Macrofinance and Resilience

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Abstract

This address reviews macrofinance from the perspective of resilience. It argues for a shift in mindset, away from risk management toward resilience management. It proposes a new resilience measure, and contrasts micro- and macro-resilience. It also classifies macrofinance models in first- (log-linearized) and second-generation models and links the important themes of macrofinance to resilience.

Keywords: Macrofinance, Resilience, Safe Assets, Traps, Tipping Points, Fiscal and Monetary Policy

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Contents

Macrofinance, which examines how finance impacts the macroeconomy, gained renewed prominence after the Global Financial Crisis (GFC). Its roots, however, go far back in the history of economic thought. Indeed, arguably many eminent economists throughout history have been interested in the relationship between the macroeconomy and finance.

Most fundamentally, macrofinance is concerned with macroeconomic growth and efficiency as well as with the stability of the financial sector. The literature encompasses a wide variety of models—mostly in dynamic general equilibrium settings—and empirical analyses. In most macrofinance models with financial frictions and heterogeneous agents the distribution of wealth matters, also because the wealth shares are important state variables. Inequality is an important policy concern on its own but also since it interacts with growth and stability.

Macrofinance is a "broad church" that touches on most subfields of economics and finance. In finance, it is tightly connected to asset pricing, intermediary finance, corporate, household, and behavioral finance. In economics, the overlap is greatest with monetary economics and public finance.

A presidential address gives one the liberty to raise new questions, sketch out new concepts, and outline new challenges.[1] First, I would like to shed light on the field of macrofinance from a resilience point of view in this address. Resilience is the ability to bounce back after a shock or to manage a transition in a smooth manner. It is different from resistance, which can be thought of as the ability to withstands a shock without adjusting. A rigid system can be resistant. In contrast, resilience derives primarily from adaptability.

Second, I advocate for a *shift in mind-set* beyond static risk management towards resilience management. Most finance models focus on the trade-off between expected returns and risk after exhausting diversification benefits. I argue that reducing risk or resisting shocks should not be non-plus ultra. In short, I argue that resilience should be the guiding North star for researchers, practitioners, as well as policy makers.

As we consider how to enhance resilience several important questions arise. What exactly is resilience and how should one measure it? How does resilience management differ from risk management? What shocks is the financial system or the macroeconomy resilient to? Why would one forgo growth to resist shocks if one has the ability

[1] I take the liberty to do so without dotting all i's and crossing all t's.

to bounce back after them? And how should one prepare to ensure that the system bounces back after a shock? How can one manage a transition phase so that it does not drift away and ends up in a worse outcome?

Figure 1 depicts the striking resilience of the U.S. economy over time. As can be seen, U.S. GDP bounced back after most recessions returning to the previous growth trend (that is, the economy made up the previous output losses). There are two exceptions: the Great Depression in the 1930s, after which the recovery took almost a decade and the GFC of 2008, which led to the Great Recession. Figure 1 therefore suggests that, while regular business cycles come and go, the economy is less resilient after financial crises.

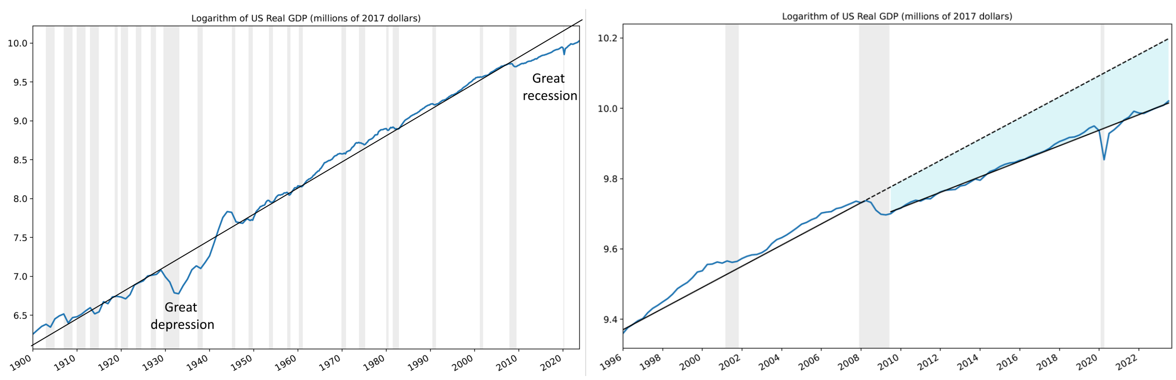

Figure 1: Panel A depicts the log-level of U.S. GDP from 1900 to 2023, while Panel B zooms in log GDP-level from 1996 onwards. Shaded areas show recession periods.

After the Great Depression in the 1930s, the economy did not fully bounce back to the previous GDP trendline until fiscal spending associated with WWII. The GFC 2008 led to the Great Recession, because the fiscal spending was arguably not aggressive enough. As Panel B highlights, since 2008 both the level of GDP and the subsequent growth rate have remained depressed. In contrast, the U.S. economy was remarkably resilient to the Covid19 pandemic shock: U.S. GDP returned to its post-GFC trend. The U.S. economy was also resilient after smaller financial crises, like the Savings & Loan crises in the 1980s and earlier crises in the 1800s. The prolonged economic stagnation in Japan following the collapse of its stock and real estate markets in the late 1980s serves as a notable international example of how financial crises can undermine economic resilience.

I. Resilience

Resilience is a property of a stochastic process, a path of random variables realized over time, that is linked to the adaptability of the underlying system after a shock or shift. In economics, a prominent stochastic process is GDP, both in levels and in growth rates. In finance, price and cash flow processes are common stochastic processes.

A. Resilience Measures

Before we delve into measuring resilience, let us recall some key measures of risk and risk preferences. Risk measures capture the dispersion of a random variable, with variance being a classical example. In finance, we typically focus on downside risk, which is often measured by a specific quantile of a random loss, known as Value-at-Risk (VaR). Another widely used risk measure is the expected shortfall, which is the expected value given that the loss exceeds the VaR threshold. Measures of risk preferences are usually related to the curvature of the utility function normalized by its slope, with the Arrow-Pratt measures of absolute and relative risk being the most commonly used.

Resilience is a dynamic concept. Above I note that it is a property of a stochastic process that refers to the ability of a stochastic process to bounce back due to the adaptability of the underlying system. Mean reversion is one simple measure of resilience. However, it is not ideal since the mean reversion coefficient does not need to be constant, an average mean reversion coefficient does not take into account whether the recovery occurs early or late, and mean reversion ignores the initial amplification of the shock. Alternatively, one could take the half-life of a shock as a measure of how unresilient a process is. Many macroeconomic models study IRFs and how a particular variable behaves on average after a shock. The area between the pre-shock trend line and the IRF, referred to as the cumulative IRF, can be viewed as another resilience measure.

In this address, I propose a new conceptual measure of resilience, $\mathcal{R}$. The aim is to measure how the ability of a system, such as the economy or a network, to adapt to an exogenous shock affects an endogenous process X_t. In particular, it measures to what extent it speeds up or worsens the bounce-back.

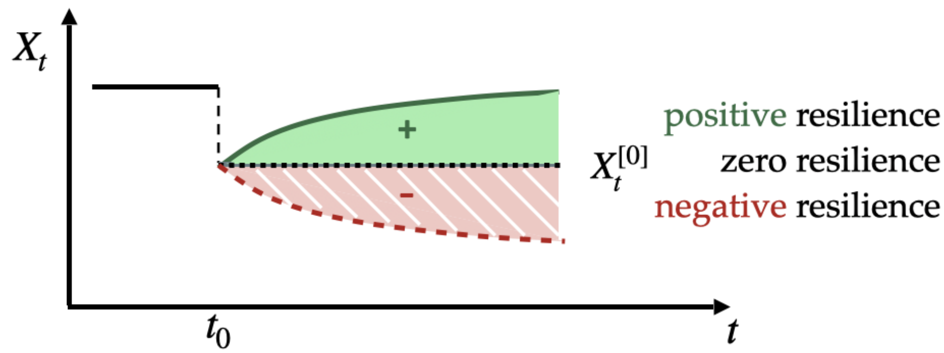

Figure 2: **Graphical illustration of the resilience measure.** The horizontal dashed black line after the shock at t_0 has zero resilience. If adaptation leads to the green process that bounces back, the resilience measure is positive as represented by the green shaded area. In contrast, if adaptation leads the process to further drift away after the shock, the resilience measure is negative as depicted by the red shaded area.

A.1. Intuition

Figure 2 illustrates the intuition behind the resilience measure, $\mathcal{R}$, conditional on a shock at t_0. Suppose that the system, for example, the economy, suffers an adverse shock at t_0. It also impacts the stochastic process X_t, for example, GDP or cash flows, at t_0. The subsequent path of X_t depends on how the system, and agents living in the system, reacts and adapts to the shock. Let the process $X_t^{[0]}$ be the one that emerges when the system does not react, say due to high adjustment costs. In the example of Figure 2, let us assume that $X_t^{[0]}$ simply stays constant due to high adjustment costs. The horizontal dashed black line depicts the endogenous process, $X_t^{[0]}$, that arises with high adjustment costs. We treat $X_t^{[0]}$ as our zero-resilience benchmark. If adjustments costs are low, the system can react and the subsequent process X_t may differ. It may bounce back (as with the green curve) or diverge further (as with the dashed red curve), depending on how agents' reactions impact X_t. The resilience measure $\mathcal{R}$ captures the extent to which the endogenous process X_t recovers relative to a zero benchmark $X^{[0]}$ and is given by the area between X_t and $X^{[0]}$. In the case of the green X_t-process, adaptation results in positively resilient process captured by the green positive area. In contrast, for the dashed red X_t-process in Figure 2 shows how the endogenous reactions of the system to an exogenous shock can induce the endogenous process to drift further away. The red curve in Figure 2 captures this case. The $\mathcal{R}$-measure is negative, graphically by the red area.

Importantly, divergence of X_t from its benchmark can lead to a measure of resilience of negative infinity, even with discounting. This would be the case, for example, if the process crosses a tipping point and the system enters an adverse feedback loop. A feedback loop can emerge if individuals' actions lead to spillovers that trigger others to react in a way that leads to spillbacks, which cause further spillovers, etc. Negative externalities/spillovers are about payoff impacts on others. Strategic complementarities are about reaction to others' actions. It is the combination of negative externalities and strategic complementarities that leads to adverse feedback loops, often also referred to as spirals.

In general, the proposed $\mathcal{R}$- measure can be linked to the present value of the net benefits of adaptability. If the system adapts and the benefits of adaptation over time are positive, the resilience measure is positive.

A.2. Formal Derivation

A formal derivation of the $\mathcal{R}$-measure requires that we specify the effect of an exogenous shock at t_0 on the system and its ensuing reaction, taking into account the interactions between agents. I define the $\mathcal{R}$-measure as a property of the conditional distribution of the endogenous process X_t after the shock and of the characteristics of the underlying system. The state process s_t represents the underlying stochastic exogenous process that suffers a shock to which the system together with X_t subsequently adapt.

State-evolution. Consider an exogenous time-state space, defined by the set $\mathcal{T} \times \mathcal{S}$, with both time and state spaces being discrete. Let s_t be the exogenous state at time t and $\underline{s}^\tau$ be the history of state evolution up to time τ, and denote by $\pi(s_t; \underline{s}^\tau)$ the probability of future states s_t for $t > \tau$.[2] We zoom in at the shock that occurs at time t_0. The probabilities are updated from $\pi(s_t; \underline{s}^{t_0-1})$ to $\pi(s_t; \underline{s}^{t_0})$ for all $t > t_0$.

Let us first apply the notation to a simple example that is used in many first-generation macrofinance models. They often consider a deterministic environment that is shocked by a single unanticipated *zero-probability shock*. In this case, the state is simply assumed to be constant over time. That is, a particular state $s \in \mathcal{S}$ has an assigned probability of one, while all other states have zero probability of occurring. However, at t_0 there

[2]For simplicity, we consider the case in which all agents i have the same beliefs.

occurs a zero-probability shock that pushes the state to a new state $s' \in \mathcal{S}$ and from then on $\pi(s'_t; \underline{s}^{t_0}) = 1$ for all $t > t_0$.

Our setup is very general. It also allows for a temporary shock, a transition phase, and a volatility shock. A *shock* moves the state from s_{t_0-1} to s_{t_0}. It can be temporary, for example, it can last only for a single period, or it can be permanent.[3] However, a shock can also trigger a steady decline in the state space over time, sometimes referred to as a transition or *shift*. Examples of shifts are the green transition and other transition phases that lead to long-lasting exogenous changes, like innovations triggered by artificial intelligence. The speed of the transition is often a decisive factor affecting whether the transition is resilient or not. Another class of shocks, *risk shocks*, alter the volatility of the exogenous process.

From exogenous shock to endogenous X_t-process. Unlike pure statistical models in which the stochastic process $X_t = X(s_t; \underline{s}^{t-1})$ is simply adapted to the state s-process, we consider a system in which agents possibly react to the s-shock, and in turn affect the endogenous stochastic process X_t. Each agent $i \in \mathcal{I}$ forms an *action plan/strategy*. Each agent's action plan describes how she behaves in all future date-states. Each plan is conditional on the history $\underline{s}^\tau$ and the strategy profiles/action plans of all others.

