communities. The Silicon Valley Bank's depositors clustered in the technology industry and were connected through venture capital networks, the Silvergate Bank's in crytocurrency, and the Signature Bank's in law, real estate, and more recently also in crytocurrency.[1] Socially connected depositors were also prominent in the Panic of 1930 among the particularly hard-hit small rural banks, whose depositors were typically local and worked in the agricultural sector. Empirically, depositors in the same community receive correlated information from clustered sources and thus tend to make identical run choices (Kelly and Ó Gráda, 2000; Iyer and Puri, 2012). However, does correlated information make depositors more inclined to run? Is a bank more fragile when its depositors cluster in fewer communities? If so, why would a bank's depositors cluster in the first place?

We model deposit clustering in an otherwise standard global games framework: A bank's depositors cluster in multiple communities, within each they receive near-identical information about the bank that is engaged in liquidity transformation. We show that clustering makes depositors strictly more inclined to run, and more so as depositors cluster into fewer, larger communities. Yet, clustering is privately optimal despite raising the social costs runs.

Underlying our result is an inherent positive correlation between the marginal depositor's strategic uncertainty and fundamental uncertainty, in that she believes fewer other depositors would run conditional on a better fundamental. With a better fundamental, the depositor is also more concerned about others running because runs are more detrimental to her payoff when the bank's liquidated project would have otherwise generated a high payoff. Thus, the positive correlation between the two uncertainties alleviates this concern—the depositor cares the most about others running precisely when she believes the fewest would run. In contrast, a weaker correlation would heighten this concern and raise the depositor's incentive to run.

Clustering into fewer communities monotonically weakens the positive correlation between the two uncertainties. Specifically, since all depositors within a community act upon

[1] Several post-mortem book chapters and policy reports highlight that these banks had heavily sectorally and socially concentrated depositor bases (Beck et al., 2024; Adrian et al., 2023; Acharya et al., 2023, 2024).

almost the same information, that quasi-common information overshadows the true fundamental in forecasting the behavior of other within-community depositors. With fewer, larger communities, clustering decouples the fundamental uncertainty from an increasingly larger component of the strategic uncertainty and thus makes depositors more inclined to run.

Our model of deposit clustering builds upon the classic work of global games and bank runs, with one key departure.[2] A bank's continuum of depositors cluster in K communities of equal size. Every depositor i within a community k observes a noisy signal about the bank's fundamental θ, subject to a common community noise and an infinitesimal idiosyncratic noise. We show that the model subsumes a canonical global game without clustering as the limiting case of infinitely many communities, $K \to \infty$, each comprising only one depositor. The remaining setup is otherwise standard. Upon observing her signal, every depositor may choose to run. A depositor has a stronger incentive to run if a larger proportion n of others do so (strategic complementarity) or if the fundamental θ is worse (state monotonicity). We assume a general payoff function, only requiring the gain from choosing one action rather than the other to be separable in θ and n or a sum of any such separable functions.

A unique equilibrium exists and is a switching equilibrium, wherein depositors run upon observing a signal below a run threshold θ_K^*. The two signal noises together generate the strategic uncertainty—the core feature of global games that ensures equilibrium uniqueness. Specifically, the marginal depositor observing the threshold signal θ_K^* is uncertain about the proportion of runners in other communities because of the community noises and also uncertain about the proportion of runners in her own community because of the idiosyncratic noises. We show that the equilibrium run threshold θ_K^* strictly and monotonically increases with greater clustering into fewer communities, making depositors more likely to run.

Clustering incentivizes runs by *decoupling* the marginal depositor's fundamental uncertainty and strategic uncertainty. Specifically, clustering impacts neither uncertainty's distribution:[3] *(i)* Regardless of degree of clustering, $K \in [1, \infty]$, the marginal depositor's strategic

[2] Diamond and Dybvig (1983) pioneered the literature on bank runs. Carlsson and Van Damme (1993) originated global games as an equilibrium selection theory. Morris and Shin (1998) started the applied literature, introducing global games to currency attack. Goldstein and Pauzner (2005) applied them to bank run.

[3] The literature usually summarizes each "uncertainty" by the respective own posterior distribution. Our results emphasize that this approach entails a loss of information because it misses the interdependence between the two uncertainties which is captured by their the joint distribution.

belief is always Laplacian, $n \sim \text{Uniform}(0,1)$. Upon observing a signal, a depositor expects that others likely observed similar signals. A signal is thus uninformative about its ranking within the population of signals, and each depositor expects her signal's ranking to be uniformly random. *(ii)* A depositor's posterior belief about the fundamental θ does not change either. Rather, clustering affects their joint distribution by weakening the positive correlation between the two uncertainties.

To illustrate decoupling, we compare two extreme cases: no clustering, $K = \infty$, and maximum clustering where all depositors cluster into $K = 1$ community. With no clustering, the two uncertainties are positively correlated: A better fundamental implies fewer others would observe a signal below threshold θ^*_∞ and run. With maximum clustering, the two uncertainties become fully independent: A depositor knows that all others act upon an almost identical signal, thus her signal is a sufficient statistic for resolving her strategic uncertainty, and the true fundamental contains no incremental information relevant for a depositor to infer the choice of others. Because the expected payoff gain from running increases with the correlation between the two uncertainties, the decoupling increases incentives to run.

Between these two extreme cases, clustering partially decouples the two uncertainties. With $K \in (1, \infty)$ communities, the true fundamental is independent of a depositor's uncertainty about the proportion of runners in her own community. Fewer, larger communities, decouples the fundamental uncertainty from a larger component of the strategic uncertainty, making depositors monotonically more inclined to run. Therefore, clustering raises the mass of runners and thus the real cost of liquidations in *all* fundamental states, and strictly so *ex-ante*.

It is however privately optimal for a depositor to choose a bank where she would be part of a community, *ceteris paribus*, because then observing any non-threshold signal would in addition reveal the choice of other depositors within her community.

How large is the impact of clustering? In a numerical example, moving from $K = 2$ to $K = 1$ community is equivalent to a reduction of 4.17% in the project's return in terms of raising the *ex-ante* liquidation cost from runs.

Why do not regional banks diversify their deposits? Unlike assets, a regional bank's branches are limited to a specific area, meaning its depositor base is typically drawn from the

same clients. As we show, this clustering is also privately optimal for depositors. Therefore, our findings suggest a role for regulators: When reviewing mergers, regulators should assess how the merger would diversify a bank's deposit base. For example, a merger between a bank in San Francisco and one in Iowa could be beneficial, while a merger between Signature and Silvergate would not.

As diversification of asset holdings reduces the risk of portfolio return, we establish the new result that diversification on the funding side reduces the risk of bank run. However, diversifications of asset and funding have fundamentally different mechanisms and implications. Asset diversification does not change each asset's return, crucially relies on an investor's risk aversion, and generates benefit through aggregation of consumption across all states of the world. In our model, diversification of funding endogenously reduces each depositor's incentive to run and lowers the run risk for both risk neutral and risk averse banks in any "run-prone" state of the world (that is, for any fundamental outside the dominance regions). As a result, when an investor, such as an active fund, believes he possesses superior information about asset returns, it may choose to forgo the benefit of diversification. Diversification of funding is a no-brainer for a social planner, who need not do any guess work on the fundamental state of the world.

We differentiate deposit clustering from two resembling concepts: size concentration and risk concentration. *(i)* Clustered depositors might be able to make their withdrawal decisions jointly, effectively acting as one large depositor. Deposit clustering encompasses communication to and among clustered depositors, allowing them to coordinate their run decisions. As an example, many venture capitalists (VCs) advised their clients to withdraw from SVB in the early hours of the bank run. Upon receiving such information, we assume that each depositor is still free to make her own decision. Deposit clustering does not contain the case where a VC can make the run decisions on behalf of their clients. *(ii)* Depositors may experience exogenous liquidity shocks that force them to withdraw, and these shocks are more likely to be correlated among clustered depositors. In theory, exogenous and correlated liquidity shocks function like undiversifiable risk in portfolio returns. For them to negatively affect the prospect of a bank run, depositors' run incentive need to be concave in the proportion of other depositors withdrawing, an assumption uncommon in the bank run

literature. Our mechanism operates through endogenous runs alone and our results do not require concavity in run incentives. In practice, a shocked depositor could borrow or sell her certificate deposit on the secondary market to avoid the interest penalty of early withdrawal, making liquidity shocks unlikely to drive panic runs.

Significant informational clustering and reliance on social networks in the past is not surprising given likely scarcity of common sources of information. However, informational clustering persists even in the modern age despite significant improvements in communication technology and widespread access to common sources of public information. For instance, recent evidence suggests that different social media platforms can generate divergent responses to similar public information. Indeed, Cookson et al. (2024b) examine attention and sentiment on several platforms (Twitter, StockTwits, and Seeking Alpha) towards publicly traded firms and find that sentiment is not highly correlated across platforms. Moreover, Cookson et al. (2023) show that information clustering can arise even on the same platform.

Our contributions are detailed in Section 7. In summary, *(i)* We uncover an inherent positive correlation between an agent's fundamental and strategic uncertainties in coordination games. This correlation is a general property of all coordination games yet never exploited in existing papers. Under general payoff functions, this correlation tilts an agent's choice toward an action that is consistent with a better fundamental. *(ii)* We propose a mechanism that decouples the fundamental and the strategic uncertainties with conditionally correlated signals. *(iii)* This mechanism provides a new result: Conditionally correlated signals tilt agents' choices downward to an action that is consistent with a worse fundamental. This result answers a basic question: What is the information structure that induces fewer agents to choose an inefficient action (run on a bunk, attack a currency regime, underinvest in a project, etc.)? *(iv)* We introduce a framework to study conditionally correlated signals. The framework guarantees equilibrium uniqueness.

The rest of the paper is organized as follows. Section 2 builds a model of deposit clustering upon the classic global games framework. Section 3 shows how clustering makes depositors more inclined to run by decoupling the strategic and the fundamental uncertainties. Section 4 shows that clustering is privately optimal. Section 5 benchmarks the effect of deposit clustering. Section 6 discusses policy implications of our results and other applications of

our framework. Section 7 describes our contribution. The last section concludes.

2 Model

2.1 Setup

We model deposit clustering in an otherwise standard three-period global games framework.

Bank. At $t = 0$, a bank collects one unit of demand deposit from each of a continuum of depositors $i \in [0, 1]$. The bank invests the deposits in a project that matures at $t = 2$. The gross return on the investment is a function of θ, which represents the fundamental quality of the investment. The fundamental θ follows a uniform distribution $\text{Unif}(\underline{\theta}, \bar{\theta})$.

To honor any depositors' withdrawal demands at $t = 1$, the bank has to liquidate some of the long-term investment. The liquidations incur real costs. If the bank has to raise S units of funds, the real cost is $c(S)$ such that $c(S)$ is an increasing and weakly convex function with $c(0) = 0$ (we discuss this and other assumptions in the next section).

Depositor Communities. A unit-mass of depositors form K equal-sized communities. In the interim period $t = 1$, each depositor i in community k receives a private noisy signal about the fundamental θ,

$$x_{K,i} = \theta + \sigma\varepsilon_k + \delta\nu_i, \tag{1}$$

where $\sigma\varepsilon_k$ is the common noise all depositors in community k are exposed to and $\delta\nu_i$ is the idiosyncratic noise of depositor i. The community noise ε_k is independent across communities and identically distributed with a cumulative distribution function (CDF) $F(\varepsilon)$ and the idiosyncratic noise ν_i is independent across depositors and identically distributed with a CDF $G(\nu)$. Both CDFs F and G are continuous and have support $[-\frac{1}{2}, \frac{1}{2}]$. We fix the magnitude $\sigma > 0$ of the community noise and consider a vanishingly small idiosyncratic noise, $\delta \to 0$. Upon observing her signal, each depositor i decides whether to withdraw early at $t = 1$ ("run") or to wait until $t = 2$.

Depositor Payoffs. We let n denote the mass of depositors who run. The payoff gain from

staying over running is

$$v(\theta, n) = \sum_{h=1}^{H} R_h(\theta) u_h(n), \tag{2}$$

where $R_h(\theta)$ is weakly increasing in θ and not a constant, $u_h(n)$ is weakly decreasing in n and not a step function. Depositors are risk neutral and have no time preference.

Finally, as it is common in the global games literature, we assume that the state space $[\underline{\theta}, \bar{\theta}]$ of the fundamental is wide enough so that there are two dominance regions. In the lower dominance region, $\theta \in [\underline{\theta}, \theta_L)$, the depositor's payoff is such that her best action is to run regardless of her belief about the behavior of the other depositors while, in the upper dominance region, $\theta \in (\theta_U, \bar{\theta}]$, the depositor's payoff is such that her best action is to stay regardless of her belief about the behavior of the other depositors. To guarantee that there are θ for which all agents receive signals that assure them that the fundamental is in the respective dominance region, we assume $\theta_L > \underline{\theta} + \sigma$ and $\theta_U < \bar{\theta} - \sigma$.

2.2 Discussion

That the payoff gain $v(\theta, n)$ from staying with the bank is monotonic in the mass n of runners and fundamental θ are the standard strategic complementarity and state monotonicity in global games, respectively (Morris and Shin, 2003). We assume a general payoff function, requiring $v(\theta, n)$ to be only separable in θ and n or a sum of any such separable functions. Therefore, $v(\theta, n)$ can (1) have a downward jump at certain n to capture the liquidation of an indivisible asset when the mass n of runners crosses above a critical value, (2) have a kink at certain n to reflect the transition into a different type of asset, as a less liquid asset with a greater liquidation loss would make $v(\theta, n)$ more sensitive to n, or (3) be flat for a range of n when no costly liquidation occurs in this range.