An s-shock alters future states and with it agents' actions and outcomes. Changing the action from one period to the new future actions can be costly. The *adjustment cost* function of agent i is $\Phi^i(\cdot; s_t)$ and captures these costs. High adjustment costs typically lower the agents' adaptation. Said differently, agents' action plans depend on these adjustment costs. Note that the adjustment cost function can also be state-contingent, nonlinear (e.g., include fixed costs) or vary randomly over time (e.g., for the case with Calvo pricing frictions).

Any endogenous equilibrium stochastic process X_t^Φ depends on the *equilibrium action plans* of all agents for a given adjustment cost function Φ.

A relative measure of resilience. The $\mathcal{R}$- measure compares the endogenous stochastic process X_t^Φ relative[4] to the hypothetical zero-benchmark endogenous process $X_t^{[0]}$ that would arise if adjustment costs Φ were unexpectedly higher from t_0 onwards. One natural benchmark, $X_t^{[0]} = X_t^{\Phi=\text{high}}$, is the minimum feasible adjustment given very

[3] Note that if the shock process is expressed in changes, then a temporary shock is permanent.

[4] The resilience measures shares its relative nature with other important measures like the KL divergence measure in entropy.

high adjustment costs. For simplicity, I refer to this particular benchmark as the "no adjustment" benchmark, $X_t^{[0]}$.

Sunspot shocks deserve special mention. After a sunspot the nonadapting zero-resilience benchmark/counterfactual is simply the current state, that is, $s = s'$. In this case the resilience measure coincides with the signed traditional cumulative IRF used in macroeconomic papers.

The $\mathcal{R}$-measure is a "cumulative gap measure" between the equilibrium process X_t^{Φ} conditional on the shock s_{t_0} given history $\underline{s}^{t_0-1}$ and the no-adjustment benchmark, $X_t^{[0]}$. It measures the expected cumulative distance,

$$\mathcal{R}^{X,\Phi,[0]}(s_{t_0}|\underline{s}^{t_0-1}) := \mathbb{E}_{t_0}\left[\sum_{t\geq t_0}(X_t^{\Phi} - X_t^{[0]})\Big|s_{t_0};\underline{s}^{t_0-1}\right].$$

Note that the conditional resilience measure is shock-specific, for example, the shock can be negative or positive. One can also focus on specific adverse shock, say s_{t_0}-5%-quantile shock given the history $\underline{s}_{t_0-1}$.[5] Instead of specifying the resilience measures conditional on a particular shock in t_0, one can also take ergodic unconditional expectations over all possible t_0-shocks.

There are several ways to generalize the resilience measure, which allows one to link it to other concepts. One simple way to generalize the resilience concept is to simply apply it to a modified X_t-process. For example, one could consider a growth process $\hat{X}_t := X_t^{\Phi}/X_t^{[0]} - 1$ or a discounted process $\bar{X}_{t;t_0} := X_t^{\Phi}/(1+\rho)^{t-t_0}$. Discounting by the rate ρ also ensures that early recoveries receive a greater weight than late recoveries. In addition, one can apply the resilience measure to discounted utility flow, $u(X_t)/(1+\rho)^{t-t_0}$, instead of simply X_t. More generally, and going beyond exponential discounting, one can apply a general valuation functional $\mathcal{U}(\cdot)$ to the whole process X_t. The generalized resilience measure then becomes $\mathcal{R}^{X,\Phi,[0]\mathcal{U}}(s_{t_0}|\underline{s}_{t_0-1}) = \mathcal{U}\left(X_{\geq t}^{\Phi}|s_{t_0};\underline{s}^{t_0-1}\right) - \mathcal{U}\left(X_{\geq t}^{[0]}|s_{t_0};\underline{s}^{t_0-1}\right)$.

Special cases. If X_t is the consumption process and assuming the agent derives utility only from consumption, then a natural $\mathcal{U}$ is agent's utility value function. In this case, the resilience measure represents the utility gains from having lower adjustment costs Φ instead of the high zero-benchmark adjustment cost $\Phi^{[0]}$.

[5] This is analogous to the VaR measures.

Next, consider the case in which $\underline{X}_t$ is a cash flow process, possibly of an asset, and $\mathcal{U}(\cdot)$ is a valuation functional, for example, $\mathcal{U}_{t_0}(\cdot) = \mathbb{E}_{t_0}\left[\sum_{t=t_0}^{T} SDF_{t_0,t}\underline{X}_t\right]$, where $SDF_{t_0,t}$ is the stochastic discount factor (SDF) that discounts future cash flows from time t back to t_0. Assuming that the SDF is independent of $\underline{X}_t$, the $\mathcal{R}$- measure is then the *price difference* due to adaptation, that is, $\mathcal{R}_{t_0}^{X} = p_{t_0}(X_t^{\Phi}) - p_{t_0}(X_t^{[0]})$.

Marginal resilience measure $\partial\mathcal{R}$. Alternatively to specifying a no adjustment $X_t^{[0]}$-benchmark, one can also apply the resilience measure to a "marginal gap". That is, one can pick as the $\mathcal{R}$=0-benchmark the process that arises with just marginally higher than Φ cost, that is $X_t^{[0]} = X_t^{\Phi+\varepsilon}$. Formally, the *marginal resilience measure* $\partial\mathcal{R}$ is given by

$$\partial\mathcal{R}^{X,\Phi}(s_{t_0}|\underline{s}^{t_0-1}) = -\mathbb{E}_{t_0}\left[\sum_{t\geq t_0} \frac{\partial X_t(\cdot)}{\partial\tilde{\Phi}}\bigg|_{\tilde{\Phi}=\Phi} \Big| s_{t_0};\underline{s}^{t_0-1}\right].$$

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Increasing the adjustment costs marginally from t_0 onwards typically impacts each agent's future action plan, which in turn affects the endogenous stochastic process X_t for $t \geq t_0$. If agents' actions change discontinuously with jumps, then our definition of $\partial\mathcal{R}$ has to be generalized.

As for the $\mathcal{R}$-measure, the marginal $\partial\mathcal{R}$-measure can also be applied to the $\mathcal{U}(\cdot)$-valuation functional. In that case, the marginal resilience measure becomes

$$\partial\mathcal{R}^{X,\Phi}(s_{t_0}|\underline{s}^{t_0-1}) = -\nabla_{X_{\geq t}}\mathcal{U}(X_{\geq t}|s_{t_0};\underline{s}^{t_0-1})\frac{\partial X_{\geq t}(\cdot)}{\partial\tilde{\Phi}}\bigg|_{\tilde{\Phi}=\Phi}.$$

B. Resilience and Related Concepts

Several concepts are related to resilience.

Stability is classically used to describe points of a system to which it eventually returns with all its elements after some small (local) disturbance. Importantly, it is not allowed to adapt after the disturbance. Resilience differs in two aspects. First, it also covers large shocks. Second, it refers to a particular endogenous stochastic process and may even require that parts of the system adapt, and hence might be permanently altered to ensure that the stochastic process bounces back. In other words, a state of a system is stable if after an infinitesimally small shock all of its elements return to the starting point, while a particular stochastic process is resilient after a possibly large shock precisely because part of the system adapts and is subsequently in a different state.

Antifragility, introduced by Taleb (2014), refers to a system that is "uber-resilient." Such a system not only recovers but also surpasses its original state after a disruption. The shock disrupts an inefficient situation, ultimately leading to an improved long-term outcome. In other words, antifragility is the ability to thrive and grow stronger following a shock. The resilience measure $\mathcal{R}$ also encompasses antifragility. If the outcome is permanently higher after a shock, $\mathcal{R}$ takes on a value of positive infinity.

Mitigation and amplification are also related concepts. Instead of bouncing back with a delay, the system might be so resilient that a shock is immediately mitigated. Hence, *mitigation* can be seen as an instantaneous form of resilience. While resilience takes the whole future path into account, mitigation only considers the instantaneous/simultaneous reaction. *Amplification* is the opposite of mitigation and is therefore a form of instantaneous negative resilience. *Persistence* and *mean reversion* as well as *momentum/reversals* in the form of positive/negative autocorrelation are properties purely of a stochastic process and are not necessarily associated with the adaptability of (elements of the) system such as resilience.

The *propagation* of a shock relates to how a shock propagates in the cross-section across a system, that is, it captures how a shock spills over across stochastic processes. The emphasis is on the joint evolution of the cross section.

Resistance requires that a system withstand a shock even without reacting to it. Such a system is fault-tolerant despite or even because of its rigidity. This is in contrast to resilience, where the setback is temporary followed by a recovery because the system adapts to new circumstances. *Robustness* involves unforeseeable shocks, uncertainty over states without probability assignments, and models in which decision makers acknowledge misspecification in economic modeling (e.g., Hansen and Sargent (2011)).

C. Risk versus Resilience Management

Risk management focuses on the traditional risk-expected return trade-off in finance. For a given expected return $\mathbb{E}_{t_0}[R_{t_0+1}]$, optimal diversification between projects or assets allows one to minimize risk. Diversification is a key concept of risk management.

Rather than exposing oneself to a few projects and assets, it is advisable to spread the risk over many assets. Colloquially speaking, people refer to the common wisdom investment advice "don't put all your eggs in one basket." The key input variable is the return correlation and co-movement at time t_0. If one wants to reduce the risk beyond diversification, one has to forgo some of the expected return as the risk-expected return trade-off indicates that avoiding more risk reduces the expected return or growth rate. The black solid line in Figure 3 depicts a situation in which an agent avoids all risk and chooses a risk-free growth path (y-axis is in log-scale). In contrast, the blue curve is a realization of a risky stochastic process that stochastically mean-reverts to the trend line - like U.S. GDP in Figure 1. Interestingly, the risky but resilient option dominates the risk-avoidance option in the long run.

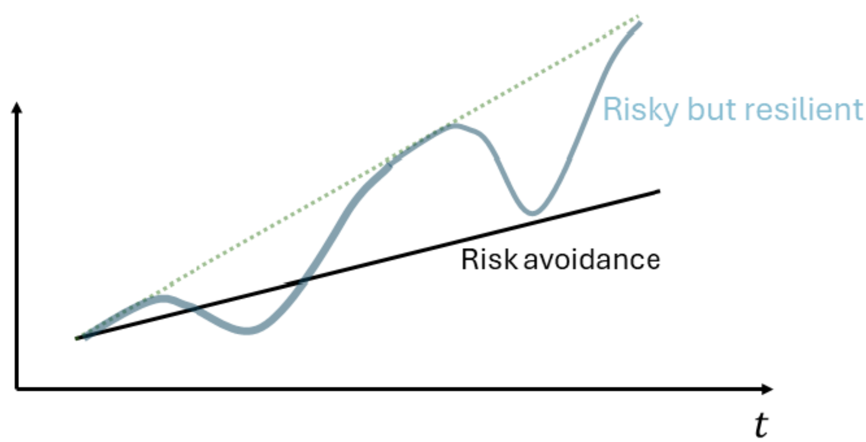

Figure 3: Two paths

How does resilience management differ from risk management? Short-term risk management primarily focuses on diversification and mitigating risks in the short to medium term. One might argue that long-term risk management (with a sufficiently low discount rate) would also choose the resilient path over the risk-avoidance path in Figure 3.[6] However, this overlooks that *resilience management* has two elements: first, how to adapt at $t_0 + 1$ after a shock is realized, and second, how to invest and prepare at time $t_0 - 1$ to increase adaptability and agility ahead of a shock , or in other words, how

[6]The emphasis to choose the more risky option over the low risk-low growth option as long as setbacks are followed by recoveries can also be linked to Lucas (1987), who argues that macroeconomic research should focus more on growth theory than on business cycle theory.

to reduce future adjustments costs $\Phi_{t>t_0}$. In a sense, the sentence "open many doors, so that one can easily and swiftly adapt" following possible future shocks captures an important part of a resilience management strategy.

How can one enhance adaptability ex-ante to minimize future adjustment costs Φ? Investing in both substitutability and scalability can make it easier to switch from one project to another. The concept of multi-sourcing in the context of global value and supply chains illustrates this. To reduce risk, it is wise to source from multiple suppliers, ideally from different continents, as any shocks they might face would be less correlated. Such diversification is a good risk management tool. If a supplier in one continent breaks away, then a firm can still run part of their production by relying on their suppliers from another continent. Resilience goes beyond this. Rather than simply relying on existing suppliers in other continents, one can try to substitute products and scale up this input supply from the other continents. That is, one can establish international supply chains in a way that they can easily replace missing inputs from one supplier with inputs from another supplier. Correlation is the key statistic for risk diversification; altering future adjustment costs Φ is a key statistic for resilience management.

In the context of finance, improved market liquidity reduces the cost of portfolio adjustments. Similarly, a fund that gains expertise in several areas, for example, by operating several trading desks for a handful of asset classes, has more resilience. It can more easily switch to a different trading strategy should circumstances change. Investors who follow an optimal dynamic hedging demand implicitly take resilience reasoning into account. If they know that a positive investment opportunity arises after a possible negative shock, then taking more risk is not so risky. However, if after a negative shock investors hit a margin constraint and are forced to fire-sell assets at unfavorable prices, resilience is inhibited.

More generally, part of resilience management is to avoid adaptability inhibitors, such as traps and tipping points. When hitting a trap, one is stuck and by definition one cannot bounce back. This undercuts resilience. Tipping points are even worse. When hitting a tipping point, the situation deteriorates further, possibly due to an adverse feedback loop. Building buffers in the form of equity capital, reserves, and other redundancies is key to stay away from traps and tipping points. In other words, "building up a war chest" can be an important measure to enhance resilience.

For long-run risk where shocks impact the long-run growth rate, as studied, for example, in Bansal and Yaron (2004), adaptability is the only way to return to a higher growth path after a negative shock, as these risks are typically aggregate risk. In other words, resilience-enhancing measures are essential to reduce long-run risk.

D. Macro- versus Micro-Resilience

How does resilience aggregate across various parts of a system or of the economy? For a system to be resilient, must all parts of it be resilient? Recall that the state of a system is stable if it returns to the exact starting point after a small shock. In contrast, resilience also refers to large shocks, adaptability, and stochastic processes, that can bounce back even though other parts of the system reach a new point. Resilience does not aggregate. Micro-resilience might actually inhibit the macro-system from being resilient. Resilience is subject to a fallacy of composition. If certain parts of the system are not resilient, they might even vanish, which can open up space for other parts, which may in turn make the whole macro-system more resilient.

For example, an economy that consists of very resilient zombie firms may be highly micro-resilient, but the lack of adaptability reduces its macro-resilience. This is especially true if the underlying shocks are structural. The cornerstone of Schumpeterian creative destruction is that inefficient and less innovative firms should be less resilient and should ultimately be replaced by more innovative firms. Darwinian selection also works to enhance macro-resilience but not micro-resilience. For example, the restaurant scene in a megacity can be very dynamic and resilient, precisely because restaurants that go out of fashion or are not run well are not resilient. In short, resilience's emphasis on adaptability leads to a paradox of aggregation.

E. Resilience and Networks

The resilience of a stochastic process depends on the action plans of all actors $i \in \mathcal{I}$ and, more importantly, on how their actions interact. How does one actor's action impact others? How are they linked and what are the externalities and feedbacks? These interactions can be represented with a network structure, with links that possibly have different strengths. In short, the underlying network structure is a key input in the mapping from all agents' action plans to an endogenous process $X_t(\cdot)$.

In addition, a shock at t_0 can impair the network structure itself. This raises the question of how resilient the network structure is on its own. Can broken links be recovered? Can neighboring links substitute for a broken link? Measurement of a network's resilience is a challenge. Note that X_t^{Φ} is a network structure. One way to reduce the dimensionality of this measurement problem is to apply our resilience measure to network statistics, like centrality measures. Applied over time this network statistic forms a stochastic process.

The resilience of a network is not independent of its structure. The nodes of a network with their interdependent links can be organized in a variety of topologies.

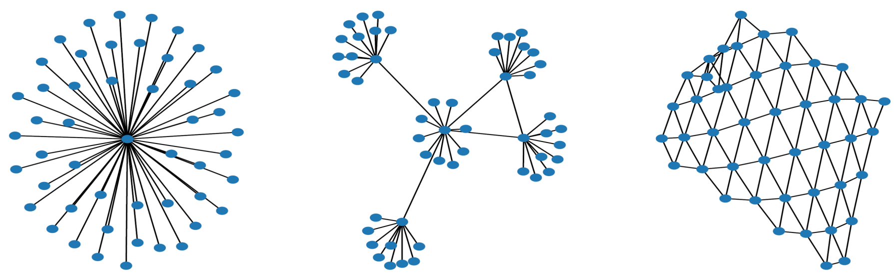

Figure 4: **Centralized (left), decentralized (middle), and distributed (right) networks.**

The left-hand side of Figure 4 displays a *central network*, where all links run through a central node and the peripheral nodes are not connected to each other except through their link in the center. One can think of the central network as a hierarchical structure in which one key player, the central node, has much more influence than the other nodes. The resilience of this network critically depends on the resilience of the central node, and thus measuring the central node's resilience is a good proxy for the resilience of the whole network. An example in finance could be a centralized exchange with a well-designed clearing house. Such an arrangement can pool liquidity, limit exposure to counterparty credit risk, and provide a uniform price signal. Such a centralized network allows all players in the system, and possibly the system as a whole, to adjust quickly and with little cost to shocks. Hence, endogenous processes such as the price or liquidity processes can be more resilient to small shocks. However, for shocks that threaten the central clearing house, the resilience of these endogenous processes, as well as of the entire network, might be compromised.

The *decentralized network* in the middle of Figure 4 is vulnerable to the failure of some of the local central nodes. In decentralized networks, nodes within a subgroup - often referred to as islands in economics - are well connected. The nodes within an island may even be linked bilaterally. The resilience of a decentralized network depends on how easily the link between the central nodes across the islands can be repaired or replaced with other nodes. An example in finance is an over-the-counter market with connected intermediary dealers as in Farboodi, Jarosch, and Shimer (2022).

The *distributed network*, depicted on the right-hand side of Figure 4, has a flat hierarchy. Each node is linked to its neighbors. In search markets without a centralized market structure, links emerge randomly as people find each other. Instead of a single centralized price, there are many price processes. The network on its own might be more resilient if a broken link can be easily made up with indirect connections through some neighboring node. The topology of our brains, some blockchains, terrorist networks, as well as a large part of the economy in a free society take this form.

II. Classifying Macrofinance from a Resilience Perspective

In this section I divide macrofinance models into first- and second-generation models. I do so by focusing on macrofinance models that emphasize financial frictions rather than on models that enrich agents' preferences. Frictions limit adaptability, and hence typically dampen resilience. Financial frictions matter only if agents are heterogeneous. If all agents are always homogeneous, then no trading or financial contracting is needed. Heterogeneity across different groups of agents can come in different forms: agents in the model might differ in their productivity, endowment shocks, institutional constraints, time or risk preferences, or beliefs. Some might be optimists, others pessimists. The net worth share of each agent group that matters for the equilibrium outcome is an important state variable.

A. Contrasting Different Frictions

Financial frictions come in different facets and can be classified along different dimensions. One possible classification is as follows

Intertemporal issuance/contracting frictions and funding liquidity

Limitations on what contracts an agent can write to raise funding in the primary market are at the center of many macrofinance models. That is, funding liquidity is limited.

In many models, an agent can only offer debt contracts and cannot go short on contingent claims, like equity contracts. *Equity issuance constraints* limit the extent to which agents can off-load risk to other investors. If agents can issue equity, the amount may be limited by a skin-in-the-game constraint to contain moral hazard complications. Markets are incomplete.

Debt issuance constraints limit borrowing. The amount of borrowing, that is, debt issuance, can be exogenously capped to a fixed amount or restricted by a collateral constraint. For the latter case, that is, for margin borrowing, the debt issuance limit depends on the value of the underlying collateral. As the collateral value drops, margin calls kick in and borrowing constraints tighten. Note that not only borrowers may be constrained but lenders could also be limited in how much credit they can extend.

Intratemporal trading frictions and market liquidity

A financial contract becomes a security if it can be easily passed on to another agent. Trading costs that arise when securities are traded between two agents are another form of friction. The higher the trading costs, the lower the liquidity in the market. Trading costs reduce retrading and hence they also limit the dynamic completion of incomplete markets via dynamic trading strategies.

Asymmetric information frictions are a particular type of trading friction. Market breakdowns and freezes à la Akerlof's market for lemons may occur as traders who are informationally disadvantaged may withdraw from the market. Market freezes are traps, and hence resilience killers, as it is difficult to bounce back from them. If market liquidity is high during normal times but disappears during stress scenarios, researchers often refer to it as "fair weather" market liquidity.

Market liquidity and funding liquidity are connected in various ways. First, note that an entity that needs long-term funding can issue long-term assets that can be traded subsequently in secondary markets, thereby relying on market liquidity. The long-term asset then changes hands to different investors. Alternatively, the entity with long-term funding needs can issue short-term assets that mature earlier and can roll them over by issuing new contracts to possibly different investors. Of course, rollover risk arises, which can provide a disciplinary force to reduce moral hazard problems (Calomiris and Kahn (1991), Diamond and Rajan (2005)); it can also lead to (non-linear) inefficiencies like bank runs (Diamond and Dybvig (1983)). Brunnermeier and Pedersen (2009) stress that market liquidity depends crucially on the liquidity of market makers, who use assets as collateral and may face margin calls.

Search frictions in financial markets as developed in Duffie, Gârleanu, and Pedersen (2005) that lower market liquidity can be seen as a trading friction with an intertemporal component.

Monetary frictions

Monetary frictions are a form of intratemporal friction, as they prevent agents from barter, that is, from costlessly exchanging one good for another good. Barter typically happens only if there is a double coincidence of wants: The seller of a particular good or service wants to receive the buyer's good or service in return. Because of these frictions, a special asset— money—serves as a medium of exchange. Due to its specialness, money commands a convenience yield.

Recontracting frictions

Frictions that limit the recontracting of existing contracts can be viewed as another category of financial frictions. Recontracting typically involves renegotiation. In a certain sense, trading frictions can be seen as the inability to pass a contract on to a different contracting partner as a special form of recontracting friction.

Recontracting frictions can be good or bad. They can be good because they can serve as a commitment device. This enables contract enforcement and ex-ante risk sharing, which may not be possible with easy recontracting. On the other hand, with recontracting frictions, the contracting partners might end up being trapped in an ex-post inefficient situation.

A classic example in finance is the debt overhang problem. Zombie firms may delay debt restructuring and fail to take advantage of new positive net present value (NPV) projects. Equity owners of overly indebted companies delay debt restructuring and prefer to repay ongoing debt obligations to maintain the equity call option and gamble for resurrection (Leland (1994)). These zombie firms favor debt repayment and forgo new profitable investments as part of the return of new investments accrues to existing bondholders rather than equity owners (Myers (1977)). Importantly, zombie firms also bind resources and hence depress the growth rate of the macroeconomy, explaining why after a financial crisis the economies do not return to the previous growth paths. The lost decades after the 1990s burst of the Japanese real estate and stock market bubbles are prime examples of this.

The role of financial intermediaries
Intermediaries have the role to mitigate financial frictions that agents are exposed to, in order to improve risk-sharing and maturity transformation. To do so, they have to be sufficiently capitalized, that is, sufficiently equity-financed. When they suffer losses, they scale back their activities and financial frictions come to the forefront. Financial intermediaries, particularly banks, also help overcome monetary frictions by issuing money, a standardized short-maturity, highly liquid asset that is backed by a variety of less liquid, long-maturity assets. "Money and banking" is part of macrofinance, highlighting the close ties between macrofinance and intermediary and institutional finance.

In this section, we classify the macrofinance literature from a resilience perspective and split them into two generations of models.

B. First-Generation Models

First-generation macrofinance models typically assume reversion to the steady state. The dynamics are characterized by the following properties:

(i) The focus is on the local dynamics around the steady state after a small shock.

(ii) Instead of characterizing the true dynamics after a shock, the dynamic response functions are approximated, that is, log-linearized around the steady state. It is assumed that the response to a large shock is simply a log-linear scaled-up version of the response to a small shock.

(iii) Log-linearization implies that agents living in the model expect the return to the steady state to be deterministic. The focus on the certainty equivalence implies that there is no perceived risk and no price of risk, let alone risk premium dynamics.

(iv) The ex-ante probability of an aggregate shock is assumed to be zero.

(v) Absence of rich volatility dynamics.

In addition, in most models the steady state is deterministic, and hence there is no (anticipated) aggregate/systemic risk. However, there can be (time-invariant) uninsurable idiosyncratic risk.

Within macrofinance, the financial accelerator literature is prominent. Starting with Bernanke and Gertler (1989), this literature tries to resolve the puzzle of why relatively small shocks translate into large fluctuations in aggregate economic activity. The net worth dynamics (the wealth shares) of subgroups of the society drive the economy. Kiyotaki and Moore (1997) ,(KM) , provide a particularly elegant framework for highlighting the mechanism of static and dynamic amplification. An adverse zero-probability shock lasts for only a single period. Financial frictions amplify the shock, and economic activity slowly reverts back to the initial steady state. Financial frictions limit the funding of more productive agents in the economy from less productive agents. Since agents cannot issue equity, risk-sharing is limited. In addition, debt financing is limited by a collateral constraint. In KM only collateralized borrowing is possible, since productive agents will never repay more than the value of their asset holdings. They cannot pledge more than the next period's value of the collateral, which is physical capital like machines.

In theory the productive agents can adjust their capital holding, that is their actions A_t^i, in two ways. First, they can divest some of the physical capital and convert it back into consumption goods. In KM this is not possible. Second, they can fire-sell some of their physical capital to the less productive agents.

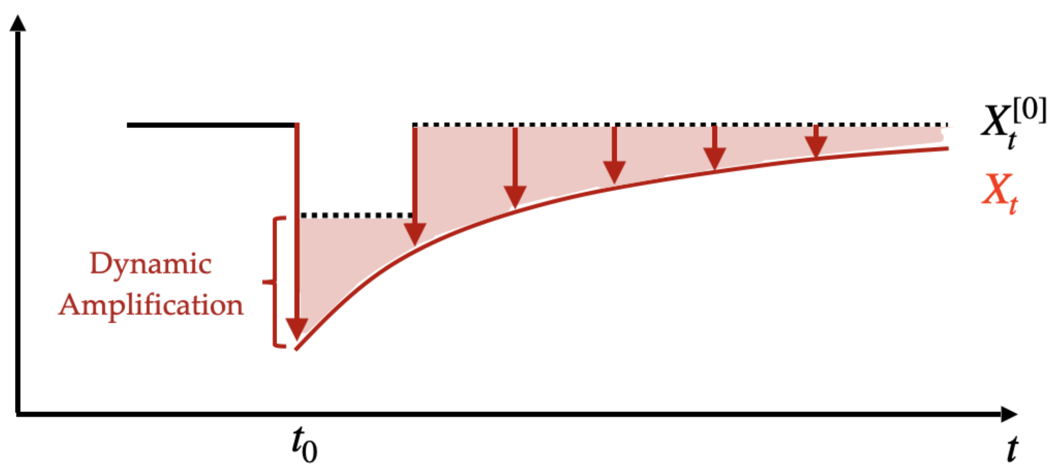

Figure 5: **First-generation macrofinance** as, for example, in Kiyotaki and Moore (1997).