Depositors from the same echo chamber receive information that is exposed to the same error, which we model as the cluster noise $\sigma\varepsilon_k$. Our focus on the importance of local common information during a bank run is inspired by the literature that uncovers the role of depositor social networks. Kelly and Ó Gráda (2000) examine behavior of Irish immigrants during two bank runs in 1854 and 1857 and show that a depositor's social network—primarily determined by their county of origin in Ireland—was a key factor in whether they withdrew

money. Importantly, Kelly and Ó Gráda (2000) identify clustering of depositors' decisions: Individuals from one set of counties tended to close their accounts, while otherwise identical depositors from other counties tended to stay with the bank. Analyzing a more recent run from 2001, Iyer and Puri (2012) show that a depositor is more likely to run if other depositors in their social network do the same.

Several papers in the literature on the 2023 bank runs provide empirical results suggestive of the importance of public signals.[4] Cookson et al. (2024a) show that banks with higher social media attention are associated with a higher likelihood of stress while Cipriani et al. (2024) show that banks with publicly traded stock experience significantly higher deposit outflows.[5] These empirical results are consistent with the prediction of our paper that a higher information commonality makes depositors more run-prone.

In addition, we assume a vanishingly small idiosyncratic noise $\delta\nu_i$, a standard global games technique to avoid equilibrium multiplicity.

Below, we study the effect of depositors clustering into a smaller number K of bigger echo chambers. While reducing K, we keep all other parameters constant to avoid the contamination of other effects. For example, we fix the magnitude of the depositors' signal noise about the fundamental to avoid any mechanical effect of the fundamental uncertainty on runs.

With a non-vanishing noise, we assume a uniform prior of the fundamental θ so that the posterior $\frac{1}{\sigma}f(\frac{x_i-\theta}{\sigma})$ does not depend on the prior's parameters, another common global games technique to minimize the prior's role in determining outcomes and to ensure equilibrium uniqueness (Morris and Shin, 1998).

The real cost $c(S)$ of liquidations may arise because the outside investors who acquire the bank's investments need to raise capital, which is costly due to financial frictions in the capital market (such as information asymmetry Myers and Majluf (1984), agency costs Jensen and Meckling (1976), etc.), or the outside investors are less efficient than banks in managing the investments (Shleifer and Vishny, 1992; Kiyotaki and Moore, 1997).

[4]Among other notable papers in the literature on the 2023 runs are Koont et al. (2024) and Benmelech et al. (2023) who point out that digital banking can increase the speed of deposit outflows during a run.

[5]Empirically, Cipriani et al. (2024) show that concentration of uninsured depositors is a significant predictor of a bank run even after controlling for the fraction of uninsured deposits in the total bank funding.

3 Equilibrium and Mechanism

This section establishes the equilibrium results and delineates the mechanism. *(i)* The model's unique equilibrium is a switching strategy equilibrium, where depositors run upon observing a signal below a run threshold (Proposition 1); *(ii)* Our setup nests a conventional model of bank run without deposit clustering as the limiting case of infinitely many small communities, $K \to \infty$, each comprising only one depositor (Proposition 2); *(iii)* Deposit clustering strictly raises the equilibrium run threshold, and more so as depositors cluster into fewer, larger communities (Theorem 1); and *(iv)* The social cost of runs increases with a higher degree of depositor clustering (Proposition 5). Finally, to explain the mechanism, we show that deposit clustering raises depositors' run incentives by decoupling the fundamental uncertainty and the strategic uncertainty of the marginal depositor (Proposition 4).

3.1 Unique Equilibrium

We first characterize the unique equilibrium of the model.

Proposition 1. *In the unique equilibrium surviving iterated deletion of dominated strategies, every depositor i runs if and only if her signal is below a threshold, $x_{K,i} < \theta_K^*$.*

We apply a global games technique and assume the idiosyncratic noise ν_i to avoid equilibrium multiplicity. Without the idiosyncratic noise ν_i, all depositors within the same community would observe an identical signal $\theta + \sigma\varepsilon_k$ and may decide to take any given action because of their self-fulfilling belief that others within the same community are taking the same action. The indeterminacy of within-community beliefs may lead to multiple equilibria. Inserting an idiosyncratic noise ν_i to every depositor's private signal pins down which within-community belief will prevail in equilibrium, similar to how global games resolve the indeterminacy of beliefs (Morris and Shin, 2003). The proof of Proposition 1 extends that of Proposition 2.1 in Morris and Shin (2003) to a setting with deposit clustering (all proofs are in Section A).

The equilibrium run threshold θ_K^* is determined by the indifference condition of a marginal depositor who observed the threshold signal θ_K^*. This depositor has to be indifferent between

staying and running:

$$\mathbb{E}\left[R(\theta)u(n) \,|\, x_{K,i} = \theta_K^*\right] = 0. \tag{3}$$

This condition and the threshold θ_K^* intimately depend on the depositor's uncertainty about both the fundamental θ and the strategic state n. Below, we show that deposit clustering decouples the two uncertainties and therefore has a non-trivial impact on the threshold θ_K^*.

3.2 Infinite Clustering as Conventional Model

We first show that our model naturally extends to the case with the infinite number of communities.

With $K = \infty$ small communities, each comprising only one depositor, the community noise ε_k effectively becomes idiosyncratic and our model intuitively approximates a conventional model of bank run without deposit clustering, where each depositor i observes signal

$$x_i = \theta + \sigma\varepsilon_i, \qquad \varepsilon_i \overset{\text{iid}}{\sim} F.$$

(The other idiosyncratic noise $\delta\nu_i$ is vanishingly small and can be removed without affecting the signal structure.) This conventional model is under the standard global games framework and thus has a unique equilibrium in which depositors follow a switching strategy. We let θ_∞^* denote this model's equilibrium run threshold that is determined by the familiar indifference condition of the marginal depositor,

$$\mathbb{E}[R(\theta)u(n) \,|\, x_i = \theta_\infty^*] = 0. \tag{4}$$

The next result formalizes this intuitive approximation.

Proposition 2. *As the number of communities approaches infinity, $K \to \infty$, the equilibrium run threshold converges to the one without deposit clustering, $\theta_K^* \to \theta_\infty^*$.*

Proposition 2 shows that our setup nests the conventional model without depositor clustering as the limiting case of infinitely many small communities, $K \to \infty$. Thereby, Proposition 2 allows us to study the effect of varying degrees of depositor clustering on the equi-

librium run threshold θ_K^* as a comparative statics on the number K of communities within our model, starting from no clustering $K = \infty$ to greater clustering into fewer communities.

3.3 The Effect of Deposit Clustering

We now present our main result and explain the mechanism behind it.

Theorem 1. *The equilibrium run threshold θ_K^* strictly and monotonically increases as the number of communities K decreases.*

Theorem 1 establishes that deposit clustering strictly raises the equilibrium run threshold, $\theta_\infty^* < \theta_K^*$, and more so as depositors cluster into fewer communities. Deposit clustering raises depositors' run incentives by decoupling the fundamental uncertainty and the strategic uncertainty of the marginal depositor. We next derive each uncertainty's distribution and show that clustering increasingly weakens the positive correlation between the two.

Fundamental and Strategic Uncertainties. For any given degree of deposit clustering, $K \in [1, \infty]$, the marginal depositor who observes the threshold signal θ_K^* is uncertain about both the fundamental θ and the strategic state n. Her posterior belief about the fundamental θ is given by $\frac{1}{\sigma} f\left(\frac{\theta_K^* - \theta}{\sigma}\right)$, and she holds the Laplacian belief $\text{Unif}(0,1)$ about the strategic state n.

Proposition 3. *The marginal depositor's belief about the strategic state n is* $\text{Unif}(0,1)$.

The Laplacian property holds for any given degree of deposit clustering, $K \in [1, \infty]$. With a uniform prior on θ and an infinitesimally small idiosyncratic noise, $\delta \ll 1$, observing a signal $x_{K,i} = \theta + \sigma\varepsilon_k + \delta\nu_i$ gives no information about either the signal's community noise ε_k nor its idiosyncratic noise ν_i, and thus gives no information about the signal's ranking within the population of signals. That is, the signal's rank is uniformly distributed. Therefore, the strategic belief of a marginal depositor, which coincides with her rank, is uniform—an extension of the belief constraint of (Sákovics and Steiner, 2012) to clustered signals.

Uncertainty Decoupling. To see how deposit clustering decouples the strategic uncertainty from the fundamental uncertainty, we first compare the conventional case of no deposit

clustering, $K = \infty$, to the other extreme case of maximum deposit clustering where all depositors belong to the same community, $K = 1$.

In the conventional case of no deposit clustering ($K = \infty$), the two uncertainties have the perfect Spearman rank correlation of 1, in that resolving one uncertainty is equivalent to resolving the other. A better realization of the fundamental uncertainty (a higher θ) is equivalent to a better realization of the strategic uncertainty (a lower proportion n of runners). Precisely, if the true fundamental state is θ, the law of large number implies that the strategic state n—the proportion of depositors observing a signal less than the threshold signal θ^*_∞—is deterministic and equal to

$$n = F\left(\frac{\theta^*_\infty - \theta}{\sigma}\right). \tag{5}$$

In the other extreme case of maximum deposit clustering ($K = 1$), the two uncertainties become fully independent, in that the realization of one uncertainty contains no information for resolving the other. Intuitively, since all depositors observe and act upon an almost identical signal, the quasi-common signal overshadows the true fundamental θ, making θ irrelevant for resolving the strategic uncertainty. Precisely, each signal $x_{K,i}$ is the sum of the common community signal $\theta + \sigma\varepsilon_k$ and an idiosyncratic noise $\delta\nu_i$. Thus, the community signal $\theta + \sigma\varepsilon_k$ is strictly more relevant for the signals $(x_{K,i})_{i\in[0,1]}$ than the true fundamental θ, which contains no incremental information relevant to the signals $(x_{K,i})_{i\in[0,1]}$,

$$\mathcal{D}((x_{K,i})_{i\in[0,1]} \,|\, \theta + \sigma\varepsilon_k, \theta) = \mathcal{D}((x_{K,i})_{i\in[0,1]} \,|\, \theta + \sigma\varepsilon_k).$$

Here, $\mathcal{D}$ denotes "distribution." Upon an almost perfect observation of the community signal $\theta + \sigma\varepsilon_k$, with only an infinitesimally small error $\delta\nu_i$ in interpreting the signal, a depositor cannot extract any incremental information from the true fundamental θ for resolving her strategic uncertainty,

$$\mathcal{D}(n \,|\, x_{K,i}, \theta) = \mathcal{D}(n \,|\, x_{K,i}).$$

To summarize, the marginal depositor's posterior belief about the fundamental θ is given by $\frac{1}{\sigma} f\left(\frac{\theta^*_K - \theta}{\sigma}\right)$, and she holds the same Laplacian belief $\text{Unif}(0,1)$ about the mass n of

runners in both cases. In the conventional case of no deposit clustering ($K = \infty$), a better fundamental θ is equivalent to fewer runners for the marginal depositor. With maximum clustering, the proportion n of runners is independent of the fundamental θ for the marginal depositor. Figure 1 provides an illustration.

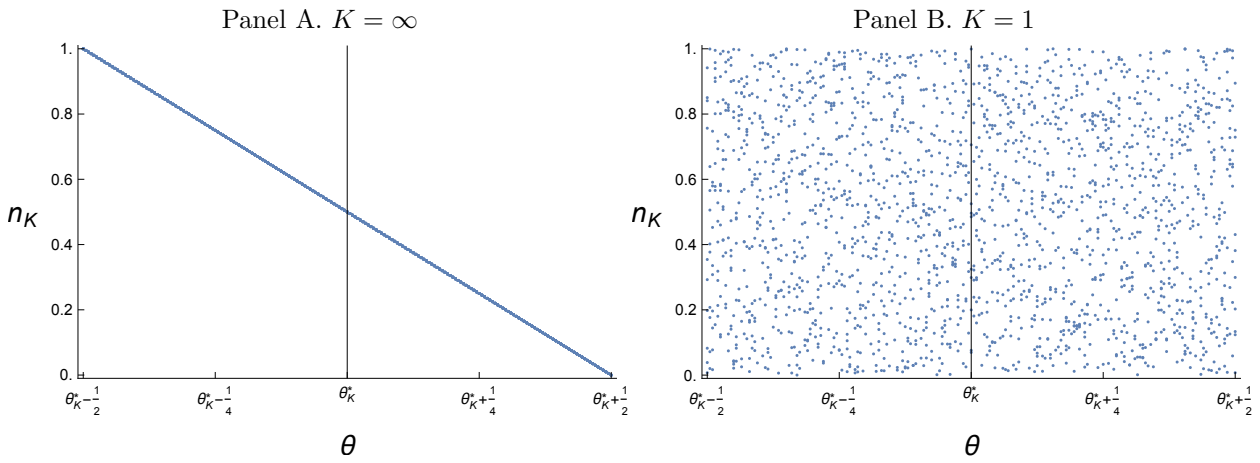


Figure 1. The joint beliefs of the marginal depositor: Uncertainty decoupling. These figures plot a sampled distribution of the marginal depositor's joint fundamental and strategic uncertainty (θ, n_K) for $K \in \{1, \infty\}$. In the graph, we consider a setting with $\sigma = 1$, $\varepsilon \sim \text{Unif}(-\frac{1}{2}, \frac{1}{2})$.