In the KM equilibrium, capital will be sold to less productive agents after a zero probability shock at t_0, depressing the price. This also erodes part of the net worth of productive agents who receive "margin calls" and have to fire-sell capital. Worse capital allocation persists and the capital price that reflects the future marginal productivity of less productive agents is further reduced. This tightens collateral constraints, depressing economic activity even further. Capital allocation improves only gradually as the productive agents rebuild their net worth through retained earnings. As their net worth gradually increases, they are able to buy back the capital. The red curve in Figure 5 depicts the resulting (detrended) output dynamics X_t.

To determine the resilience of the economy, we have to specify the zero-resilience benchmark, $X^{[0]}$. One option is to assume that productive agents do not adapt to the shock. In this case means (i) not fire-selling parts of their physical capital and (ii) not changing their repayment by walking away from debt obligations. The latter relaxes the collateral constraint. If the productive agents could simply hold on to their capital, after the temporary zero-probability shock the output would be depressed only for one period (as long as they also reduce their consumption temporarily accordingly). From the subsequent period onward, everything would be normal again. The (de-trended) black line in Figure 5 represents the $\mathcal{R}$=0-benchmark case, $X_t^{[0]}$. The red area captures the resilience measure $\mathcal{R}$. It is negative since the adjustment through fire-sales lowers the GDP process and slows down the recovery.

Bernanke, Gertler, and Gilchrist (1999) , (BGG), provides another seminal financial accelerator model. In this first-generation macrofinance model, as in its precursor Bernanke and Gertler (1989), external financing is plagued by costly state verification costs á la Townsend (1979). The optimal contract is a defaultable debt contract as it minimizes the verification costs. Only if the borrower defaults on her loan, will her true revenue stream need to be verified. If she pays off the full promised face value, the true state is irrelevant, and hence verification costs do not need to be incurred. In contrast, for equity contracts, payoffs are always state dependent and hence verification costs have to be paid after each realized state. As a consequence, equity is not issued.

Note that an increase in the amount of borrowing increases the face value of the debt and default occurs in more states of the world. Consequently, expected verification costs are higher. Note that the verification costs are, in equilibrium, ultimately paid by the borrower through a higher equilibrium interest rate. In other words, while in KM the borrower's interest rate is constant relative to the amount borrowed and jumps to infinity as one hits the collateral constraint, in BGG's costly state verification framework the external financing cost increases smoothly with the amount borrowed. In BGG borrowers face idiosyncratic shocks. Borrowers who face a large negative shock default and go bankrupt and verification costs arise, while borrowers experiencing a positive shock can pay their debt. A negative aggregate shock erodes borrowers' net worth and induces more borrowers to default. In general, more verification costs are incurred, interest rates are higher, and borrowing is reduced.

In BGG entrepreneurs' action plans do not involve any fire-sales because, unlike in KM, there are no less productive agents to whom to sell capital. However, physical capital can be divested and reverted back to consumption goods, at adjustment costs Φ. What could be a sensible zero-resilience benchmark case? Consider an alternative hypothetical benchmark world in which at t_0 adjustment costs jump and capital adjustment becomes prohibitively high. For simplicity, we assume for now that goods prices are flexible. In this $\mathcal{R}$=0-benchmark case, the aggregate capital stock stays the same and aggregate output is purely driven by a total factor productivity (TFP)shock. In contrast, in the actual economy with lower adjustment cost, some capital is converted into consumption goods, and output X_t is persistently depressed. This implies that the resilience of the output $\mathcal{R}^X$ is negative. While switching off divestment in the $\mathcal{R}$=0-benchmark case holds capital steady, the price of capital collapses and with it the net worth of the entrepreneurs. That implies that the resilience of the capital price process, $\mathcal{R}^q$, is positive.

BGG is embedded in a full New Keynesian (NK) Dynamic Stochastic General Equilibrium (DSGE) model with price stickiness. The action plans of the retail firms include price-setting rules, which are subject to Calvo price-setting frictions. Again, we have to specify a $\mathcal{R}$=0-benchmark, for example, the extreme case in which prices are perfectly sticky. In this case, quantity adjusts. As quantities are now affected due to price stickiness (also in the $\mathcal{R} = 0$-benchmark), the output and price resilience measures above are also different. Overall, BGG is a more involved model than KM, and hence analytical results are limited. One has to resort to numerical simulations.

In BGG the option to default on debt provides partial insurance against adverse idiosyncratic risk. In Bewley (1977, 1980) and Aiyagari (1994) agents can only issue or hold default-free debt. Agents in these models face idiosyncratic risk that they cannot diversify away via risk-sharing. The key financial friction in these models is the assumption of incomplete markets. In addition, they may also face a borrowing constraint. Agents are heterogeneous in wealth. Agents who suffer a series of negative shocks are poorer compared to agents who were more lucky. Since agents are exposed to idiosyncratic risk, they save more in the risk-free asset for precautionary reasons. Their increased desire to save given demand for borrowing depresses the risk-free interest rate, r, possibly below the growth rate of the economy, g. If the risk-free (government) bond or money is the only store of value, as in Bewley models, a "money bubble" is sustainable. In Aiyagari models, physical capital is added as a productive store of value. Since capital is risk-free, it yields only the risk-free rate. Hence, agents' portfolio choice between capital and risk-free bonds is trivial. The emphasis of these models is not on the portfolio choice, but rather on the consumption-savings choice. Agents with different wealth have different marginal propensities to consume.

The HANK model in Kaplan, Moll, and Violante (2018) merges a heterogeneous-agent model (with uninsurable idiosyncratic endowment risk) à la Aiyagari (1994) with an NK price stickiness model à la Woodford (2003). Instead of risk premia, the model emphasis is on the marginal propensity to consume (MPC) across agents with different net worth. Importantly, they also introduce illiquid assets. The consumption of agents with illiquid asset holdings strongly responds to income shocks. That is, these "wealthy hand-to-mouth" agents have a high MPC. Consequently, the net worth effects due to monetary policy interest rate moves are the primary drivers of the consumption channel rather than the traditional substitution channel of an interest rate change.

Most Aiyagari and HANK models focus on the steady state. The state variable is characterized by a steady state net worth distribution across the heterogeneous agents. Aggregate shocks are typically limited to zero-probability shocks. To characterize the dynamics, that is, how the dynamic system reverts back to the steady state, these models are log-linearized around the steady state. Like in BGG, log-linearization focuses on the certainty equivalence, and hence agents in these models behave as if they expect the economy to revert back deterministically to the long-run steady state.[7]

While in Aiyagari (1994)-type models the endowment of agents is subject to idiosyncratic risk and capital is risk-free, in Brunnermeier and Sannikov (2016b) capital is subject to (uninsurable) idiosyncratic risk. Capital earns a risk premium, and the

[7]Solving these models with positive probability repeated aggregate shocks to study risk premium dynamics is challenging as shocks shift the entire net worth distribution. Recently, modern neural network deep learning models have made some progress in solving these models numerically (Gu et al. (2023)).

portfolio choice between capital and a government bond, the safe asset, is nondegenerate. These types of models are also more tractable, as agents' capital holdings scale up linearly with their net worth. Li and Merkel (2020) add price rigidities to this model and bridge the gap to NK models. As the prices of goods are sluggish, the real value of the nominal price of the government bond is also sticky. However, the real value of physical capital becomes more volatile. A demand shock due to an increase in idiosyncratic risk largely depresses the price of physical capital, and a negative output gap in the form of underutilization of capital opens up. The interest rate and fiscal policy are resilience tools since they may be used to target the output gap and inflation.[8]

C. Second-Generation Models: Tipping Points, Traps and Volatility Dynamics

First-generation models make simplifying assumptions to keep dynamic systems, such as the economy or financial system, and their resilience after the shock more tractable. However, this rules out important real-world phenomena. Second-generation models try to incorporate richer dynamics.

(i) Large shocks might affect the economy very differently than small shocks. In particular, the system may be self-stabilizing for small shocks, while for large shocks it is de-stabilizing, that is, resilience is highly negative. This is sometimes referred to as "corridor stability." In a world in which nonlinearities are omnipresent, (log)-linearization is not appropriate.
When a shock is large enough, the system might hit:

   (a) tipping points - thresholds that trigger adverse feedback loops (or spirals) so that the system drifts further away. In the worst case, the system might even drift out of control, in which case the resilience goes to minus infinity. In general, a system might have multiple attractors or may even enter a region in which it then cycles.
   Note also that hitting a tipping point does not need to trigger an immediate sharp decay. The system could simply enter a vulnerability region in which it is subject to jumps, possibly triggered by sunspots.

[8] As these macrofinance models are solved globally, they could be grouped within the second generation of models.

(b) traps - points or lock-ins from which bouncing back is difficult. Traps without escape are absorbing states, where the system remains stuck in the trap. Traps with escapes have at least a small chance of bouncing back.

(ii) Facing a shock when the system is away from the (stochastic) steady state might lead to very different resilience dynamics compared to facing the same shock around the steady state. In other words, global solutions are needed.

(iii) Volatility dynamics might be as rich as the expected path of a dynamic system. While in first-generation models all agents in the economy expect a deterministic return to the initial point, it is realistic that risk rises after a shock. There can be resilience in the volatility process.

The volatility process also interacts with the expected path/drift process. For example, additional and persistent risk can lead to several amplification channels. First, the increase in risk—even if it is only uninsurable idiosyncratic risk, which averages out in aggregate—increases the risk premium that agents require. As agents have different asset exposure, this impacts their expected net worth dynamics differently. Second, additional risk also leads to more precautionary savings and depresses consumption. This can lead to an even more pronounced endogenous amplification of the initial shock, but possibly also to faster mean-reversion as agents subsequently earn a higher risk premium, which helps to rebuild their net worth over time. All of these forces affect the resilience measure $\mathcal{R}$.

C.1. Tipping Points

Tipping points are resilience killers. After hitting a tipping point, the endogenous state variable may jump discontinuously or enter a zone of negative drift. This typically occurs due to adverse feedback loops because of self-reinforcing behavioral actions. Feedback loops arise when people face strategic complementarities: The action of one group leads to a similar reaction by others, which in turn leads to the first group to react, and so forth. If these externalities, spillovers, and spillbacks across agents are negative, then the feedback loop is adverse.

One might expect individuals to try to stay away from tipping points, in which case tipping points should be less of a concern. Each individual's action, for example leverage, is not decisive in coming closer to the tipping point. However, in many circumstances, hitting a tipping point might be due to a joint group action. Each individual does not internalize the externality it imposes on others by pushing the system closer to the edge.

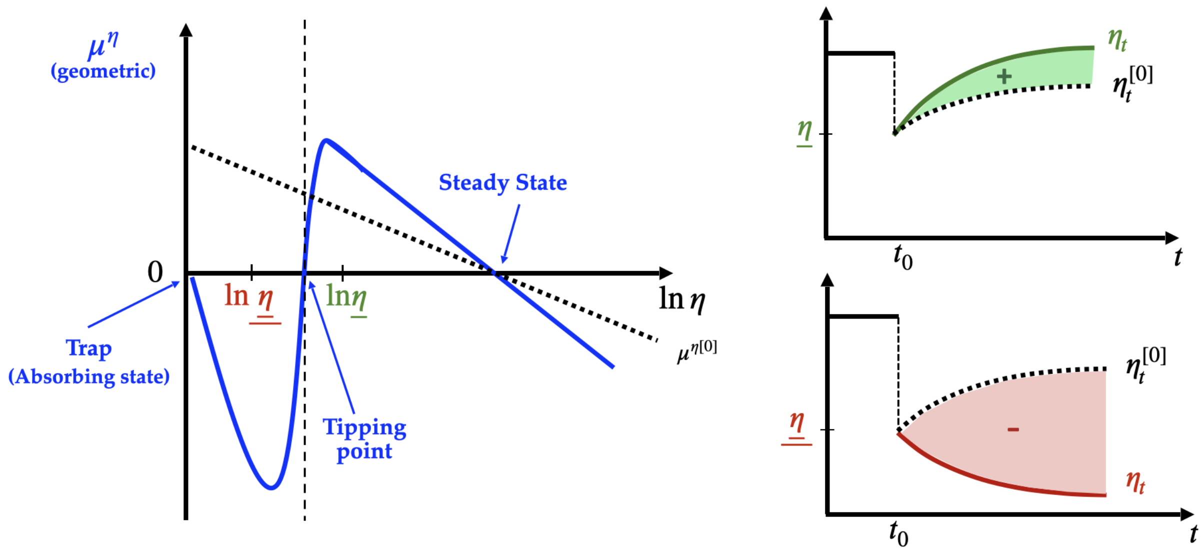

Figure 6: **Drift dynamics of stochastic process η.** The drift of the stochastic process η is log-linear only around the stochastic steady state of η with $\mu^{\eta} = 0$. When η drops below the tipping point, the drift becomes negative and η drifts further down towards the trap of an absorbing state at $\ln \eta = 0$. The dotted $\mu^{\eta[0]}$ represents the $\mathcal{R}$=0-benchmark drift after a shock absent adjustment by the agents in the system. The top-right panel sketches the IRF after a shock to point $\underline{\eta}$, while the bottom-right panel depicts the IRF after the larger shock beyond the tipping point to $\underline{\underline{\eta}}$.