The decoupling implies that the maximum clustering must induce a higher equilibrium run threshold than no clustering, $\theta_K^* > \theta_\infty^*$ $(K = 1)$. If the equilibrium run thresholds were identical in the two cases, $\theta_K^* = \theta_\infty^*$, the marginal depositor with maximum clustering would strictly prefer to run,[6]

$$\begin{aligned} 0 &= \mathbb{E}[R(\theta)u(n) \,|\, x_i = \theta_\infty^*] \\ &> \mathbb{E}[R(\theta) \,|\, x_i = \theta_\infty^*]\, \mathbb{E}[u(n) \,|\, x_i = \theta_\infty^*] \\ &= \mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta_K^*]\, \mathbb{E}[u(n) \,|\, x_{K,i} = \theta_K^*] \\ &= \mathbb{E}[R(\theta)u(n) \,|\, x_{K,i} = \theta_K^*]. \end{aligned} \tag{6}$$

The inequality follows because the payoff $u(n)$ is decreasing in n, strategic complementarity,

[6]The same contradiction follows if $\theta_K^* < \theta_\infty^*$, in which case the second equality $=$ in (6) becomes a strict inequality $>$ due to

$$\mathbb{E}[R(\theta) \,|\, x_i = \theta_\infty^*] > \mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta_K^*].$$

and $R(\theta)$ is increasing in θ. Indeed, a better fundamental θ amplifies the strategic complementarity, making the depositor more sensitive to the mass n of runners,

$$\frac{\partial^2 v(\theta, n)}{\partial \theta \partial n} < 0, \tag{7}$$

as early withdrawals are more detrimental to her payoff when the liquidated project would have otherwise generated a high return. With no clustering, a better fundamental θ also implies fewer others running. Together, the depositor cares the most about mass n of runners precisely when the fewest would run. Therefore, the depositor's run incentive is strictly lower than if the fundamental θ and the mass n of runners were independent for her.

Partial Uncertainty Decoupling. Between these two extreme cases, the equilibrium run threshold θ_K^* monotonically increases with the degree of deposit clustering. An intermediate degree of deposit clustering "partially decouples" the strategic uncertainty from the fundamental uncertainty, and makes them monotonically "closer" to being fully independent with fewer communities. To see how, we write the strategic uncertainty n as the simple average of the uncertainties $n_{K,\ell}$ in each of the K communities,

$$n_K = \frac{1}{K} \sum_{\ell=1}^{K} n_{K,\ell}. \tag{8}$$

For the marginal depositor, her within-community uncertainty $n_{K,k}$ is independent of the fundamental θ,

$$\mathcal{D}(n_{K,k} \,|\, x_{K,i}, \theta) = \mathcal{D}(n_{K,k} \,|\, x_{K,i}),$$

because all within-community depositors observe and act upon a nearly identical signal, which overshadows the true fundamental θ in resolving the within-community uncertainty. With a higher degree of clustering, the within-community uncertainty $n_{K,k}$ carries a larger weight $1/K$ in the overall uncertainty n_K, which then becomes more independent of the fundamental θ for the marginal depositor. Figure 2 jointly simulates the couple (θ, n_K) according to the marginal depositor's belief and illustrates how clustering gradually decouples the two uncertainties.

To formalize the increasing independence between the two uncertainties, the proof of

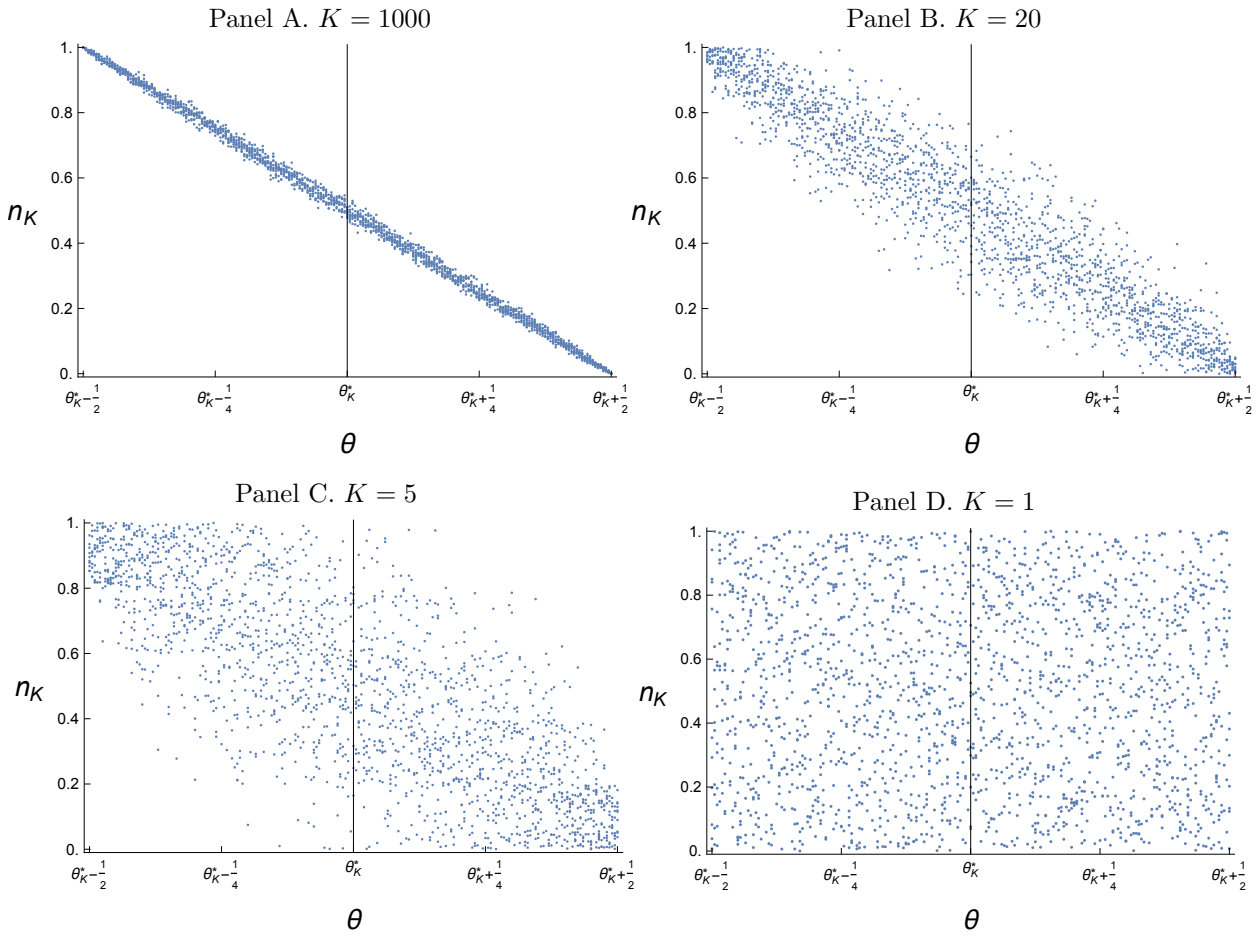


Figure 2. The joint beliefs of the marginal depositor: Partial uncertainty decoupling. These figures plot a sampled distribution of the marginal depositor's joint fundamental and strategic uncertainty (θ, n_K) for $K \in \{1, 5, 20, 1000\}$. In the graph, we consider a setting with $\sigma = 1$, $\varepsilon \sim \text{Unif}(-\frac{1}{2}, \frac{1}{2})$.

Theorem 1 computes the marginal depositor's conditional expectation of the fundamental return given the strategic state n_K, $R_K(n_K) = \mathbb{E}(R(\theta) \,|\, n_K, x_{K,i} = \theta^*_K)$, and shows that it becomes less sensitive to the realization of n_K with a higher degree of clustering. Precisely, assuming that $\theta^*_K = \theta^*_{K+1}$, we show

$$\int_0^n R_K(s)\mathrm{d}s \leq \int_0^n R_{K+1}(s)\mathrm{d}s$$

with the inequality being strict for all $n \in [0,1]$ except a finite subset. The above inequality implies that the conditional distribution $\mathcal{D}[R_K(n_K) \,|\, x_{K,i} = \theta^*_K]$ is a mean-preserving spread of $\mathcal{D}[R_{K+1}(n_{K+1}) \,|\, x_{K,i} = \theta^*_{K+1}]$ if $\theta^*_K = \theta^*_{K+1}$.[7] Figure 3 plots the curves $[0,1] \ni n \mapsto \int_0^n [R_K(s) - R(\theta^*_K)]\mathrm{d}s$ for different values of K.

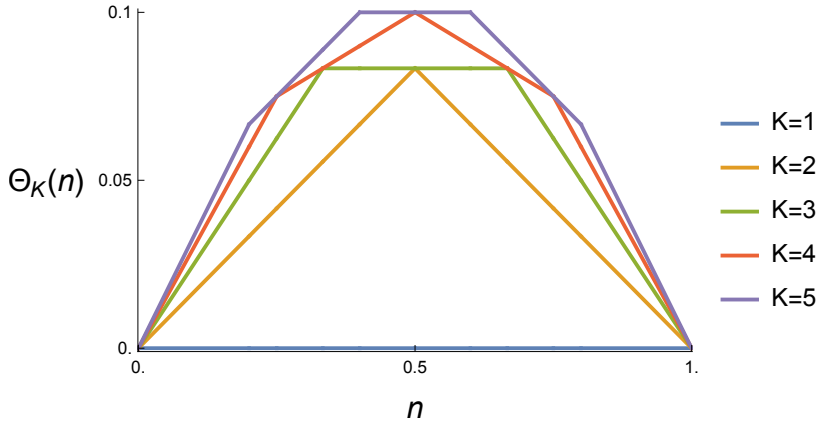


Figure 3. Stochastic ordering of the expected fundamental return conditional on the strategic state. The demeaned integral of the marginal depositor's conditional expectation of the fundamental return $\Theta_K(n) = \int_0^n [R_K(s) - R(\theta^*_K)]\mathrm{d}s$ for $K \in \{1,2,3,4,5\}$. In the graph, we consider a setting with $R(\theta) = \theta$, $\varepsilon \sim \text{Unif}(-\frac{1}{2}, \frac{1}{2})$, and $\sigma = 1$.

Due to the partial decoupling, the equilibrium run threshold increases with a higher degree of clustering, $\theta^*_K > \theta^*_{K+1}$. Otherwise, if $\theta^*_K = \theta^*_{K+1}$, the marginal depositor would

[7] The mean-preserving spread requires only the inequality to be strict for some n.

strictly prefer to run,

$$\begin{aligned}
0 &= \mathbb{E}[R(\theta)u(n) \,|\, x_{K,i} = \theta^*_{K+1}] \\
&= \mathrm{Cov}[R(\theta)u(n) \,|\, x_{K,i} = \theta^*_{K+1}] + \mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta^*_{K+1}]\,\mathbb{E}[u(n) \,|\, x_{K,i} = \theta^*_{K+1}] \\
&> \mathrm{Cov}[R(\theta)u(n) \,|\, x_{K,i} = \theta^*_{K}] + \mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta^*_{K}]\,\mathbb{E}[u(n) \,|\, x_{K,i} = \theta^*_{K}] \\
&= \mathbb{E}[R(\theta)u(n) \,|\, x_{K,i} = \theta^*_{K}]
\end{aligned}$$

The inequality follows because $\mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta^*_{K+1}] = \mathbb{E}[R(\theta) \,|\, x_{K,i} = \theta^*_{K}]$ and $\mathbb{E}[u(n) \,|\, x_{K,i} = \theta^*_{K+1}] = \mathbb{E}[u(n) \,|\, x_{K,i} = \theta^*_{K}]$, as the distributions of the fundamental and strategic uncertainties do not change, while the covariance term decreases due to the weaker correlation between the two uncertainties.

Vanishing Community Noise. We further show that the above mechanism is not only sufficient but also necessary for our results. If the decoupling of the two uncertainties plays a crucial role, then the effect of clustering should vanish when the fundamental uncertainty does.

We let the community noise be infinitesimally small, $\sigma \ll 1$. In this case, the fundamental uncertainty vanishes as a depositor observes an arbitrarily precise signal $x_{K,i} = \theta + \sigma\varepsilon_k + \delta\nu_i$ of the fundamental. Proposition 4 shows that the effect of deposit clustering indeed vanishes as well.

Proposition 4. *If the community noise is infinitesimally small, $\sigma \ll 1$, the equilibrium run threshold θ^*_K does not depend on the number of communities K.*

With an infinitesimal community noise, the marginal depositor's fundamental uncertainty vanishes and her strategic uncertainty remains. The decoupling of the two uncertainties has a minimal effect on the depositors' run incentives. Precisely, upon observing the threshold signal $x_{K,i} = \theta^*_K$, the marginal depositor believes that the fundamental θ is deterministic and equal to her signal $x_{K,i}$ while her strategic belief remains uniform, $\mathcal{D}(n_K \,|\, x_{K,i} = \theta^*_K) = \mathrm{Unif}(0,1)$. Therefore, the depositor's indifference condition does not change with the degree of clustering,

$$\mathbb{E}[R(\theta)u(n) \,|\, x_{K,i} = \theta^*_K] = R(\theta^*_K)\int_0^1 u(n)\,\mathrm{d}n.$$

3.4 Social Cost of Runs

Deposit clustering's effect on the equilibrium run threshold carries over into the cost of runs.