The left panel of Figure 6 shows a simple dynamical system for the endogenous state variable η. The endogenous state variable η summarizes the history of shocks $\underline{s}$ as well as all past actions of all agents. In most macrofinance models, the agents' net worth shares are part of the endogenous state variable η. Here, we depict along the x-axis the $\ln \eta$ and along the y-axis the geometric drift, so that the figure for the corresponding log-linearized system would simply be a straight line.

In this example, the geometric drift is linear only around the (stochastic) steady state but nonlinear for low $\ln \eta$ values. Let us first consider a deterministic setting with volatility $\sigma^{\eta} = 0$ for all η. There is a tipping along the dashed vertical line of the left panel of Figure 6. For $\ln \eta$ below this point, the drift is negative and consequently η

decreases subsequently further.

Starting at the steady state, for a small shock the system is self-stabilizing, while for a large shock that pushes the system below the tipping point threshold, the system is destabilizing. In other words, there is a stability corridor around the steady state. Once below the point, the system drifts towards the trap of the $\ln \eta = 0$-absorbing state and remains there forever.

Our $\mathcal{R}$-measures capture resilience relative to a zero-resilience benchmark. Let us assume that the $\eta^{[0]}$-drift of an $\mathcal{R}$=0-benchmark after a shock at t_0 is governed by the dotted declining line $\mu^{\eta,[0]}$ in left panel of Figure 6. The top-right panel sketches the IRF after a shock from, say, the steady state to $\underline{\eta}$ (assuming the same t_0-amplification for η and $\eta^{[0]}$). Since the drift of η is positive, $\underline{\eta}$ drifts back toward the steady state as depicted by the green curve. So does the $\mathcal{R}$=0-benchmark along the dotted black curve, although at a slower pace. The positive green area between both curves is our resilience measure $\mathcal{R}$ of the η-process.

Next, consider a shock at t_0 that pushes the system below the tipping point. As the drift of η is now negative, the corresponding IRF is downward-sloping as shown by the red curve in the lower-right panel. In contrast, the dotted $\eta^{[0]}$-IRF of the $\mathcal{R}$=0-benchmark is increasing. Resilience for this case is negative as captured by the red area. Indeed, it is negative infinity (absent any discounting), as the red curve never recovers.

Of course, we could have picked a different $\mathcal{R}$=0-benchmark, depending on what (non)-adjustments we assume, for example, if $\mu^{\eta,[0]}$ is simply zero for all η. For this case, the dashed black $\mathcal{R}$=0-IRF curves in the right panels would simply be horizontal lines and the areas would have to be adjusted appropriately.

Another $\mathcal{R}$=0-benchmark is where the shock does not impact $\eta^{[0]}$ at all. The system simply withstands the shock (even absent any adjustment). Now the dotted curves simply extend the initial horizontal solid black lines (before t_0), without any jump. For this benchmark our resilience measure $\mathcal{R}$ coincides with the negative of the standard cumulative IRF.

Often the exact threshold of a *tipping point* is *not known*, at least for some agents in the economy. In this case, agents face a probability distribution about the exact location of the tipping point. The bursting point of a *bubble* is a particular tipping point. When this point is reached, the speculative asset bubble is no longer sustainable and collapses. In Abreu and Brunnermeier (2003), each rational agent does not know the bursting point and therefore has a truncated exponential distribution over it and prefers to ride the bubble for a while.[9]

Most second-generation models are not deterministic but stochastic. That is, volatility $\sigma^{\eta}(\eta)$ is nonzero, possibly a rich endogenous function of the state variable η. Knowing the drift and volatility one can directly derive the stationary distribution of η, which specifies how much time the system spends on average at a particular η.

C.2. Traps with or without Escape Routes

Most macro and finance models are assumed to be stationary with a nondegenerate stationary distribution. In models with traps without escape, the world gets stuck in an absorbing state, as in the example of Figure 6. Formally, an absorbing state implies that a stationary distribution degenerates to a single point. The desire to set up models with a well-behaved stationary distribution explains why there are not many macrofinance models with traps without escape.

In macrofinance models, low endogenous η-states with low net worth share of the productive or financial sector are typically crisis regions. The economy might even be trapped in a so-called "*net worth trap*." If there is a net worth trap without any escape, these η-states are absorbing. Net worth traps with escape feature at least some resilience. Formally, a net worth trap with escape can be defined as a situation in which the stationary distribution is double-humped shaped. The main probability mass is around the stochastic steady state. As the economy faces a small shock around the

[9]The reason for the asymmetric information about the tipping point is that people become sequentially aware of the bubble and nobody knows where in the queue they are, that is, whether they are the first, middle, or last to learn about the bubble. As time passes the bubble grows, and each rational agent's hazard rate of the bubble bursting rises. Each agent has the following trade-off. By "riding the bubble" she can earn excessive returns since momentum traders with extrapolative expectations make the bubble grow at a fast rate. However, she risks that the bubble might burst when she still holds the bubbly asset. The bubble bursts as soon as sufficiently many rational agents are attacking the bubble, that is, are not invested. Overall, all agents play a game of co-opetition. There is an element of competition: Nobody wants to be left behind and exit the market before the critical agent who bursts the bubble sells. The element of coordination arises since if others ride the bubble longer, the tipping point is pushed into the future, and each individual can ride the bubble and benefit from the fast growth rate of the bubble longer. With respect to resilience, the analysis gets even more interesting when rational agents, who are sufficiently long aware of the bubble, jointly observe coordinating sunspots. They can then exit the market, and if the bubble is large and old enough, it bursts. However, if the bubble is not too excessive yet, the attack will fail, in which case even agents who previously sold the bubbly assets reenter the market and restart riding the bubble asset. That is, bubbles in their early phases show remarkable resilience. They can not only survive a coordinated attack, but also emerge from it stronger.

steady state, it drifts back to it, that is, it is stable or locally resilient. Hence, the economy spends a significant amount of time around the stochastic steady state. However, the economy can also be stuck in the crisis region, where fire-sales occur. Since it is not easy to escape, the economy also spends a significant amount of time in the crisis region, leading to a second hump in the stationary distribution.

What are the necessary ingredients to generate a net worth trap? While empirically financial crises often lead to long-lasting slumps, that is, resilience of economic activity is very low, a net worth trap is surprisingly difficult to generate in bare-bones macrofinance models. The reason is as follows. A crisis region is characterized by depressed asset prices, often due to fire-sales from the first-best holder of assets to the second- or even third-best holder. With low asset prices, subsequent expected returns and risk premia are high. As long as first-best holders can hold assets with leverage, their return on net worth is higher than other agents. This implies that the expected growth of their net worth share is higher than that of the second-best holders. As a consequence, the economy grows out of the crisis regions relatively quickly. This feature is present in most parsimonious macrofinance models. One way to ensure a net worth trap is to make it impossible for undercapitalized productive agents to take advantage of the high-risk premium. Equity issuance constraints together with sufficiently tight debt issuance constraints that limit the productive agents' risk-taking can do the trick (Brunnermeier, Merkel, and Sannikov (2022)). Another option is to introduce a belief bias in the form of sentiment distortions. In the calibrated model in Gopalakrishna, Lee, and Papamichalis (2024) productive expert agents could earn the high excess risk premium but do not take advantage of it, since they overestimate the risk associated with it or underestimate the risk premium.

In Krishnamurthy and Li (2024), resilience is negative as recovery is very slow. The model adds to Brunnermeier and Sannikov (2014) discrete belief dynamics about the arrival rate of redistributive liquidity shocks in order to empirically match the entire crisis cycle. An observed liquidity run leads to a Minsky moment, a discrete jump in probability estimate of subsequent additional runs. The model is calibrated for both rational as well as diagnostic beliefs to match the entire crisis cycle, starting with the frothy pre-crisis behavior of asset markets and credit, the sharp transition to a crisis with asset price declines, disintermediation, and output drop, followed by a slow post-crisis recovery in output.

C.3. Vulnerability Regions

The underlying system might bifurcate and allow for a *vulnerability region*. In this region of the endogenous state space, the system is vulnerable to shocks, which otherwise would not have any effect. For example, as the net worth share of expert agents deteriorates, multiple equilibria may arise. In the vulnerability region, a simple (non-fundamental) sunspot shock might trigger a large adverse jump. Bank runs, collateral runs, and debt revaluation are just a few examples of multiple-equilibria settings. In Mendo (2020), expert agents are highly leveraged in the vulnerability region and thus multiple equilibria are possible. The price of the physical capital is a function of the endogenous state variable, η, expert agent's net worth share. If a sunspot is ignored, nothing occurs, the price stays the same, and experts' net worth share is unchanged. Hence, a natural no-adaptation $\mathcal{R}$=0-benchmark is the current state. If, in contrast, a sunspot worries levered expert agents and they develop "cold feet", they fire-sell their risky assets to less productive agents. This depresses the asset price, which leads to a jump in the expert agent's net worth share. The lower expert net worth share corresponds to a lower asset price, which justifies the loss in experts' net worth share. Hence, adaptation leads to lower output, prices, etc., and for all these processes the $\mathcal{R}$-resilience measure is negative. Interestingly, the $\mathcal{R}$ measure corresponds in this case to the signed cumulative IRF measure.

C.4. Volatility/Risk Dynamics

A macroeconomy or financial system can be resilient in levels but also in volatility. Volatility might spike during a crisis, but the key question is whether uncertainty calms down again, that is, whether volatility is resilient or not. In second-generation macro-finance models, such as Brunnermeier and Sannikov (2014) as well as in intermediary asset pricing models, such as He and Krishnamurthy (2012, 2014), the volatility dynamics play a central role. Not only do risk dynamics matter in their own right, but the price of risk is time-variant and state-dependent. Hence, risk premia, the product of risk and the price of risk, are also time-varying. Given holders of risky assets earn on average the risk premium, it affects the expected growth of net worth across agents. That is, the risk dynamics and the price of risk dynamics impact the drift dynamics of agents' net worth. However, this is not a one-way street. The drift dynamics move the state variable and, in turn, the volatility dynamics. In short, drift and volatility dynamics are intertwined, and hence so is the corresponding resilience. Even in the case of idiosyncratic risk as in Di Tella (2017); Brunnermeier and Sannikov (2016b), which could in theory wash out in aggregate, it still affects the drift of net worth shares, as agents who take on this uninsurable risk earn a risk premium. The exact connection between drift and volatility dynamics can be highly complex as it is typically endogenously linked through agents' risk-taking behavior.

Importantly, volatility dynamics can also affect the severity of financial frictions. In particular, the constraints on debt issuance tighten as volatility increases. Tighter constraints limit the agent's adaptability to shocks and typically reduce resilience. In the first-generation model of Kiyotaki and Moore (1997), debt limits depend on the next period's asset price, which is deterministic. Models in which the next period's price is stochastic are more realistic. In Geanakoplos (1997, 2003) and Simsek (2013), agents with heterogeneous prior beliefs face an endogenous collateral constraint which is given by the next period's worst asset price. In Brunnermeier and Pedersen (2009); Adrian and Boyarchenko (2012, 2013a,b) the collateral constraint is given by a VaR constraint, that is, by the π-quantile of the next period's asset price distribution. As volatility rises, the VaR constraint becomes more binding. If the price follows an autoregressive conditional heteroskedasticity process, a large adverse shock drives up price volatility and forces leveraged agents to fire-sell their assets, which decreases the price further, drives up price volatility, and tightens the VaR/margin constraint. Brunnermeier and Pedersen (2009) call this volatility effect the "*margin spiral*" and distinguish it from the "loss spiral," where the decline in net worth rather than the increase in volatility tightens the constraint. Note that the margin spiral forces the leveraged agent to delever since they receive margin calls. Consequently, leverage declines in times of crisis. Without the volatility effect, a decline in net worth does not necessarily imply a decrease, but rather an increase in leverage. That is, in most macrofinance models, the volatility effect determines whether leverage is countercyclical or procyclical, that is, whether there is a leverage cycle in the words of Geanakoplos (2010). Gorton, Metrick, and Ross (2020) focus on the repo market, where traders pledge long-dated bonds as securities to borrow cash. Repo runs occur when margins for repo borrowing spike. Margin spirals are at work in the repo market, since the price volatility of long-dated bonds rises during crisis times. In sum, leverage cycles, margin spirals, and repo runs cover the same volatility-driven mechanism.

Volatility can also make financial frictions more severe as debt becomes more *infor-*

mationally sensitive. Debt is an attractive financing instrument, since as long as default is unlikely, the lender does not need to worry what other lenders know about how well the borrower is doing. The lender almost always gets the promised face value back, so no lender has an incentive to collect information that gives him an informational advantage. Since information asymmetries do not arise in the form of Akerlof's market for lemons, market freezes are contained (Gorton and Pennachi (1990); Dang et al. (2017); Gorton and Ordoñez (2023)). In contrast, when volatility rises, the probability of default rises as well, and suddenly investors who have superior technology to collect information about the borrower's financial situation enjoy an information advantage compared to other investors. The resulting information asymmetries in the form of adverse selection problems induce less well-informed agents to withdraw from lending and trading. Consequently, the debt market freezes. Again, volatility dynamics are key for the resilience of functioning of debt markets.

High volatility also exacerbates *debt overhang* problems in a world with financial frictions (Myers (1977); DeMarzo and He (2021)). When the payoff volatility of existing projects rises and firms are under water, firms are reluctant to invest in new positive NPV projects since part of the upside accrues to the existing bond holders rather than to the investors who provide new funding. Also, when volatility rises, zombie firms' equity owners delay debt restructuring further as it wipes out their equity stake. Instead, they focus on debt payments to maintain their option value by gambling for resurrection (Leland (1994)). Zombie firms' lack of investments in new profitable projects and of debt restructuring reduce the probability of their recovery. Moreover, from a macro-perspective, zombie firms tie down resources instead of freeing them up for use by more productive companies. The economy does not adjust to a full degree and hence resilience is suppressed.

C.5. Fan Charts as Generalized Impulse Response Functions

The dynamic response after a shock in the first generation models is well depicted by impulse response curves. Such response illustrates how, in expectation, relevant variables evolve after a shock.

For second-generation macrofinance models, the volatility dynamics are of first-order importance. Fan charts are useful to depict not only the expected path, but also the volatility dynamics. Fan charts using different shades of color show the different quantiles of the distribution. The center points around the median response dynamics are plotted darkest, while areas of outliers are depicted in very light color. In stationary models, the distribution after a shock converges back to the stationary distribution.

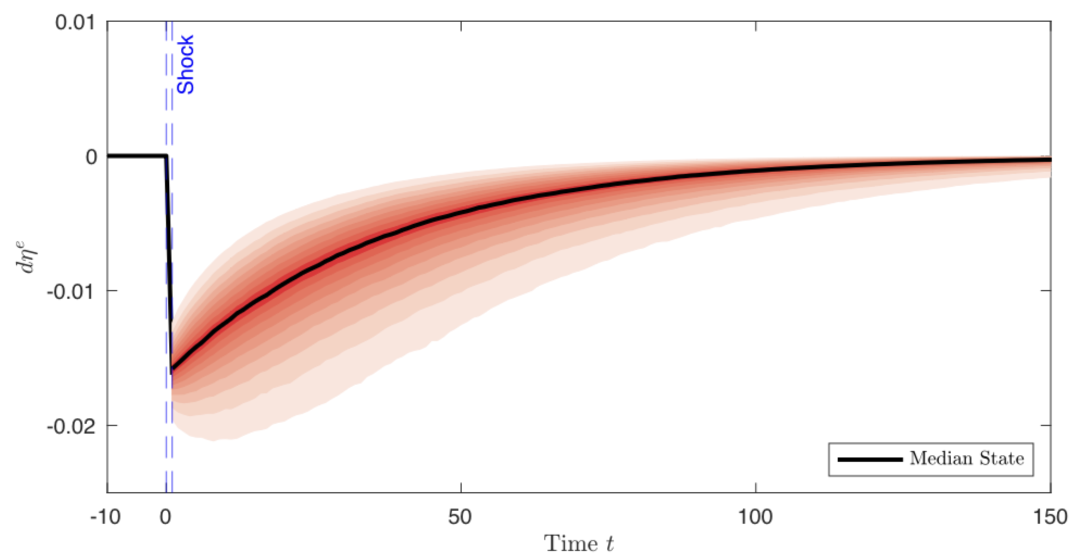

Figure 7: **Fan charts depicting the difference in evolution with and without a shock at t_0.**

Often it is useful to depict not the evolution of the distributions, but rather the difference an initial shock makes relative to a benchmark case. To show this, the same subsequent shock sequence is considered twice after the initial t_0-shock: once for the case in which the shock occurred, and once for the $\mathcal{R}$=0-benchmark case. Figure 7 uses as a benchmark the case without shock in t_0, to obtain a fan chart that corresponds to the classic IRF. The shading depends on the likelihood of the subsequent shock scenarios. Note that in a stationary model with resilience, the distributional difference loses importance after a sufficiently long time, and hence the distribution of differences converges to zero.[10]

[10] Borovička, Hansen, and Scheinkman (2014) construct shock elasticities that are pricing counterparts to IRFs measuring the contributions to the price and to the expected future cash flow from changes in the exposure to a shock in the next period.

III. Linking Macrofinance Themes to Resilience

Macrofinance touches on many important themes in economics and finance that are connected to resilience. Safe assets are a resilience instrument for agents in the economy. Individuals, by adapting their portfolio after experiencing a personal shock, can overcome financial frictions and partially insure each other. If the safe asset resides with the government bond, it also enhances the resilience of the government. The government enjoys an exorbitant privilege. The safe asset grants extra fiscal space and fiscal policy is a resilience tool.

Money is also a special safe asset as it also takes on the additional role as medium of exchange. Monetary policy, appropriately executed, is a resilience instrument for the central bank as it can help orchestrate a timely recovery of the macroeconomy. Flexibility to adapt and discretion, which typically improve resilience, might limit the power of monetary policy. A "Monetary Policy Resilience Dilemma" arises.

Section C. examines the role of financial intermediaries. While they help reduce financial frictions during normal times, their micro-prudent behavior can lead to macro-imprudent outcomes. Hence, in times of crisis, their fragility can destabilize the entire economy and hinder a swift macroeconomic recovery. Finally, the resilience of the financial market infrastructure is crucial. Financial markets can experience freezes, and central bank interventions as market makers of last resort can help overcome these disruptions.

A. Safe Assets

One major theme in macrofinance is the concept of safe assets. Safe assets are different from risk-free assets. A risk-free asset provides a deterministic payoff in real or nominal terms at a particular point in time. A risk-free asset is a default-free bond contract with a certain maturity. A safe asset is like a "good friend," it is around, valuable, and tradable when one needs to trade it, possibly at a random horizon. Its characteristic is part of a general equilibrium structure. A safe asset should be easily tradable and not plagued by high transaction costs. Brunnermeier, Merkel, and Sannikov (2024) argue that a safe asset has to satisfy $Cov[SDF^i, r^{safe} - r^{n^i}] \geq 0$, the covariance between the SDF of agent i and the excess return of the safe asset beyond agent i's net worth

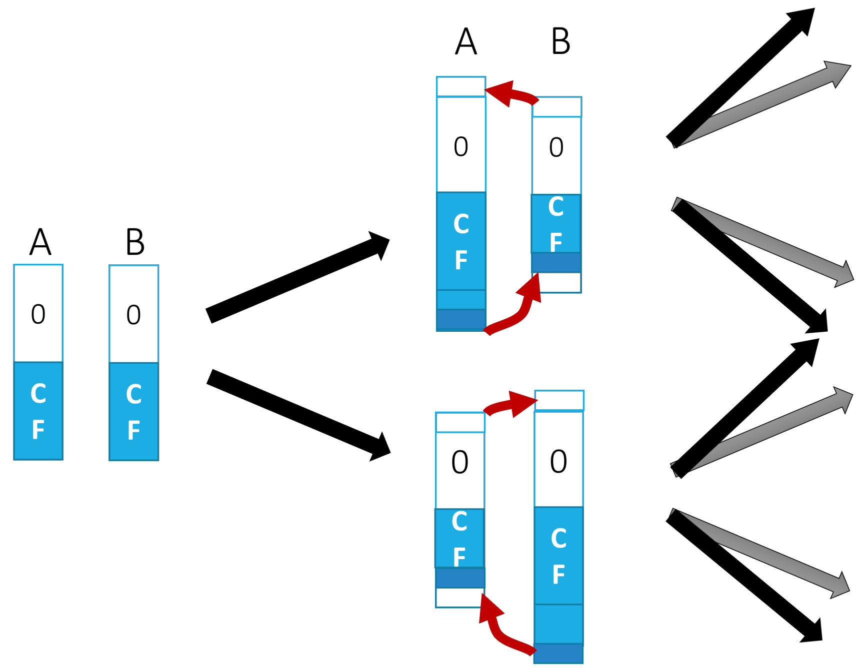

Figure 8: **Zero-cash-flow asset that agents A and B retrade serves as safe asset.**

return at time t is positive. They show these characteristics in a setting in which agents face uninsurable idiosyncratic risk. Agents hold safe assets for precautionary reasons, to have resources should they face an uninsurable shock.

When hit by a shock, agents adjust and adapt their portfolios to mitigate the impact of the uninsurable shock. In this sense, safe assets are related to the concept of resilience. Resilience is all about adapting to new situations when a shock hits. In short, safe assets are a resilience tool. Hence, a safe asset is different from a risk-free asset: it is not about getting a risk-free return, but rather about the ability to do something with it when the need arises.

Figure 8 illustrates the safe asset mechanism in a simplified version with two agents, A and B. Both types of agents hold a zero-cash-flow asset, the safe asset (white box labeled zero), and a positive-cash-flow-asset (blue box labeled CF). Instead of idiosyncratic risk, agents A and B have perfectly negatively correlated "personal" shocks in their positive-cash-flow assets. When the world follows the upward-pointing black arrow, A's positive-cash-flow asset experiences a positive shock, while B's faces a negative shock. In contrast, when the world follows the downward-pointing arrow, the roles of A and B are reversed: A loses and B gains. In a world without frictions, A and B are ideal candidates to write a risk sharing insurance contract with each other.

However, due to incomplete markets, the stochastic upward/downward movements are uninsurable. Holding ex-ante the zero-cash-flow asset, our safe asset, enables them to obtain some insurance through adaptation, that is, retrading. In the upward case, A sells part of his positive-cash-flow asset in exchange for a zero-cash-flow asset from B. In the downward case, trading happens in the opposite direction. Portfolio adaptation creates resilience.

Paradoxically, even though the safe asset never pays any cash flows, it has positive value. It is desirable because the retrading creates some "service flow" in the form of (partial) insurance between A and B. Retrading helps to partially overcome the financial frictions. Consequently, the agents of the economy value this "bubbly" asset with a fundamental cash flow value of zero. Put differently, the issuer of a safe asset only has to pay no (or little) cash flow, as buyers derive service flow. One can rewrite the asset pricing equation as one that separates the two benefits of safe assets: cash flows, possibly negative, and service flows resulting from the ability to self-insure via retrading. The real value of a safe asset (or any tradable asset) is thus

$$price_t = \mathbb{E}_t \left[\sum_{s=0}^{\infty} \mathrm{SDF}^{**}_{t,t+s} [cash\ flows_{t+s}] \right] + \mathbb{E}_t \left[\sum_{s=0}^{\infty} \mathrm{SDF}^{**}_{t,t+s} [service\ flows_{t+s}] \right]. \quad (1)$$

While the traditional asset pricing formula prices the cash flow of a buy-and-hold strategy of the safe asset, this modified pricing formula prices the cash flow of a "dynamic adaptation strategy" whose cash flow is positive when the asset is sold (after a negative shock) and negative when additional safe assets are bought (after a positive shock). Valuing individual dynamic-trading cash flow streams and aggregating them leads to the above pricing equation, where a different discount rate, r^{**}, arises naturally.[11] Note that the corresponding SDF^{**} can be viewed, in some settings, as a form of a "representative agent interest SDF" in an incomplete market setting. It is the risk-free rate that excludes the component that is due to precautionary demand driven by the exposure to uninsurable idiosyncratic risk.

Note that as a safe asset is constantly traded, *tradability* and high market liquidity are key features of a safe asset. An asset with high trading costs is not a good candidate for a safe asset. This is also why asymmetric information frictions for trading should be

[11] While it is applied here to the safe asset, this "dynamic trading perspective" is a general valuation approach and can be used in any incomplete market setting to isolate the benefits from equilibrium trades.

low. Hence, safe assets are typically bond contracts with low default probability. They are less informationally sensitive. That is, no investors should have an incentive to collect information about the fundamental value of the asset, gain an informational advantage, and expose the asset's trading market to market freezes à la Akerlof's market for lemons (Dang et al. (2017); Gorton, Metrick, and Ross (2020), Gorton and Ordoñez (2023)).

Adapting one's portfolio to idiosyncratic shock increases individuals' resilience. In addition, a safe asset also benefits its holders after an adverse aggregate shock – and thus serves as a *safe haven*. Safe assets appreciate in times of high risk driven by the flight-to-safety phenomenon. Since risks are typically high during recessions, safe assets typically have a negative capital asset pricing model beta (CAPM-β). The underlying mechanism is as follows. During recessions, (idiosyncratic) risk is typically elevated. Hence, the present value of service flow from retrading (the second term in the asset pricing equation above) is particularly high, exactly when output is depressed and hence marginal utility is high. People then flock to safe assets, that is, flight-to-safety occurs.

The issuer of a safe asset, often government debt, enjoys an *exorbitant privilege* for two reasons: First, investors do not require a high interest rate r, since they enjoy the "service flow" from retrading, and second, since the CAPM-β is negative, investors are happy to hold the asset for an even lower expected cash flow.