Proposition 5. *The social cost of runs strictly increases as the number K of communities decreases.*

Ex-ante, deposit clustering raises the cost of runs. A higher degree of clustering raises the equilibrium run threshold θ_K^* (Theorem 1). Since each depositor's signal distribution does not change with clustering, each depositor runs with a higher probability $\mathbb{P}(x_{K,i} < \theta_K^*)$, implying *(i)* a larger expected mass $\mathbb{E}\, n_K$ of runners. The proof of Proposition 5 shows that clustering also leads to *(ii)* a more dispersed distribution $\mathcal{D}(n_K)$ of the mass of runners. Together, clustering results in a larger expected mass and dispersion of runners and thus a higher *ex-ante* real cost $\mathbb{E}\, c(n_K)$ of liquidations.

4 Negative Externalities of Deposit Clustering

Given that deposit clustering induces more runs and costly liquidations, why would deposits be clustered in the first place? This section shows that deposit clustering is privately optimal despite being socially inefficient.

Given two banks as in Section 2, we consider whether a depositor i in Bank 1 is better off switching to Bank 2 at $t = 0$. Bank 2 differs to depositor i only in one way: She would no longer find herself to be part of any community in Bank 2. The two banks are otherwise identical to i. Precisely, both banks have identically distributed fundamentals and K deposit communities. Each depositor's signal is exposed to a community noise following distribution F and an idiosyncratic noise following distribution G. Every depositor's payoff is given by (2). Depositor i would observe an equally informed signal $\theta + \sigma\varepsilon_k + \delta\nu_i$ about the fundamental θ of Bank 2, where $\varepsilon_k \sim F$, $\nu_i \sim G$. Her signal would however be conditionally independent of everyone's signal in Bank 2, instead of being exposed to a community noise in Bank 1.

The next result establishes that it is strictly optimal for the depositor to choose Bank 1.

Proposition 6. *Given two banks with identical primitives, any depositor of Bank 1 has a strictly higher ex-ante payoff than that from switching at $t = 0$ to Bank 2, where she would*

not be part of any community.

Being part of a community makes a depositor's signal more payoff relevant, which allows her to make a more informed run decision. Specifically, her fundamental uncertainty remains unchanged if switching to Bank 2. Her strategic uncertainty is nevertheless lower in Bank 1, where her signal is infinitesimally close to other within-community depositors' signals and thus reveals their run decisions almost surely, as long as her signal is not equal to the threshold signal θ_K^*. In contrast, her signal about Bank 2 would be conditionally independent of everyone's signal there and thus would contain no information regarding their run decision conditional on the bank's fundamental θ.

5 Benchmarking the Impact of Deposit Clustering

How large is the impact of clustering in raising the real cost of liquidation? This section benchmarks this impact against that of a reduction in the quality of the bank's assets.

Proposition 7. *An increase in the degree of deposit clustering from K to $K-1$ communities raises the ex-ante liquidation cost $\mathbb{E}\, c(n_K)$ from runs by weakly more than a downward shift of $\theta_{K-1}^* - \theta_K^*$ in the fundamental's prior distribution.*

Proposition 7 states that clustering into one fewer community is equivalent to a reduction of at least $\theta_{K-1}^* - \theta_K^*$ in the bank's fundamental in terms of raising the expected liquidation cost from runs. Clustering raises the equilibrium run threshold by $\theta_{K-1}^* - \theta_K^*$, which has the same impact on the mass of runners as lowering the fundamental by the same magnitude. Having one fewer community also makes the mass of runners more volatile, further raising the liquidation cost.

In a numerical example, moving from $K = 2$ to $K = 1$ community is equivalent to a reduction of 4.17% in the project's return.

Numerical Example. We let $v(\theta, n) = (1+\theta)\left(1 - \frac{n}{B+1}\right) - 1$, $\sigma = 1$, $\varepsilon \sim \text{Uniform}\left(-\frac{1}{2}, \frac{1}{2}\right)$, and define $p(\theta, \theta_K^*) = \frac{1}{2} + \theta_K^* - \theta$.

The marginal depositor's indifference condition is

$$\begin{aligned}
1 &= \mathbb{E}[v(\theta, n(\theta_K^*)) \,|\, x_{K,i} = \theta_K^*] \\
&= \frac{1}{\sigma} \int_{\theta_K^* - \frac{\sigma}{2}}^{\theta_K^* + \frac{\sigma}{2}} (1+\theta)\, \mathbb{E}\left[1 - \frac{n_K}{B+1} \,\middle|\, x_{K,i} = \theta_K^*, \theta\right] \mathrm{d}\theta \\
&= \frac{1}{\sigma} \int_{\theta_K^* - \frac{\sigma}{2}}^{\theta_K^* + \frac{\sigma}{2}} (1+\theta) \left[1 - \frac{1}{(B+1)K}\left(\frac{1}{2} + (K-1)p(\theta, \theta_K^*)\right)\right] \mathrm{d}\theta.
\end{aligned}$$

Solving for θ_K^*, we obtain $\theta_K^* = \frac{(6-\sigma)}{6(1+2B)} + \frac{\sigma}{6(1+2B)}\frac{1}{K}$. Figure 4 plots the equilibrium run threshold θ_K^* as a function of the number K of communities.

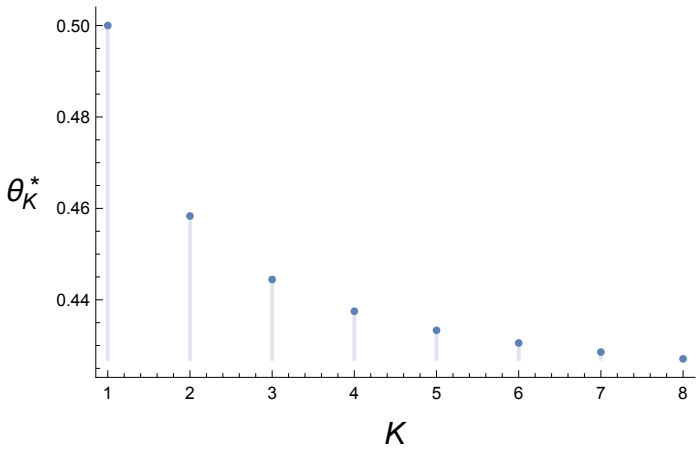


Figure 4. The equilibrium run threshold. In the graph, we consider a setting in which $v(\theta, n) = (1+\theta)\left(1 - \frac{n}{B+1}\right) - 1$ with $B = 0.5$ and $\sigma = 1$, $\varepsilon \sim$ Uniform $\left(-\frac{1}{2}, \frac{1}{2}\right)$.

To evaluate the liquidation cost, we first assume a linear cost $c(n) = c \cdot n$. With K communities, the *ex-ante* cost of liquidation is $\mathbb{E}(cn_K) = c\,\frac{\theta_K^* - \underline{\theta}}{\overline{\theta} - \underline{\theta}}$. Thus, moving from $K = 2$ to $K = 1$ community is equivalent to a reduction of $\theta_1^* - \theta_2^* = \frac{\sigma}{24} = 4.17\%$ in the project's expected return in terms of raising the *ex-ante* liquidation cost.

Alternatively, we assume a quadratic liquidation cost $c(n_K) = c \cdot n_K^2$. With K communities, the *ex-ante* cost of liquidation is $\mathbb{E}\left(cn_K^2\right) = \frac{c}{\overline{\theta} - \underline{\theta}}\left(\theta_K^* - \underline{\theta} - \frac{\sigma}{6} + \frac{\sigma}{6}\frac{1}{K}\right)$. Thus, moving from $K = 2$ communities to $K = 1$ community is equivalent to a reduction of $\theta_1^* - \theta_2^* + \frac{\sigma}{6}\frac{1}{2} = \frac{\sigma}{8} = 12.5\%$ in the project's expected return in terms of raising the *ex-ante* liquidation cost.

6 Related Mechanisms, Policy Implications, and Other Applications

We discuss how uncertainty decoupling differs from related mechanisms, its unique policy implications, and other applications beyond bank run.

6.1 Related Mechanisms

We find that the lack of funding diversification raises run risk via deposit clustering and uncertainty decoupling. That lack of diversification increases risk is well known. One might wonder if uncertainty decoupling repackages a known mechanism of diversification. Below, we discuss whether other mechanisms can generate our main result: The downside risk rises while the upside risk falls, with general payoff and in any state of the world.

Asset diversification

The concept of diversification is a key foundation of finance. Diversification of asset holdings reduces the risk of the average return across multiple assets in a portfolio by canceling out the idiosyncratic risk across the assets. Three fundamental differences Lack of diversification increases both the downside and the upside risks of the portfolio return, raising the second moment—the volatility—of the return. Both risks move in lockstep because diversification does not change an individual asset's return. Diversification does not change each asset's return, relies on a concave payoff function, and generates benefit through aggregation of consumption across all states of the world. Uncertainty decoupling raises the downside risk and reduces the upside risk, raising the *first* moment of the mass of runners, because each depositor becomes more inclined to run.

6.2 Geographic Expansion of Banking

Our results contribute to the long-standing policy debate on how bank branching affects bank stability.

The U.S. banking system has historically been highly fragmented, with a large number of small, local banks. It has also faced numerous bank runs over the years. Those two facts

have prompted an argument that local banking exacerbates bank fragility (e.g., Calomiris and Gorton, 1991). Supporting this concern is the numerous failures of local banks during the Panic of 1930, as well as of small community banks and thrifts in the 1970s and 1980s. Additionally, international evidence suggests that countries with extensive bank branching experience significantly fewer bank panics (Grossman, 1994).

One of the key factors preventing geographic expansion of U.S. banking in the past were long-standing restrictions on interstate branching. The restrictions ended with the passage of the Riegle-Neal Interstate Banking and Branching Efficiency Act in 1994. The Act triggered a wave of bank consolidation and the emergence of major national banks. Despite the consolidation, a significant number of community banks continue to operate locally. Whether local banking harms bank stability therefore remains to be a relevant question today.

The existing theoretical literature points out that branching could affect bank fragility through the bank's asset risk. However, the direction of this effect is ambiguous. On the one hand, branching could help a bank diversify its idiosyncratic loan risk. On the other hand, branching could lead to an increased systemic risk (e.g., Wagner, 2010). Both predictions the empirical literature that uses the staggered interstate deregulation as an exogenous source of variation for branch expansion.[8]

In contrast, our results show that branching enhances stability through the funding side. In our model, branching unambiguously reduces bank fragility by making depositors less run-prone for any given level of asset risk, without any countervailing effect. Diversification of asset and funding have fundamentally different mechanisms and implications, which Section 7 explains in more details.

We map branching to our model as follows. Initially, M identical community banks each operate one branch, funded by a unit mass of depositors.[9] Each community bank and its depositors are described by our model with parameters $(\underline{\theta}, \bar{\theta}, \sigma, \delta, v, K)$, with $K = 1$ capturing that depositors at each branch receive correlated information about the bank's fundamental.

[8] Goetz et al. (2016) find that geographic bank expansion diversifies exposure to idiosyncratic local loan portfolio risk, while Chu et al. (2020) find that branching leads to increased systemic risk measured as the change in conditional value at risk.

[9] Aguirregabiria et al. (2016) finds that the dispersion of deposit sizes across branches remained low throughout their sample period of 1976–2006.

The M community banks have the same fundamental, which represents the state of their identical asset portfolios. Therefore, no asset diversification results from a merger of the M banks into one bank, which is described by the same parameters $(\underline{\theta}, \bar{\theta}, \sigma, \delta, v, K)$ except $K = M$ as the consolidated bank operates M branches. Such a merger improves bank stability.

Corollary 1. *Conditional on any fundamental, the expected total mass of runners on the M community banks first-order stochastically dominates that on the consolidated bank.*

Corollary 1 says that the merger strictly reduces runs in any state of the world. Every depositor becomes less inclined to run on the consolidated bank, because it has a lower degree of deposit clustering than each community bank (Theorem 1). Corollary 1 implies that branching diversifies the bank's depositor base and thus reduces the risk of a bank run. [10]

6.3 Ring-fencing

Ring-fencing refers to a policy that separates a large bank or a banking group into several divisions. The separation lines can be drawn along different business units or geographic borders. The goal of such separation is to insulate certain divisions within a bank from the risks arising in other divisions. The previous academic work and policy discussions on ring-fencing focus on the risks that arise on the asset side of a balance sheet. Ring-fencing is much less discussed with regards to the risks that could arise on the funding side. Our mechanism works through the funding side. In our model, greater concentration of depositor base leads to greater fragility. Thus, our results offer a message of caution to regulators: To insure that ring-fencing does not increase bank fragility, it has to be implemented such that a funding base of each ring-fenced unit remains well-diversified.

[10] Empirically, the geographic expansion or branching reduces the volatility of the total volume of bank deposits (Aguirregabiria et al., 2016), lowers deposit volatility over time and deposit rates (Doerr, 2024), and funding costs (Levine et al., 2021).

6.4 Community Noise Accuracy

How does the level of community noise σ affect the equilibrium threshold? In this section, we show that the total effect is comprised of the two forces moving in the opposite directions. On the one hand, higher fundamental uncertainty, larger σ, amplifies the mechanism uncovered in the previous sections. As a result, larger community noise leads to lower equilibrium thresholds. On the other hand, if the payoff function $R(\theta)$ is concave, agents are averse to the fundamental uncertainty and thus larger community noise leads to higher equilibrium thresholds. Below we show that the latter force dominates for small σ.