Interestingly, safe assets are often *bubbles*. Although both concepts are distinct, there is a two-way complementarity between safe assets and bubbles. A safe asset is more likely to satisfy the bubble condition that the cash flow/interest rate r is below the economy growth rate g. Precautionary savings depress the interest rate on safe assets r, and so does the negative CAPM-β. The complementarity also holds the other way around: a bubbly asset more easily satisfies the safe asset condition that $Cov[SDF^i, r^{safe} - r^{n^i}] > 0$, since a bubble can easily expand in recessions and has a high return, even though the asset's fundamental cash flow payoffs decline. Note also that the bubble component can make an asset "safer," since the value of the service flow is proportional to the market value of the (bubbly) asset – and the service flow is highly priced, not least because it carries a negative β. In fact, under certain circumstances, the same asset without a bubble can have a positive β (driven by discounted cash flows), while when the bubble is associated with the asset, its β becomes negative. In that case, the asset is a safe asset only if the bubble is attached to the asset.[12]

Large parts of the safe asset literature emphasize the possible *shortage of safe assets*, (Caballero, Farhi, and Gourinchas (2017)). In these models a group of individuals only want to hold very safe, risk-free assets. This depresses the real risk-free interest rate into negative territory. If the economy faces a zero lower bound, markets clear only if all agents become sufficiently poor relative to the outstanding supply of safe assets.

Brunnermeier et al. (2011) and Brunnermeier and Merkel (2024) stress that the *asymmetric supply* and not the shortage of safe assets are the key distortionary force of the international monetary system. Consider a world in which one country has a larger share of the bubbly safe asset relative to the rest of the world. This country enjoys an exorbitant privilege: a rise in idiosyncratic risk leads to an appreciation in the value of safe assets due to flight-to-safety. This benefits this particular country at the expense of the rest of the world, whenever volatility is high.

Of course, the exorbitant privilege of being able to issue a safe asset is not guaranteed forever. As the *loss of the safe asset status* becomes more likely, the CAPM-β increases and with it the required cash flow return. In addition, the asset becomes more informationally sensitive. This makes it more difficult to satisfy the safe asset condition (as well as the bubble condition). Ultimately, one can hit a tipping point so that the loss of the safe asset status becomes self-fulfilling. It is difficult to bounce back — a lack of resilience. The fact that there are multiple equilibria, one in which the safe asset status with low β is maintained and one without a safe asset given a high β, can be referred to as "safe asset tautology." An asset is safe if and only if it is perceived to be safe.

In short, a safe asset creates micro-level resilience through portfolio adaptation after idiosyncratic shocks. However, the possible loss of safe-asset status can hurt macro-resilience.

Note that the service flow here is due to adaptability in the form of retrading. An asset that relaxes the collateral constraint especially in crisis times when the constraints are binding provides another form of service flow. Money is a special safe asset that serves as a medium of exchange and thereby relaxes the cash-in-advance constraint or provides extra utility. The *convenience yield*, like the BAA-Treasury interest rate spread used in Krishnamurthy and Vissing-Jorgensen (2012), is also a special service flow, but

[12]Note also that in an incomplete market setting, the transversality condition can hold for each citizen but does not need to hold for the government, which can issue safe bubbly assets.

it is not directly captured by the SDF.

B. Government Debt and Money as Special Financial Asset

B.1. Government Debt and Battle for the Bubble

Being able to issue a safe asset, especially if it is a bubbly asset, is an exorbitant privilege. Since the asset offers a service flow to its holder, the issuer does not have to pay much in terms of real cash flows. Indeed, governments are keen to defend the safe-asset status of their debt. The cash flow that all holders of government bonds receive is the government primary surplus, the budget surplus before interest expenses. Government primary surpluses are typically negative and higher in booms than in recessions. Jiang et al. (2019) document empirically that pricing the future stream of primary surpluses without a bubble term/service flow term is difficult to square with the current value of U.S. Treasuries. They coin the term government debt valuation puzzle. Viewed differently, their approach can be seen as an empirical bubble test on government debt.

The government can accrue a form of seigniorage revenues through "mining the bubble" by expanding the number of outstanding bonds, that is, to run a Ponzi scheme to cover deficits. By issuing bonds more rapidly, the government induces greater inflation, diminishing the actual real return on these bonds. Accelerating the issuance of bonds functions similarly to a tax on bond ownership, or more precisely, on the partial self-insurance by possessing and retrading the safe asset. This practice constitutes so-called financial repression. As the tax rate is heightened, "tax revenue" increases, yet it simultaneously degrades the "tax base," in this case the bond's value. This scenario gives rise to a "debt Laffer curve", where past a certain tax threshold, the total tax revenue from bubble mining starts to fall. "Bubble mining" is quantitatively sizable only when the safe public debt exhibits a negative β (Brunnermeier, Merkel, and Sannikov (2024)).

This raises the important question of which entity should enjoy the exorbitant privilege to issue a bubbly safe asset or run a Ponzi scheme. This privilege is assigned in equilibrium, and hence is an equilibrium selection issue. In other words, the selected "bubble equilibrium" determines who is subject to a no-Ponzi constraint. Brunnermeier, Merkel, and Sannikov (2021) argue that the government's ability to tax and impose regulations on the private sector puts it in a unique position to defend a bubble on its debt. According to this view, the government asserts this exorbitant privilege as a safe-asset issuer that sets it apart from private entities. Although the latter may also issue a safe-asset with service flows, unlike governments, they cannot run a Ponzi scheme. The possible loss of the exorbitant privilege is resilience's weak point.

B.2. Nominal versus Real Government Debt

Governments can issue real bonds, like TIPS in the United States, whose real payoff is inflation-protected, or nominal bonds that promise interest and principle in money. For real bonds, if the economy faces an aggregate shock, the government still owes the same amount. In contrast, if the government debt is in nominal bonds, then a supply shock that triggers an inflation spike devalues their real value. In other words, the real price of a nominal bond is contingent on aggregate shocks. This partially completes the market and improves risk-sharing among agents in the economy - even with agents that are not active in the financial markets. Improved risk-sharing ensures more stable net worth shares, reduces amplifications, and enhances resilience.

B.3. Money as Special "Government Debt": Financial and Medium-of-Exchange Frictions

To study monetary phenomena and money, one has to include additional intratemporal frictions. These frictions reduce the ease with which one can swap one good for another good at the same point in time. Intratemporal frictions further limit adaptability and hence reduce resilience. Holding money is one way to mitigate these frictions, although it does so at a cost.

More specifically, instead of swapping one good for another one, one can first swap the good for the low-transaction-cost "money good" and then use it to purchase the other good or asset. In theoretical models, all of this can occur simultaneously. If this special money good is free from any transaction costs, all trades occur through it as a medium of exchange, and in equilibrium no transaction costs are incurred. If this medium-of-exchange good has some, but low, transaction costs, only its transaction costs are incurred, provided that agents are able to coordinate on this "money good". Typically, transaction costs and market liquidity are endogenous and depend on which commodity/asset people coordinate on as money.

In reality, matters are more complex. Not all transactions occur simultaneously, as not all agents can meet at the same time in the same centralized market place. Bilateral barter is typically not possible due to the double-coincidence-of-wants problem: The buyer does not have the product that the seller wants in exchange. In addition, there may be a timing/asynchronicity problem. Hence, a special intertemporal financial asset or durable good may serve as a medium of exchange to lower the equilibrium transaction costs. In many models, the money asset has to be held one period in advance. Compared to other assets, it offers the medium-of-exchange service, and hence the cash flow return of money is lower compared to an asset with the same nominal payoffs that does not offer this convenience to overcome the double-coincidence-of-wants problem. In short, money lowers intratemporal transaction costs, which are infinite for other assets in cash-in-advance models, but has an intertemporal component as money has to be held one period in advance. The difference in yield $\Delta i_t^{\mathcal{M}}$ is referred to as the convenience yield, an intertemporal return difference.[13] By holding money, one forgoes cash flow returns but maintains flexibility should a purchasing opportunity arise.

The government, together with its central bank, issues not only bonds, but also money. Since money yields a lower interest, government sectors save on interest expenses. Hence, the fiscal theory of the price level (FTPL) equation, which prices the money supply plus nominal government debt outstanding divided by the price level, generalizes to

$$\frac{\mathcal{M}_t + \mathcal{B}_t}{\wp_t} = \mathbb{E}_t\left[\sum_{s=0}^{\infty} \mathrm{SDF}_{t,t+s}(\mathit{primary\ surplus}_{t+s} + \underbrace{\Delta i_{t+s}^{\mathcal{M}} \frac{\mathcal{M}_{t+s}}{\wp_{t+s}}}_{\text{seigniorage}})\right] + \mathit{Bubble}_t. \quad (2)$$

Note that we here use the standard (buy-and-hold) multi-period $\mathrm{SDF}_{t,t+s}$, unlike in equation (1). In a setting with incomplete markets as in Brunnermeier, Merkel, and Sannikov (2021) or overlapping generations as in Samuelson (1958) and Blanchard (2019) , a bubble term might arise.

The convenience yield $\Delta i_t^{\mathcal{M}}$ depends on the money supply and the velocity of the money. If the interest rate differential $\Delta i_t^{\mathcal{M}}$ is high, agents economize on money holding

[13]New monetarist models (e.g., Lagos and Wright (2005); Williamson and Wright (2010)) have similar features as simple cash-in-advance models but model the decentralized exchange explicitly, for example with a search market, and thereby microfound and endogenize the medium-of-exchange services of money.

by increasing velocity $V(\Delta i_t^{\mathcal{M}})$. They convert smaller amounts more frequently to pay for (goods) transactions. The money demand has to equal money supply to satisfy the quantity equation:

$$\wp_t Y_t / V_t(\Delta i_t^{\mathcal{M}}) \leq \mathcal{M}_t. \tag{3}$$

Both the FTPL equation (2) and the quantity equation (3) determine the price level $\wp_t$ and convenience yield $\Delta i_t^{\mathcal{M}}$.[14]

B.4. Monetary and Fiscal Policy as Resilience Enhancer

To minimize the impact of an adverse shock and ensure a timely recovery, governments can stimulate the economy with monetary and fiscal policy. Fiscally, governments can stimulate the economy by lowering taxes or increasing government expenditures. Enjoying a safe asset exorbitant privilege that expands the fiscal space especially in times of crises or high risk increases resilience. Monetary policy can stimulate or cool the economy by changing the nominal interest rate i_t or by swapping money for government bonds. Central banks want not only to ensure the resilience of economic growth, but also price stability. Monetary policy is an effective resilience tool only if it is credible so that other actors adapt appropriately to changes to it and if it is not dominated by fiscal policy.

"The Monetary Policy-Resilience Dilemma". Resilience is based on adapting to shocks and shifts. Consequently, one might think that central bank policy should ensure maximum flexibility so that one can change course at any time. However, such flexibility diminishes the effectiveness of central banking, since it also requires that other economic actors adapt their behavior. If central banks possess the flexibility to easily undo their action, others are unlikely to be convinced to adapt their behavior, especially if central banks are subject to a time-inconsistency problem. Hence, committing to rules increases the effectiveness of central banking, even though it limits future flexibility. That is the dilemma: central banks have to commit themselves in advance to make monetary policy more effective, but the commitment reduces their flexibility to adapt, especially when they have to react to unforeseen contingencies. Applied to interest rate policies, the dilemma is the following: On the one hand, central banks want to main-

[14] In the case of constant velocity $V_t = \bar{V}$ for low money supply, the price level $\wp_t$ is determined by the quantity equation and the FTPL equation determines Δi_t^M, while for large saturated money supply $\Delta i_t^M = 0$ and the FTPL equation determines $\wp_t$.

tain their flexibility to adjust the short-term policy interest rate to new circumstances. On the other hand, they have to stick to less flexible (Taylor) rules to ensure that other economic actors translate their short-term interest rate move to a change in medium-term interest rates, which ultimately affect economic activity. Overall, this dilemma is closely related to the traditional commitments versus discretion debate.

Inflation anchor. An inflation anchor is a resilience enhancer, as it makes monetary policy more effective. The inflation anchor grants the central bank the policy space to smooth out shocks even in the presence of a temporarily higher inflation. That is, the central bank can spend some of its reputational capital to ensure a quick economic recovery. Gáti (2023) studies monetary policy in a model with a potential unanchoring of inflation expectations and shows that more aggressive nonlinear interest rate moves are needed when expectations are unanchored. In Carvalho et al. (2023), long-run inflation expectations are driven endogenously by short-run inflation surprises in a way that depends on recent forecast performance and monetary policy.

Monetary and fiscal policy interacts. *Fiscal dominance* reduces central bank policy space. It might lose its effectiveness in controlling inflation. Under fiscal dominance, an increase in the policy interest rate increases the government's interest burden but does not lead to a reduction in other government expenditures or an increase in taxes. Then, it simply leads to an increase in debt issuance. Consequently, the total debt level increases further, subsequently fueling inflation rather than bringing it down. Hence, the central bank might question whether to fight inflation with an interest rate increase in the first place. In addition, a high public debt level increases the tensions between the central bank and the government, since any percentage point increase in interest rates significantly increases the government's interest expense. Ultimately, even the central bank's independence might be undermined.

C. Financial Intermediary Sector and Financial Resilience

The main role of financial intermediaries is to overcome and mitigate financial frictions. Intermediaries may be able to take on part of the idiosyncratic risk that is uninsurable for households and partially diversify it away. They may also overcome information frictions through better monitoring.

By overcoming some of the financial frictions, financial intermediaries elevate the level of economic activity, but this comes at the cost of fragility and even a lack of resilience: if a shock hits the intermediary sector, the economy is hit too and cannot easily bounce back.

C.1. Fractional Reserve Banking, Narrow Banking, and Central Bank Digital Currency (CBDC)

In addition to governments, financial intermediaries are also providers of safe assets and of (inside) money. This raises the important question of which economic arrangement is more resilient: one with public assets or one with private safe assets and money creation. In addition, there is a third arrangement, the fractional reserve system, which is a mixture whereby the government as well as intermediaries issue safe assets.