To obtain a clean decomposition into two forces and simplify the analysis, in this section we focus on the case with quadratic $R(\theta)$. As before, the equilibrium threshold θ_K^* is given by the indifference condition

$$0 = \int_0^1 R(\theta_K^* - \sigma F^{-1}(p))\, \mathbb{E}\, u(n(K,p))\, \mathrm{d}p,$$

where $n(K,p) = [U + Bin(K-1,p)]/K$ is the fraction of other depositors running from the perspective of the marginal depositor. With quadratic $R(\theta)$, the second degree Taylor expansion is exact and yields

$$R(\theta - h) = R(\theta) - hR'(\theta) + \frac{1}{2}h^2 R''(\theta).$$

Applying the decomposition to $R(\theta_K^* - \sigma F^{-1}(p))$, the indifference condition becomes a sum of the three terms

$$\begin{aligned} 0 = R(\theta_K^*) \int_0^1 \mathbb{E}\, u(n(K,p))\, \mathrm{d}p + \sigma R'(\theta_K^*) \int_0^1 (-F^{-1}(p))\, \mathbb{E}\, u(n(K,p))\, \mathrm{d}p \\ + \sigma^2 \frac{R''(\theta_K^*)}{2} \int_0^1 (F^{-1}(p))^2\, \mathbb{E}\, u(n(K,p))\, \mathrm{d}p. \end{aligned} \tag{9}$$

We next discuss how each term influences the equilibrium threshold θ_K^*.

The first term in (9) determines the equilibrium threshold θ_K^* in a model with a vanishing community noise. As we found in Proposition 4, with vanishing σ, this threshold does not depend on K and is the same as the threshold in the standard model with $K \to \infty$. Below

we formally analyze the other two terms. We show that the second term in (9) captures the mechanism uncovered in the previous sections. In particular, if $K = 1$ and thus the fundamental and strategic uncertainties are decoupled, the second term is zero and does not affect the threshold. However, if $K > 1$ and thus there is a correlation between the fundamental and strategic uncertainties, the second term is positive and increases with σ. As a result, due to this term, θ_K^* has to decrease if σ increases. The third term in (9) captures the effect due to the concavity of the payoff function $R(\theta)$. This term is negative and increases in absolute value with σ. As a result, due to this term, θ_K^* has to increase if σ increases.

The next proposition establishes that the force due to the second term dominates the force due to the third term for small σ. Specifically, we show that the equilibrium threshold θ_K^* monotonically declines for small σ and then monotonically increases for high σ.

Proposition 8. *If $K > 1$, θ_K^* monotonically declines for $\sigma \in (0, \bar{\sigma})$ and monotonically increases for $\sigma > \bar{\sigma}$. If $K = 1$, θ_K^* monotonically increases with σ.*

6.5 Other Applications

Our analysis focused on the effects of information commonality on bank fragility. However, our general framework can be applied to study the effects of local common information in other settings with strategic complementarities. In this section, we discuss several alternative applications for our framework.

Credit Market Freezes. Consider a coordination problem faced by banks when lending to the economy as in Bebchuk and Goldstein (2011). In this economy, firms are interdependent such that the profitability of one firm increases with the number of other firms operating. This interdependence induces the strategic complementarity among banks at the lending stage. For a bank, the profitability of lending to a firm depends on the amount of credit that other banks provide to other firms in the economy. As a result, an inefficient credit market freeze may arise due to self-fulfilling expectations that other banks abstain from lending. To apply our model in this setting we can consider banks specializing in lending to different sectors of the economy as distinct communities, with a higher degree of specialization in-

terpreted as a lower degree of clustering. Then the implication from our results is that the specialized lending reduces the likelihood of self-fulfilling credit market freezes.

Adoption of Network Goods. Our model can be also applied to derive implications for the adoption of network goods. The network effects of such goods generate strategic complementarities among prospective users at the adoption stage. Our results imply that the adoption is higher if the good targets a larger number of distinct groups of users who receive information about prospective benefits of the good from different sources.

Figure 5 provides an illustration for Proposition 8.

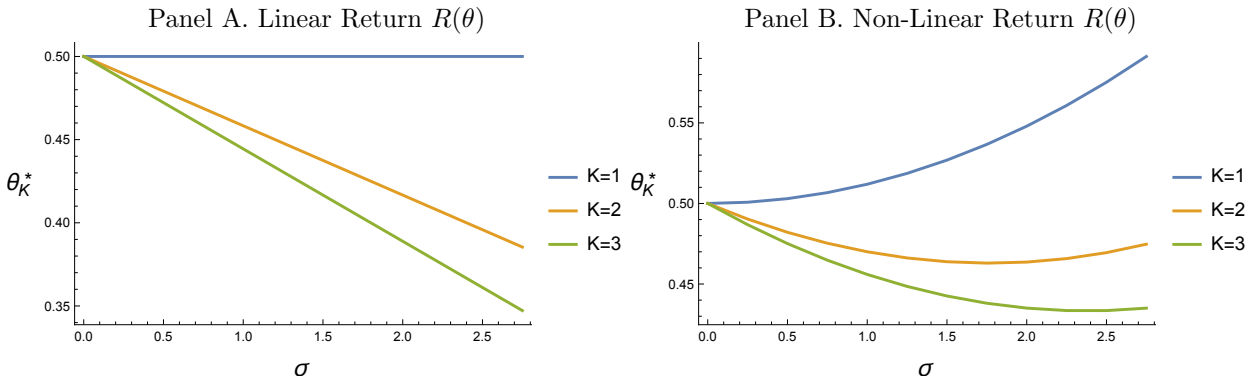


Figure 5. The equilibrium run threshold as a function of community signal precision. In the graph, we consider a setting in which $v(\theta, n) = R(\theta)\left(1 - \frac{n}{B+1}\right) - 1$ with $B = 0.5$ and $\varepsilon \sim \text{Uniform}\left(-\frac{1}{2}, \frac{1}{2}\right)$. We assume for the linear return $R(\theta) = 1 + \theta$, and for the non-linear return $R(\theta) = 0.5625 + 2\theta - 0.25\theta^2$.

7 Contributions

We make three contributions to the literature. *(i)* We uncover an inherent correlation between an agent's fundamental and strategic uncertainties in coordination games. This inherent correlation is a general property of all coordination games, yet never exploited in existing papers. This correlation steers the agent's choice toward a higher action that is consistent with a better fundamental under general payoff functions. *(ii)* We propose a mechanism that decouples the fundamental and the strategic uncertainties via conditionally correlated signals. *(iii)* This mechanism adds a new result: Conditionally correlated signals steer agents' choices downward to an action that is consistent with a worse fundamental.

This result answers a basic question: What is the information structure that induces fewer agents to choose an inefficient action (run on a bunk, attack a currency regime, underinvest in a project, etc.)?

Next, we discuss the relevance of these contributions to three strands of the literature.

Coordination Games with Public Information. The literature closest to our paper examines the effect of public information in coordination games (Angeletos and Pavan, 2007; Morris and Shin, 2002; Goldstein et al., 2011; Vives, 1990; Angeletos and Pavan, 2004; Hellwig, 2005; Morris and Shin, 2007; Woodford, 2003). In these papers, a higher precision of public information implies a greater commonality of agents' forecasts about the fundamental, akin to how clustering raises the scope of the information commonality in our model. *(i)* Constrained by tractability, this literature is limited to quadratic payoffs. In such a payoff function, the interaction term between the fundamental and the actions of other agents shows up only as a constant that does not depend and thus has no bearing on the agent's own action choice. As a result, the restrictive assumption of quadratic payoffs suppresses the role of the inherent correlation between an agent's fundamental and strategic uncertainties. *(ii)* In our model, clustering decouples the two uncertainties. This mechanism is absent in this literature because the correlation between the two uncertainties plays no role to begin with. *(iii)* In all aforementioned papers, a change in information commonality affects only the second moment of an agent's equilibrium action, similar to how clustering raises the volatility of the proportion n_K of runners in our model. In our model, a rise in commonality also strictly steers an agent's equilibrium action downward due to the uncertainty decoupling. This effect on the first moment is absent in the literature, where a change in the information structure has no impact on the mean of an agent's equilibrium action. Our result shows that a poorly designed information structure not only can make agents' actions more dispersed or volatile, it can also induce *more* agents to choose an inefficient action.

Global Games. Unlike the above coordination games with quadratic payoffs, global games would have multiple equilibria had there been common knowledge of some underlying fundamental. A global game pins down a unique equilibrium by endowing each agent with a private noisy observation of the fundamental. Incorporating public or correlated information

to a global game is challenging because such information gives rise to self-fulfilling beliefs and thus threatens equilibrium uniqueness. For example, letting any community of agents observe a semi-public signal $x_k = \theta + \sigma\varepsilon_k$ that is common within that community would obtain a model similar to ours. However, such a model may have multiple equilibria.[11] Thus, equilibrium multiplicity severely restricts the global games literature from considering the impact of correlated information (Morris and Shin, 2002).

Ours is a global game, making a fourth contribution to the literature: *(iv)* We introduce a framework to study conditionally correlated information that guarantees equilibrium uniqueness under all parameters. The key behind the global games approach is to remove complete common knowledge of other agents' actions by introducing uncertainty about their actions, strategic uncertainty. This is achieved by inserting a private noise into each agent's observation of the underlying fundamental state. Our framework applies this approach to the community signal $x_k = \theta + \sigma\varepsilon_k$ instead of the underlying fundamental to maintain strategic uncertainty and thus equilibrium uniqueness. Our framework also allows to study the effects of a public signal's precision.

The global games literature examines the separate roles of the fundamental and the strategic uncertainties, yet overlooks the correlation between the two because of assuming either specific payoff functions or a vanishing noise. We are the first to exploit this correlation and show that it has a first-order effect on the outcome of interest. In sum, our three overarching contributions *(i)*, *(ii)*, and *(iii)* continue to apply to the global games literature.

Bank Runs. Our paper also contributes to the literature on the 2023 Regional Bank Crisis. Drechsler et al. (2023) and Haddad et al. (2023) identify deposit franchise as a novel source of bank fragility and show that a bank can become vulnerable to runs even if its assets are fully liquid, because the franchise value decreases with the number of depositors running.[12] Our framework can embed this channel as our general payoff function is agnostic about the source of the strategic complementarity—we only require the payoff gain from staying to

[11] Morris and Shin (2003, 2004); Hellwig (2002); Metz (2002); Dahleh et al. (2016) derive conditions for equilibrium uniqueness and multiplicity in the presence of public or correlated information.

[12] In addition to studying the role of the deposit franchise, Jiang et al. (2024) also highlight how mark-to-market asset losses and large shares of uninsured deposits could lead to a "solvency run." Chang et al. (2023) propose a model where banks better at risk taking attract more uninsured depositors.

decrease in the number of runners.

8 Conclusion

We study the impact of deposit clustering on the likelihood of a bank run. In our model, a bank's continuum of depositors partition into K communities. Depositors in the same community observe almost-identical information about the bank. Clustering makes depositors more inclined to run, and more so with greater clustering into fewer communities. Yet, joining a community is privately optimal for an individual depositor. Our findings point to the risks of deposit clustering, as seen in the 2023 bank runs. We show that diversification of the depositor base, via the mechanism different from asset diversification, can mitigate the bank run risk and requires regulatory effort.

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Appendix

A Proofs

Proof of Proposition 1. We adapt the proof of Proposition 2.1 in Morris and Shin (2003).

First, we let $\pi(x, y)$ be the expected payoff gain from staying for a depositor who has observed signal $x_{K,i} = x$ and knows that every other depositor runs upon observing a signal less than y,

$$\begin{aligned}\pi(x, y) &\equiv \mathbb{E}\left[v\left(\theta, n_K(y)\right) \,\middle|\, x_{K,i} = x\right] \\ &= \int_{x-\frac{\sigma}{2}}^{x+\frac{\sigma}{2}} \frac{1}{\sigma} f\left(\frac{x-\theta}{\sigma}\right) \sum_{h=1}^{H} R_h(\theta)\, \mathbb{E}\left[u_h(n_K(y)) \,|\, x_{K,i} = x, \theta\right] \mathrm{d}\theta.\end{aligned}$$

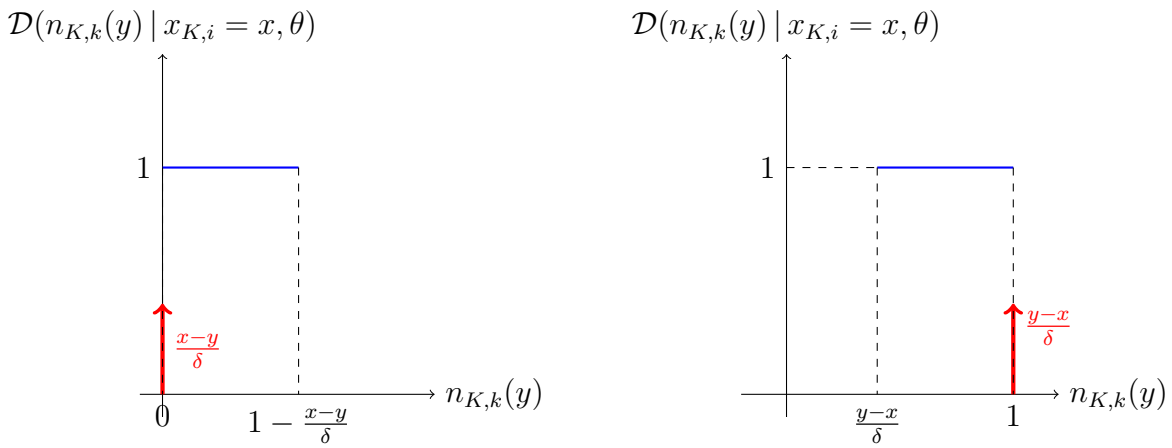
The proportion of other depositors running is the average proportion of runners across communities,

$$n_K(y) = \frac{1}{K} \sum_{\ell=1}^{K} n_{K,\ell}(y),$$

where

$$n_{K,\ell}(y) = K \int \mathbb{1}\left\{x_{\ell,j} < y\right\} \mathrm{d}j.$$

First, $\pi(x, y)$ is continuous in x and y. It suffices to show that the conditional distribution $\mathcal{D}\left(n_K(y) \,|\, x_{K,i} = x, \theta\right)$ of $n_K(y)$ given $x_{K,i} = x$ and θ is continuous in x and y in the total variation distance. *(i)* The proportion of runners in other communities, $\sum_{\ell \neq k}^{K} n_{K,\ell}(y)$, is a Binomial random variable with $K-1$ draws and the probability of success equal to $F\left(\frac{y-\theta}{\sigma}\right)$. *(ii)* The proportion of runners in community k, $n_{K,k}(y)$, follows a uniform distribution in $[0, 1]$ when $y = x$, and a "shifted and truncated uniform" distribution when $y \neq x$. The distribution shifts the standard Uniform$(0, 1)$ to the left by $|y - x|/\delta$ and then truncates the shifted distribution on the left side at 0 when $x > y$, or shifts to and truncates on the right side when $y > x$. The truncated mass $|y - x|/\delta$ concentrates at 0 when $x > y$ and at 1 when $y > x$ as a Dirac mass. Figure A.1 shows the probability density function of the shifted and truncated uniform distribution.



(a) $x > y$ **(b)** $y > x$

Figure A.1. "Shifted and truncated uniform distribution." The probability density function of the proportion $n_{K,k}(y)$ of runners in a depositor's own community conditional on the true fundamental θ and the depositor observing signal $x_{K,i} = x$, if all other depositors run upon observing a signal less than y.

Second, $\pi(x, y)$ is increasing in x and decreasing in y, because $\mathcal{D}(n_K(y) \mid x_{K,i} = x, \theta)$ monotonically increases with y and decreases with x, both in the first stochastic order.

Third, we also have $\pi(x, y) < 0$ if $x \leq \theta_L - \frac{\sigma}{2}$ and $\pi(x, y) > 0$ if $x \geq \theta_U + \frac{\sigma}{2}$ following the assumption of dominance regions.

Given the properties of $\pi(x, y)$, we can apply the iterated deletion of strictly interim dominated strategies argument of Morris and Shin (2003).[13] As a result, the only strategy that survives the iterated deletion is characterized by the cutoff θ_K^* such that $\pi(\theta_K^*, \theta_K^*) = 0$.

□

Proof of Proposition 2. Without clustering, the indifference condition that determines the run threshold θ_∞^* is given by equation (4). We expand it as

$$0 = \pi(\theta_\infty^*, \theta_\infty^*) = \int_{\theta_\infty^* - \frac{\sigma}{2}}^{\theta_\infty^* + \frac{\sigma}{2}} \frac{1}{\sigma} f\left(\frac{\theta_\infty^* - \theta}{\sigma}\right) \sum_h R_h(\theta)\, u_h\left(F\left(\frac{\theta_\infty^* - \theta}{\sigma}\right)\right) \mathrm{d}\theta. \tag{A.1}$$

[13] Note that we have assumed strict state monotonicity (the strict version of A2 which implies A3). In addition, we have shown explicitly continuity with respect to signal and density (the analogue of A5).

It follows from the law of large numbers that when $K \to \infty$,

$$\mathbb{E}\left[u_h(n_K(\theta^*)) \,|\, x_{K,i} = x, \theta\right] = \mathbb{E}\left[u_h\left(\frac{1}{K}\sum_{\ell=1}^{K} n_{K,\ell}(\theta^*)\right) \,\middle|\, x_{K,i} = x, \theta\right] \to u_h\left(F\left(\frac{\theta^* - \theta}{\sigma}\right)\right),$$

Therefore, the indifference condition with clustering in the proof of Proposition 1 above converges to (A.1), implying $\theta_K^* \to \theta_\infty^*$.

□

To prove Proposition 3 and Theorem 1, we first establish the following lemma:

Lemma 1. *The marginal depositor in community k believes that (i) the proportion $n_{K,k}$ of runners in her own community follows a continuous uniform distribution, $\mathcal{D}(n_{K,k} \,|\, x_{K,i} = \theta_K^*) = \text{Unif}(0,1)$, and (ii) the sum $\sum_{\ell \neq k} n_{K,\ell}$ of the proportions of runners in other communities follows a discrete uniform distribution on the set $\{0, 1, \ldots, K-1\}$, $\mathcal{D}(\sum_{\ell \neq k} n_{K,\ell} \,|\, x_{K,i} = \theta_K^*) = \text{Unif}(0, 1, \ldots, K-1)$. (iii) The proportion $n_{K,k}$ is independent of $(\sum_{\ell \neq k} n_{K,\ell},\, x_{K,i},\, \theta)$.*

Proof. *(i)* A depositor's signal $x_{K,i}$ is uninformative about her idiosyncratic noise ν_i since ν_i is infinitesimally small, thus also about the ranking of $x_{K,i}$ among the signals of other depositors in her community. Hence, the depositor expects her signal's ranking to be uniformly random. Applied to the marginal depositor in community k, she believes that the proportion $n_{K,k}$ of others in her community observing a lower signal, and running, is uniformly distributed.

(ii) From a depositor's perspective, depositors in another community either all run or all stay, acting as if they were one discrete depositor. Thus, the depositor's belief about the sum $\sum_{\ell \neq k} n_{K,\ell}$ of the proportions of runners in other communities is the same as in a game with discrete number of players. The marginal depositor in community k believes that $\sum_{\ell \neq k} n_{K,\ell}$ follows a discrete uniform distribution on the set $\{0, 1, \ldots, K-1\}$, because the depositor's signal $x_{K,i}$ is uninformative about her community noise ε_k, thus also about the ranking of $x_{K,i}$ among the signals of other communities (Morris and Shin, 2003, the case of finite players in Appendix B).

(iii) The idiosyncratic noises $\boldsymbol{\nu} \equiv (\nu_j)_{j \in [0,1]}$ are independent of $(\boldsymbol{\varepsilon}, x_{K,i}, \theta)$, where $\boldsymbol{\varepsilon} \equiv (\varepsilon_\ell)_{\ell \in 1,\ldots,K}$. Therefore, $n_{K,k}$ is independent of $(\sum_{\ell \neq k} n_{K,\ell},\, x_{K,i},\, \theta)$.

□

Proof of Proposition 3. Lemma 1 Part *(iii)* implies that $n_{K,k}$ and $\sum_{\ell \neq k} n_{K,\ell}$ are conditionally independent given $x_{K,i}$. Then Proposition 3 follows from $n_K = \frac{1}{K}\sum_{\ell=1}^{K} n_{K,\ell}$ and Lemma 1 Parts *(i)* and *(ii)*.

□

Proof of Theorem 1. We first establish Lemmas 2 and 3. We let

$$f_{\text{Bin}(K,p)}(m) = \binom{K}{m} p^m (1-p)^{K-m}$$

be the probability mass of the binomial distribution with parameters (K, p).

Lemma 2. *For any $m \in \{0, \ldots, K\}$,*

$$\sum_{m'=0}^{m-1} f_{\text{Bin}(K,p)}(m') + \frac{m}{K} f_{\text{Bin}(K,p)}(m) = \sum_{m'=0}^{m-1} f_{\text{Bin}(K-1,p)}(m').$$

Proof of Lemma 2. For every $m = 0, \ldots, K-1$,

$$f_{\text{Bin}(K,p)}(m) = p f_{\text{Bin}(K-1,p)}(m-1) + (1-p) f_{\text{Bin}(K-1,p)}(m),$$

where $f_{\text{Bin}(K-1,p)}(-1) \equiv 0$, and

$$\begin{aligned} f_{\text{Bin}(K,p)}(m) &= \binom{K}{m} (1-p)^{K-m} p^m \\ &= \frac{K}{m} p \binom{K-1}{m-1} (1-p)^{K-m} p^{m-1} \\ &= \frac{K}{m} p \, f_{\text{Bin}(K-1,p)}(m-1). \end{aligned}$$

Therefore,

$$\begin{aligned}
&\sum_{m'=0}^{m-1} f_{\mathrm{Bin}(K,p)}(m') + \frac{m}{K} f_{\mathrm{Bin}(K,p)}(m) \\
=& \sum_{m'=0}^{m-1} \left[p f_{\mathrm{Bin}(K-1,p)}(m'-1) + (1-p) f_{\mathrm{Bin}(K-1,p)}(m') \right] + p f_{\mathrm{Bin}(K-1,p)}(m-1) \\
=& \sum_{m'=0}^{m-2} \left[f_{\mathrm{Bin}(K-1,p)}(m') \right] + (1-p) f_{\mathrm{Bin}(K-1,p)}(m-1) + p f_{\mathrm{Bin}(K-1,p)}(m-1) \\
=& \sum_{k'=0}^{m-1} f_{\mathrm{Bin}(K-1,p)}(m').
\end{aligned}$$

□

Lemma 3. *If $\theta_K^* = \theta_{K+1}^*$, then for any function $R(\theta)$ that is non-decreasing in θ, any $K \geq 1$, and any $n \in [0,1]$,*

$$\int_0^n \mathbb{E}\left(R(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \mathrm{d}s \leq \int_0^n \mathbb{E}\left(R(\theta) \,|\, n_{K+1} = s, x_{K+1,i} = \theta_{K+1}^*\right) \mathrm{d}s,$$

with the inequality being an equality at $n = \frac{m}{k}$ for $m = 0, 1, \ldots, K$. If $R(\theta)$ is strictly increasing in θ, the inequality is strict at all other $n \in [0,1]$.

Proof of Lemma 3. From Lemma 1, $n_K = s$ and $x_{K,i} = \theta_K^*$ are equivalent to $\sum_{\ell \neq k} n_{K,\ell} = \lfloor Ks \rfloor / K$, $n_{K,k} = s - \lfloor Ks \rfloor / K$, and $x_{K,i} = \theta_K^*$. We let $m_K = K \sum_{\ell \neq k} n_{K,\ell}$ be the number of other communities running. Because $n_{K,k}$ is independent of $(m_K,\, x_{K,i},\, \theta)$ (Lemma 1 Part *(iii)*),

$$\begin{aligned}
&\mathbb{E}\left(R(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \\
=\ &\mathbb{E}\left(R(\theta) \,|\, m_K = \lfloor Ks \rfloor,\, n_{K,k} = s - \frac{\lfloor Ks \rfloor}{K},\, x_{K,i} = \theta_K^*\right) \qquad \text{(A.2)} \\
=\ &\mathbb{E}\left(R(\theta) \,|\, m_K = \lfloor Ks \rfloor,\, x_{K,i} = \theta_K^*\right).
\end{aligned}$$

Integrating over n, we have

$$\begin{aligned}\Theta_K(n) &\equiv \int_0^n \mathbb{E}\left(R(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \mathrm{d}s \\ &= \sum_{m'=0}^{\lfloor Kn \rfloor - 1} \frac{1}{K}\, \mathbb{E}\left(R(\theta) \,|\, m_K = m',\, x_{K,i} = \theta_K^*\right) \\ &\quad + \left(n - \frac{\lfloor Kn \rfloor}{K}\right) \mathbb{E}\left(R(\theta) \,|\, m_K = \lfloor Kn \rfloor,\, x_{K,i} = \theta_K^*\right).\end{aligned} \tag{A.3}$$

Thus, $\Theta_K(n)$ is piecewise in $n \in [0,1]$ over K consecutive segments of length $1/K$.

We prove the lemma in two steps. First, we show that the two functions Θ_K and Θ_{K+1} intersect at $n = \frac{m}{K}$ for $m \in \{0, \ldots, K\}$. Second, we show that function Θ_{K+1} lies strictly above function Θ_K for all other n.

Step 1: The number m_K of other communities running follows a binomial distribution conditional on fundamental θ, $\mathcal{D}(m_K \,|\, \theta) = \mathrm{Bin}(K-1, p(\theta))$, where $p(\theta) = F\left(\frac{\theta_K^* - \theta}{\sigma}\right)$. Writing (A.2) in terms of conditional density and making the change of variable $\theta = \theta^* - \sigma F^{-1}(p)$, we have

$$\begin{aligned}\mathbb{E}\left(R(\theta) \,|\, m_K = m',\, x_{K,i} = \theta_K^*\right) &= \frac{\int_\theta R(\theta)\, f_{\mathrm{Bin}(K-1,p(\theta))}(m')\, f_{\theta | x_{K,i} = \theta_K^*}(\theta)\, \mathrm{d}\theta}{\int_\theta f_{\mathrm{Bin}(K-1,p(\theta))}(m')\, f_{\theta | x_{K,i} = \theta_K^*}(\theta)\, \mathrm{d}\theta} \\ &= \frac{\int_0^1 R(\theta^* - \sigma F^{-1}(p))\, f_{\mathrm{Bin}(K-1,p)}(m')\, \mathrm{d}p}{\int_0^1 f_{\mathrm{Bin}(K-1,p)}(m')\, \mathrm{d}p} \\ &= \frac{\int_0^1 R(\theta^* - \sigma F^{-1}(p))\, f_{\mathrm{Bin}(K-1,p)}(m')\, \mathrm{d}p}{1/K}.\end{aligned}$$

For any $n = \frac{m}{K}$, where $m \in \{0, \ldots, K\}$,

$$\begin{aligned}\Theta_K(n) &= \sum_{m'=0}^{m-1} \frac{1}{K}\, \mathbb{E}\left(R(\theta) \,|\, m_K = m',\, x_{K,i} = \theta_K^*\right) \\ &= \int_0^1 R(\theta^* - \sigma F^{-1}(p)) \sum_{m'=0}^{m-1} f_{\mathrm{Bin}(K-1,p)}(m')\, \mathrm{d}p.\end{aligned}$$

For $\Theta_{K+1}(n)$, we express $n = \frac{m}{K} = \frac{m}{K+1} + \frac{\frac{m}{K}}{K+1}$. Thus,

$$\begin{aligned}
\Theta_{K+1}(n) &= \sum_{m'=0}^{m-1} \frac{1}{K+1} \, \mathbb{E}\left(R(\theta) \,|\, m_{K+1} = m',\, x_{K+1,i} = \theta^*_{K+1}\right) \\
&\quad + \frac{\frac{m}{K}}{K+1} \, \mathbb{E}\left(R(\theta) \,|\, m_{K+1} = m,\, x_{K+1,i} = \theta^*_{K+1}\right) \\
&= \int_0^1 R(\theta^* - \sigma F^{-1}(p)) \left[\sum_{k'=0}^{m-1} f_{\mathrm{Bin}(K,p)}(m') + \frac{m}{K} \, f_{\mathrm{Bin}(K,p)}(m) \right] \mathrm{d}p \\
&= \int_0^1 R(\theta^* - \sigma F^{-1}(p)) \sum_{m'=0}^{m-1} f_{\mathrm{Bin}(K-1,p)}(m') \, \mathrm{d}p \qquad \text{(following Lemma 2).}
\end{aligned}$$

Therefore, $\Theta_{K+1}(n) = \Theta_K(n)$ for any $n = \frac{m}{K}$ with $m \in \{0, \ldots, K\}$.

Step 2: To prove that $\Theta_{K+1}(n) > \Theta_K(n)$ for all other n, it suffices to show that $\Theta'_{K+1}(n) > \Theta'_K(n)$ at $n = \frac{m}{K}$ with $m \in \{0, \ldots, K-1\}$. Taking the derivative of (A.3) at $n = \frac{m}{K}$ with $m \in \{0, \ldots, K-1\}$ gives,

$$\begin{aligned}
\Theta'_K(n) &= \mathbb{E}\left(R(\theta) \,|\, m_K = m,\, x_{K,i} = \theta^*_K\right), \\
\Theta'_{K+1}(n) &= \mathbb{E}\left(R(\theta) \,|\, m_{K+1} = m,\, x_{K+1,i} = \theta^*_K\right).
\end{aligned}$$

Since the distribution $\mathcal{D}\left(\theta \,|\, m_{K+1} = m,\, x_{K+1,i} = \theta^*_K\right)$ first-order stochastically dominates the distribution $\mathcal{D}\left(\theta \,|\, m_K = m,\, x_{K,i} = \theta^*_K\right)$ for $m \in \{0, \ldots, K-1\}$, and $R(\theta)$ is non-decreasing in θ, we have

$$\mathbb{E}\left(R(\theta) \,|\, m_{K+1} = m,\, x_{K+1,i} = \theta^*_K\right) \geq \mathbb{E}\left(R(\theta) \,|\, m_K = m,\, x_{K,i} = \theta^*_K\right),$$

with the inequality being strict if $R(\theta)$ is strictly increasing in θ.

Therefore, $\Theta'_{K+1}(n) \geq \Theta'_K(n)$ at $n = \frac{m}{K}$ with $m \in \{0, \ldots, K-1\}$ and $\Theta_{K+1}(n) \geq \Theta_K(n)$ for all $n \in [0, 1]$, with the inequality being strict at all n except $n = \frac{m}{K}$ where $m = 0, 1, \ldots, K$ if $R(\theta)$ is strictly increasing in θ.

□

Now, we turn to prove Theorem 1. We can expand the gain from staying using integration

by parts,

$$\begin{aligned}
&\mathbb{E}\left(v(\theta, n_K) \,|\, x_{K,i} = \theta_K^*\right) \\
&= \int_0^1 \sum_h \mathbb{E}\left(R_h(\theta) \,|\, n_K = n,\, x_{K,i} = \theta_K^*\right) u_h(n)\, \mathrm{d}n \\
&= \sum_h \left(\int_0^1 \mathbb{E}\left(R_h(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \mathrm{d}s\; u_h(1) \right. \\
&\qquad \left. + \int_0^1 \int_0^n \mathbb{E}\left(R_h(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \mathrm{d}s\; \mathrm{d}[-u_h(n)] \right),
\end{aligned} \tag{A.4}$$

where the outer integral is a well-defined Lebesgue-Stieltjes integral with respect to the Borel measure $\mathrm{d}[-u(n)]$ induced by the non-decreasing function of bounded variation $-u(n)$.

If the equilibrium run thresholds were the same for K and $K+1$ communities, $\theta_K^* = \theta_{K+1}^*$, then Lemma 3 would imply that

$$\int_0^n \mathbb{E}\left(R_h(\theta) \,|\, n_K = s,\, x_{K,i} = \theta_K^*\right) \mathrm{d}s \leq \int_0^n \mathbb{E}\left(R_h(\theta) \,|\, n_{K+1} = s,\, x_{K+1,i} = \theta_{K+1}^*\right) \mathrm{d}s,$$

with an equality at $n = 1$ and a strict inequality everywhere except at finitely many points for $h = 1$. Thus, the first integral and the Lebesgue-Stieltjes integral in (A.4) combined would be strictly lower than

$$\begin{aligned}
&\sum_h \left(\int_0^1 \mathbb{E}\left(R_h(\theta) \,|\, n_{K+1} = s,\, x_{K+1,i} = \theta_{K+1}^*\right) \mathrm{d}s\; u_h(1) \right. \\
&\qquad \left. + \int_0^1 \int_0^n \mathbb{E}\left(R_h(\theta) \,|\, n_{K+1} = s,\, x_{K+1,i} = \theta_{K+1}^*\right) \mathrm{d}s\; \mathrm{d}[-u_h(n)] \right) \\
&= \int_0^1 \sum_h \mathbb{E}\left(R_h(\theta) \,|\, n_{K+1} = n,\, x_{K+1,i} = \theta_K^*\right) u_h(n)\, \mathrm{d}n \\
&= \mathbb{E}\left(v(\theta, n_{K+1}) \,|\, x_{K+1,i} = \theta_{K+1}^*\right).
\end{aligned}$$

It would then follow from the indifference condition $\mathbb{E}\left(v(\theta, n_{K+1}) \,|\, x_{K+1,i} = \theta_{K+1}^*\right) = 0$ that $\mathbb{E}\left(v(\theta, n_K) \,|\, x_{K,i} = \theta_K^*\right) < 0$: With K communities, the marginal depositor would strictly prefer to run. Therefore, it must be that $\theta_K^* > \theta_{K+1}^*$.

□

Proof of Proposition 4. When the community noise is infinitesimally small,

$$\mathbb{E}\left[R_h(\theta)u_h(n_K)\,|\,x_{K,i}=\theta_K^*\right]=R_h(\theta_K^*)\,\mathbb{E}\left[u_h(n_K)\,|\,x_{K,i}=\theta_K^*\right]=R_h(\theta_K^*)\int_0^1 u_h(n)\mathrm{d}n,$$

for all h and K. Then $\mathbb{E}\left[v(\theta,n_K)\,|\,x_{K,i}=\theta_K^*\right]=\mathbb{E}\left[v(\theta,n_{K+1})\,|\,x_{K+1,i}=\theta_{K+1}^*\right]$ if $\theta_K^*=\theta_{K+1}^*$. Therefore, $\theta_K^*=\theta_{K+1}^*$ for all K.

□

We need the following lemma for the proof of Propositions 5 and 7.

Lemma 4. *If $X\sim\mathrm{Bin}(K,p)$ and $Y\sim\mathrm{Bin}(K+1,p)$. Then $\frac{X}{K}$ is a mean-preserving spread of $\frac{Y}{K+1}$.*

Proof of Lemma 4. The mean-preserving spread property holds if and only if

$$\frac{X}{K}=\frac{Y}{K+1}+\epsilon,$$

for some random variable ϵ such that $\mathbb{E}(\epsilon\,|\,Y)=0$. By definition, $Y=X+Z$ where $Z\sim\mathrm{Bernoulli}(p)$, and X and Z are independent. Then $\frac{X}{K}=\frac{Y}{K+1}+\epsilon$ where

$$\epsilon=\frac{X_1}{K}-\frac{Y}{K+1}=\frac{X}{K(K+1)}-\frac{Z}{K+1}.$$

For any realization $Y=m$, $\mathbb{E}(Z\,|\,Y=k)=\frac{m}{K+1}$. Thus,

$$\mathbb{E}(\epsilon\,|\,Y=m)=\frac{\mathbb{E}(Y-Z\,|\,Y=m)}{K(K+1)}-\frac{\mathbb{E}(Z\,|\,Y=k)}{K+1}=\frac{m-\frac{m}{K+1}}{K(K+1)}-\frac{\frac{m}{K+1}}{K+1}=0.$$

Therefore, $\frac{X}{K}$ is a mean-preserving spread of $\frac{Y}{K+1}$.

□

Proof of Proposition 5. Given any fundamental θ, depositors in a community observe an almost identical signal and make the same choice, effectively acting as one depositor. As a result, conditional on fundamental θ, the total proportion of runners $Kn_K=\sum_{\ell=1}^K n_{K,\ell}\sim\mathrm{Bin}(K,p(\theta,\theta_K^*))$ where $p(\theta,\theta_K^*)=F\left(\frac{\theta_K^*-\theta}{\sigma}\right)$. Lemma 4 implies that n_K is a mean preserving spread of $\tilde{n}_{K+1}$, where $(K+1)\tilde{n}_{K+1}\sim\mathrm{Bin}(K+1,\,p(\theta,\theta_K^*))$. It follows from The-

orem 1 that $p(\theta, \theta^*_K) \geq p(\theta, \theta^*_{K+1})$, with a strict inequality for $\theta \in \left(\theta^*_{K+1} - \frac{\sigma}{2}, \theta^*_K + \frac{\sigma}{2}\right)$. Then $\mathcal{D}\left(\tilde{n}_{K+1} \,|\, \theta\right) \succeq_{(1)} \mathcal{D}\left(n_{K+1} \,|\, \theta\right)$, with the first-order stochastic dominance being strict for $\theta \in \left(\theta^*_{K+1} - \frac{\sigma}{2}, \theta^*_K + \frac{\sigma}{2}\right)$. Since the cost function $c(n)$ is increasing and convex, we have $\mathbb{E}[c(n_K) \,|\, \theta] \geq \mathbb{E}[c(n_{K+1}) \,|\, \theta]$, with a strict inequality for $\theta \in \left(\theta^*_{K+1} - \frac{\sigma}{2}, \theta^*_K + \frac{\sigma}{2}\right)$. Finally, the ex-ante costs strictly increases with fewer communities, $\mathbb{E}\, c(n_K) > \mathbb{E}\, c(n_{K+1})$.

□

Proof of Proposition 6. We let $w(a_{k,i}, \theta, a_k)$ be a depositor's expected payoff when she chooses action $a_{k,i}$, the fundamental is θ, and actions of other agents in her community k is a_k. We let $a^*(x_{K,i})$ be the depositor's optimal strategy. Since the idiosyncratic noise is infinitesimally small, $a^*(x_{K,i})$ is also the action of other members in community k for all signals $x_{K,i}$ apart from the marginal one $x_{K,i} = \theta^*_K$. Thus, if depositor stays in Bank 1, her *ex-ante* payoff is

$$\mathbb{E}\, w(a^*(x_{K,i}), \theta, a^*(x_{K,i})) \equiv \int w(a^*(x_{K,i}), \theta, a^*(x_{K,i}))\, \mathrm{d}F(\theta \,|\, x_{K,i})\, \mathrm{d}F(x_{K,i}).$$

Next, we denote the signal of the depositor in Bank 2 as $\tilde{x} = \theta + \sigma\varepsilon + \delta\nu$ and her optimal strategy as $\tilde{a}^*(\tilde{x})$. Then if the depositor switches to Bank 2, her *ex-ante* payoff is

$$\begin{aligned}
\mathbb{E}\, w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i})) &\equiv \int w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i}))\, \mathrm{d}F(x_{K,i} \,|\, \theta, \tilde{x}) \mathrm{d}F(\theta \,|\, \tilde{x})\, \mathrm{d}F(\tilde{x}) \\
&= \int w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i}))\, \mathrm{d}F(x_{K,i} \,|\, \theta)\, \mathrm{d}F(\theta \,|\, \tilde{x})\, \mathrm{d}F(\tilde{x}).
\end{aligned}$$

Since action $a^*(x_{K,i})$ is optimal for the depositor in Bank 1, it is strictly better than any other action, including action $a^*(\tilde{x})$. Thus,

$$\begin{aligned}
\mathbb{E}\, w(a^*(x_{K,i}), \theta, a^*(x_{K,i})) &> \int w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i}))\, \mathrm{d}F(\tilde{x} \,|\, \theta, x_{K,i})\, \mathrm{d}F(\theta \,|\, x_{K,i})\, \mathrm{d}F(x_{K,i}) \\
&= \int w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i}))\, \mathrm{d}F(\tilde{x} \,|\, \theta)\, \mathrm{d}F(\theta \,|\, x_{K,i})\, \mathrm{d}F(x_{K,i}) \\
&= \mathbb{E}\, w(\tilde{a}^*(\tilde{x}), \theta, a^*(x_{K,i})).
\end{aligned}$$

Therefore, switching to Bank 2 gives strictly lower ex-ante payoff than staying in Bank 1.

□

Proof of Proposition 7. The equilibrium run threshold θ^*_K is determined by the marginal

depositor's indifference condition that depends on her posterior belief about fundamental θ, which is distributed on $\left[\theta_K^* - \frac{\sigma}{2}, \theta_K^* + \frac{\sigma}{2}\right]$. Because the fundamental's prior distribution is uniform and the community noise is bounded, a downward shift of $\Delta_\theta < \bar{\theta} - \left(\theta_K^* + \frac{\sigma}{2}\right)$ in the prior does not change the posterior belief. Therefore, a downward shift of Δ_θ in the fundamental's prior distribution would not change a depositor's indifference condition and thus nor her equilibrium run threshold θ_K^*.

Instead, the downward shift of Δ_θ in the fundamental's prior raises the mass n_K of runners since depositors are more likely to observe signals below the threshold θ_K^*. The same change in the mass n_K of runners can be achieved by an upward shift of the same magnitude Δ_θ in the equilibrium run threshold θ_K^*:

$$\tilde{n}_K = \int_0^1 \mathbb{1}\left\{\theta - \Delta_\theta + \sigma\varepsilon_k + \delta\nu_i < \theta_K^*\right\} \mathrm{d}i = \int_0^1 \mathbb{1}\left\{x_{K,i} < \theta_K^* + \Delta_\theta\right\} \mathrm{d}i.$$

Therefore, the increase in the threshold θ_K^* by Δ_θ and the downward shift in the distribution of the fundamental θ by Δ_θ yield the same distribution $\mathcal{D}(\tilde{n}_K)$ and thus the same expected cost of liquidation.

We let $\Delta_\theta = \theta_{K-1} - \theta_K$. Then $\mathcal{D}(n_{K-1} \,|\, \theta)$ is a mean preserving spread of $\mathcal{D}(\tilde{n}_K \,|\, \theta)$ (Lemma 4). Thus,

$$\mathbb{E}\left[c(n_{K-1}) \,|\, \theta\right] \geq \mathbb{E}\left[c(\tilde{n}_K) \,|\, \theta\right] \quad \Longrightarrow \quad \mathbb{E}\left[c(n_{K-1})\right] \geq \mathbb{E}\left[c(\tilde{n}_K)\right].$$

Therefore, moving from K to $K-1$ communities raises the expected run cost by more than a downward shift of $\theta_{K-1}^* - \theta_K^*$ in the distribution of θ.

□

Proof of Proposition 8. The equilibrium run threshold θ^* is determined by Equation (3). By Proposition 3, $Kn_K = n_{K,k} + \sum_{\ell \neq k} n_{K,\ell}$ with $n_{K,k} \sim \text{Unif}(0,1)$ and $\sum_{\ell \neq k}^{K} n_{K,\ell} \sim \text{Bin}(K, p(\theta, \theta^*))$, where $p(\theta, \theta^*) = F\left(\frac{\theta^* - \theta}{\sigma}\right)$. Thus, making the change of variable $\theta = \theta^* - \sigma F^{-1}(p)$, the indifference condition becomes

$$0 = I(\theta^*, \sigma) = \int_0^1 R(\theta^* - \sigma F^{-1}(p))\, \mathbb{E}\, u(n_K(p))\, \mathrm{d}p.$$

By the implicit function theorem,

$$\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma} = -\frac{\partial I/\partial\sigma}{\partial I/\partial\theta^*} = \frac{\int_0^1 R'(\theta^* - \sigma F^{-1}(p))F^{-1}(p)\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p}{\int_0^1 R'(\theta^* - \sigma F^{-1}(p))\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p}. \tag{A.5}$$

For quadratic $R(\theta)$, we have $R'(\theta^* - \sigma F^{-1}(p)) = R'(\theta^*) - \sigma F^{-1}(p)R''(\theta^*)$. Thus, the denominator in (A.5) is

$$\begin{aligned}
&R'(\theta^*)\int_0^1 \left[1 + \sigma F^{-1}(p)\frac{-R''(\theta^*)}{R'(\theta^*)}\right]\mathbb{E}\,u(n_K(p))\,\mathrm{d}p \\
=&R'(\theta^*)\left[\int_0^1 \mathbb{E}\,u(n_K(p))\,\mathrm{d}p + \sigma\left(\frac{-R''(\theta^*)}{R'(\theta^*)}\right)\int_0^1 F^{-1}(p)\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p\right].
\end{aligned}$$

The first term is positive because $u(n)$ is positive. Unless $K = 1$, the second term is negative and its absolute value increases with σ because of two factors. i) $\mathbb{E}\,u(n_K(p))$ is decreasing in p because $u(n)$ is decreasing and $n_K(p)$ first-order stochastically increases in p. ii) $F^{-1}(p)$ is increasing on $[-\frac{1}{2}, \frac{1}{2}]$ and symmetric around 0 if ε is symmetric. Overall, the denominator has to remain positive because $R'(\theta^* - \sigma F^{-1}(p))$ is positive.

The numerator in (A.5) is

$$\begin{aligned}
&R'(\theta^*)\int_0^1 \left[1 + \sigma F^{-1}(p)\frac{-R''(\theta^*)}{R'(\theta^*)}\right]F^{-1}(p)\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p \\
=&R'(\theta^*)\left[\int_0^1 F^{-1}(p)\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p + \sigma\left(\frac{-R''(\theta^*)}{R'(\theta^*)}\right)\int_0^1 (F^{-1}(p))^2\,\mathbb{E}\,u(n_K(p))\,\mathrm{d}p\right].
\end{aligned}$$

Unless $K = 1$, the first term is negative as explained above. The second term is positive and increases with σ and with the coefficient of the absolute risk aversion $\frac{-R''(\theta^*)}{R'(\theta^*)}$. Therefore, unless $K = 1$, $\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma}$ is negative for σ close to 0 and could become positive for large σ.

For the monotonicity of $\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma}$ with respect to σ, note the numerator and the denominator in (A.5) are linear functions of σ and thus

$$\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma} = \frac{a + C_r b\sigma}{c + C_r a\sigma}$$

where $a < 0, b > 0, c > 0$ and $C_r = \frac{-R''(\theta^*)}{R'(\theta^*)} > 0$. Thus, the sign of the derivative of $\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma}$ with respect to σ is given by $C_r b(c + C_r a\sigma) - C_r a(a + C_r b\sigma) = C_r(bc - aa)$ which does not depend

on σ and has to be positive because $\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma}$ increases. Thus, $\frac{\mathrm{d}\theta^*}{\mathrm{d}\sigma}$ increases monotonically.

□

B Additional Examples

This section provides additional examples that illustrate our analysis.

B.1 Non-uniform Distribution of Community Noise

In this section, we provide additional figures (similar to Figure 2) that illustrate the case when the community noise ε follows a non-uniform distribution shown in Figure B.2.

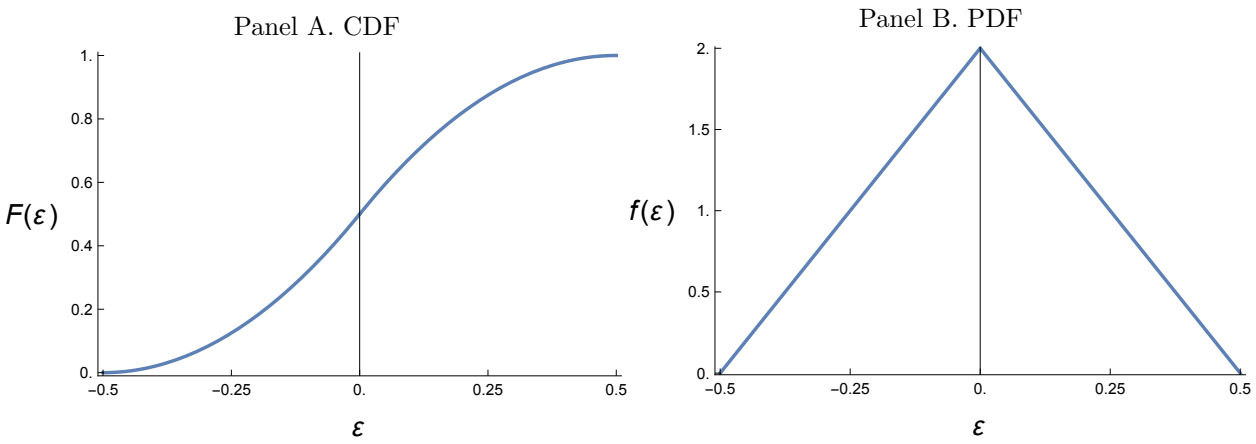


Figure B.2. The CDF and PDF of a community noise ε that follows a non-uniform distribution.

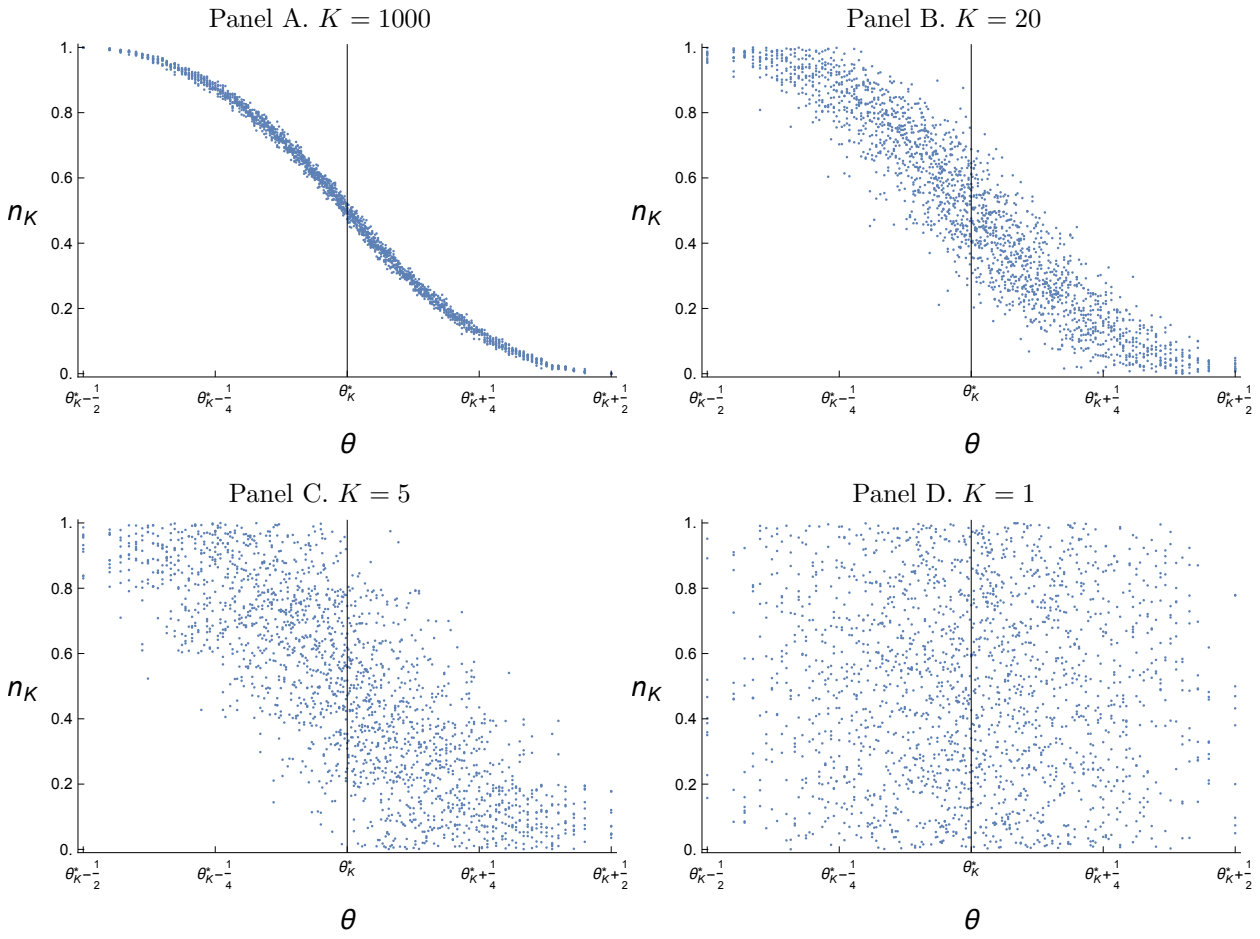


Figure B.3. The joint beliefs of the marginal depositor. Uncertainty decoupling. These figures plot a sampled distribution of the marginal depositor's joint fundamental and strategic uncertainty (θ, n_K) for $K \in \{1, 5, 20, 1000\}$. In the graph, we consider a setting with $\sigma = 1$, $\varepsilon \sim F(\varepsilon)$ shown in Figure B.2.