Two adverse feedback loops amplify an initial shock if intermediaries are not well capitalized: a *liquidity spiral* on the asset sides of intermediary balance sheets, as the price of physical capital drops, and a Fisher *disinflationary spiral* on the liability sides, as the real value of money rises (Brunnermeier and Sannikov (2016a)). Both effects erode the intermediaries' net worth. Intermediaries' response to these losses is to shrink their balance sheets, leading to fire-sales (lowering the asset prices) and a reduction in inside money (increasing the real value of money liabilities). In other words, intermediaries take fewer deposits, create less inside money, and the money multiplier collapses.[15] A "*Paradox of Prudence*" thus emerges. Each individual intermediary behaves micro-prudently by shrinking its balance sheet after a shock, but this raises endogenous risk and hence is paradoxically macro-imprudent.

The macroeconomy bounces back and is resilient if, after the amplified shock, intermediaries are able to recapitalize themselves via retained earnings in a timely fashion. This depends on (i) the risk premium they earn and (ii) the competitiveness of the financial sector. If intermediaries are not prevented from taking on more risk, the high price of risk enables them to earn a larger risk premium. In addition, if competition among intermediaries is subdued, they can extract more rent and rebuild their net worth more quickly. In a sense, there is an efficiency-resilience trade-off: If intermediaries enjoy high rent extraction all the time, there are efficiency losses, but the system is more resilient. Ideally, competition should be less fierce in crisis times to allow intermediaries

[15] In reality, rather than turning savers away, financial intermediaries might still issue demand deposits and simply park the proceeds with the central bank as excess reserves.

to rebuild their net worth and fiercer in normal times to avoid efficiency-destroying rent extraction. If intermediaries are unable to take on this risk to earn the risk premium and competition is generally fierce, then they might end up in a "net worth trap" similar to the discussion in Section C.2..

Merkel (2020) emphasizes the dual role of money as both a safe asset and a medium of exchange and hence adds a medium-of-exchange role of money to Brunnermeier and Sannikov (2016a)'s I Theory. The same asset now provides two forms of service flow, and both service flows interact. If the demand for one role increases and the money supply remains relatively stable - like in a narrow banking arrangement - , then the service flow for the other role automatically decreases. In contrast, in an arrangement with fractional reserve banking the supply of money reacts endogenously. When banks delever, they contract the total money supply creating a scarcity of medium of exchange assets. This raises the medium-of-exchange service flow and requires a more forceful relative price adjustment between capital and monetary assets. The money supply reaction represents an additional amplification mechanism. Piazzesi, Rogers, and Schneider (2022) contrast the floor and corridor system of central bank reserves and its implications on the convenience yield for safety and liquidity in a New Keynesian money and banking model.

The literature on CBDC studies the implications of replacing deposits issued by private banks with public outside money. The implications of the introduction of CBDC on macroeconomic growth and resilience depend on the extent to which and under which conditions, the central bank lends the extra resources from issuing CBDCs to the intermediary sector.[16]

Bank runs are another form of lack of resilience. The system might bifurcate if banks net worth is sufficiently low, that is, within a vulnerability region with multiple equilibria as discussed in Section C.3.. Gertler and Kiyotaki (2015) incorporate bank runs into a macrofinance model à la Gertler and Kiyotaki (2011) that builds on the Kiyotaki and Moore (2008) framework in which agents hold money to be prepared for the event in which an idiosyncratic investment opportunity may arrive. Systemic bank runs are highly nonlinear as they lead to a sharp drop in economic activity.[17] When faced with

[16]Brunnermeier and Niepelt (2019) establish a neutrality result, while in Piazzesi and Schneider (2022) the CBDC interferes with the complementarity between credit lines and deposits.

[17]See also Mendo (2020) for systemic run phenomena that arise particularly in low-volatility environments when banks are not well capitalized. Merkel (2020) emphasizes the link between bank money creation and run vulnerability.

sunspot runs it is natural to pick as the $\mathcal{R}$-0 benchmark the initial no-run equilibrium absent any adjustment. In this case the resilience measure is negative and coincides with the negative of the cumulative IRF. Typically, it is also difficult to quickly recover from a run, that is, there is a lack of resilience.

The central bank can counteract bank runs by acting as a lender of last resort (LOLR) if a bank cannot obtain funding from the interbank market or other lenders. It should lend only against collateral and at a penalty interest rate to solvent banks to ensure that illiquidity problems do not morph into permanent insolvency problems, that is, to ensure resilience.

C.2. Monetary Policy and Risk Premia

In a setting with financial frictions, the central bank may not only suffer from fiscal dominance, discussed above, but can also be trapped by *financial dominance*. Under financial dominance, the central bank might forgo a necessary interest rate increase because it is worried that an interest rate increase might trigger a financial crisis, that is, monetary policy as a resilience tool is compromised.

Redistributive interest rate policy and risk premia. An economic recovery is often delayed when a critical sector that ideally should hold certain physical capital and assets is undercapitalized. The undercapitalized sector forms a bottleneck that leads to elevated risk premia and a strangled economy.

Monetary policy that redistributes net worth to the undercapitalized sector can alleviate the bottleneck. Interest rate policy can be redistributive if (i) asset holdings are heterogeneous across agents and (ii) the policy impacts prices of different assets differently. For example, after the 2008 GFC, highly indebted homeowners benefited from the low interest rate, in part because the low mortgage interest rates propped up real estate prices (Mian and Sufi (2009)).

Often, the financial sector is balance sheet constrained and is part of the bottleneck. An important role for the financial sector is to take out and diversify away idiosyncratic risks. Hence, at times when the financial sector is undercapitalized and fails to diversify idiosyncratic risk, households and other agents are overly exposed to it. Consequently, they alter their portfolio choice. They tilt away from physical capital (which is typically loaded with idiosyncratic risk) towards the safe asset. In addition, they also alter their consumption-savings choice. The increased exposure to idiosyncratic risk depresses their consumption and increases their precautionary savings, lowering the risk-free interest rate. Redistributive monetary policy, as outlined in Brunnermeier and Sannikov (2012, 2016b), is an effective tool to mitigate these adverse forces.

Drechsler, Savov, and Schnabl (2018) study monetary policy and risk premia in a setting with two types of agents who differ in their degree of risk aversion. The less risk-averse agents, referred to as banks, borrow from more risk-averse agents, who hold deposits, that is, they lever up. As leverage exposes banks to funding risk, they hold some reserve assets as liquidity buffers. Lowering the nominal interest payment on these assets increases banks' aggregate risk-taking, leading to lower risk premia and higher asset prices, investment, and growth. This implies that an interest rate cut after an adverse shock can limit amplification and lead to a more speedy bounce back.

Kekre and Lenel (2022) embed a setting with agents that differ in risk aversion, that is, in their marginal propensity to take risk (MPR), in a New Keynesian framework with price/wage rigidities. Agents have different MPRs. Less risk-averse agents lever up and issue debt to more risk-averse agents. Monetary policy that redistributes wealth from low-MPR agents to agents with higher MPR lowers aggregate risk aversion and with it the risk premium. This stimulates borrowing and risky capital investment and in turn the overall economy.

Tobin (1982) and Auclert (2019) focus on a different form of redistributive monetary policy that emphasizes aggregate consumption demand management. Redistributing net worth from households with low marginal propensity to consume (MPC) to households with high MPC boosts aggregate demand and with it economic activity.

Tiered interest rates on reserves. When a central bank increases the policy interest rate, its interest payment to private banks rises since they hold excess central bank reserves. Central banks can enlarge the instrument tool box by having a tiered interest rate regime: one interest rate for excess reserves (marginal reserves) and possibly a different one for required reserves. In addition, the central bank can vary the amount of required reserves. If the central bank pays a lower interest rate on required reserves, this redistributes wealth away from private banks if they have no pricing power and have to pass on higher policy excess reserve rate to deposit holders. In reality, however, banks enjoy pricing power towards depositors and their interest rate margin typically rises as policy rate increases. That is, they increase their lending rate while the interest rate they pay to deposit holders rises by much less. These gains in interest rate margins can offset potential re-evaluation losses they make on long-maturity assets.

Unconventional monetary policy goes beyond simple interest rate policy and can take on different forms. Forward guidance binds central banks and limits their flexibility in the future and hence impacts the balance of the monetary policy resilience dilemma.

Quantitive Easing (QE), which involves asset purchases by central banks, works through several channels. First, by buying assets, a central bank signals that it will be reluctant to aggressively raise the interest rate in the future even in the presence of high inflation, since doing so would lead to losses on its balance sheet. If the central bank is not well capitalized, these losses might ultimately force the central bank to ask the government for recapitalization. This would reduce the future policy space of the central bank. This is a more credible commitment than pure forward guidance. QE can also enhance resilience if it lowers the likelihood of future financial dominance. Recall that, under financial dominance the central bank might be reluctant to later raise interest rates out of fear that it might trigger a financial crisis. By buying long-term assets, the central bank allows private banks to offload interest rate/duration risk. This gives the central bank in the event of a subsequent inflation spike more freedom to fight inflation with interest rate hikes (Alexandrov and Brunnermeier (2024)). Whether resilience is ultimately improved or reduced depends on the central bank's recapitalization costs and how monetary policy constraining financial dominance forces impact the monetary policy resilience dilemma.

Second, in the presence of financial frictions and segmented markets, buying particular assets could boost asset prices and lower risk premia for the purchased asset class. Doing so boosts the net worth of those agents exposed to these asset claims, that is, purchases of risky assets are typically redistributive. A prominent example is the purchase of mortgage-backed securities, which boosted the net worth of the financial sector as well as of homeowners, as it stabilized house prices.

QE increases the size of the central bank's balance sheet as it issues more (excess) reserves, held by private banks. Private banks that hold more reserves typically issue more demand deposits to households. To the extent a central bank with a larger central bank balance sheet supports market making of government debt and other assets it purchased earlier, it might also improve the functioning of these markets and its resilience to shocks.

C.3. Macroprudential Policy and Financial Repression

Effective resilience management involves ex-ante preparatory measures in addition to ex-post adaptation after the shock. The former involve ex-ante policy measures that ensure policy space in the event of a shock, but also prudential regulatory measures that force agents to build up ex-ante buffers.

Microprudential regulation focuses on the resilience of a particular institution, which requires it to build up equity and liquidity buffers. Importantly, institutions should be allowed to use these buffers in times of distress. In contrast to microprudential regulation, macroprudential regulations consider the financial sector and macroeconomy as a whole. Instead of focusing on the risk of an institution in isolation, macroprudential regulation stresses the importance of spillover effects from one institution to the next. Paradoxically, microprudent behavior might be macroimprudent. Each individual financial institution might find it prudent to shrink its balance sheet after an adverse shock, but this behavioral response can destabilize the macroeconomy and may make recovery less likely. In such circumstances, individual adaptation is harmful to the macroeconomy.

Prudential regulation that forces banks to hold more liquid assets, typically in the form of government bonds, might be seen as financial repression in disguise. Certain governments might impose such measures only seemingly for financial resilience reasons, while the true intention is to ensure a cheaper fund resource for government debt. In this sense, macroprudential measures such as financial repression are a hidden tax on the financial sector and savers.

Regulation that favors banks that hold government bonds tightly links banks resilience with the government fiscal situation. This nexus, diabolic/doom loop between bank/financial resilience and sovereign/fiscal risk played an important role during the euro crisis in the 2010s (Acharya, Drechsler, and Schanbl (2014); Brunnermeier et al. (2016)).

More generally, prudential regulation influences the composition and structure of the financial sector, often favoring government debt financing. However, the latter may prove to be shortsighted and illusory, as financial repression can reduce long-term economic growth, thereby also lowering future government's tax revenue.

C.4. Heterogeneity within the Intermediary Sector

In most macrofinance models, there is a single and uniform financial sector whose net worth share is one of the key driving state variables. This implicitly assumes that there are no frictions within the financial sector or that all financial institutions are the same. However, in the real world, different parts of the financial sector assume different roles and economic functions. Institutions may also vary over time, especially with the arrival of Fintech, while the various functions of finance are more time-invariant (Merton (1995)).

Banks account for about 50% of the liabilities of U.S. financial institutions (in 2017), pension funds account for 17% (of which roughly two-thirds are defined contributions and one-third defined benefits (9%)), life insurance for 19 %, and casualty and property insurance companies for 3.5% (Koijen and Yogo (2023)). Each of these institutions takes on very different roles, holds different assets, faces different liabilities, and has different constraints.[18] Furthermore, even within the group of banks there are significant differences ranging from global universal banks to local bank cooperatives. Banks screen, grant, and monitor loans, diversify idiosyncratic risks, and issue inside money in the form of deposits. Shadow banks, including money market funds, have a similar role as banks but take advantage of regulatory loopholes and employ novel Fintech solutions.[19] Pension funds offer savings vehicles for people's retirement. They diversify idiosyncratic risk, which in this case is individual longevity risk. Pension funds' aggregate risk exposure is predominantly interest rate and economic growth risk. These aggregate long-run risks are best addressed with adaptability through a resilience strategy. Health insurers diversify idiosyncratic health risk. The main systemic risk of health insurance companies is health expenditure shocks. Casualty and property insurance companies face large amounts of idiosyncratic risk, as well as regional and systematic risk. In the future, intellectual, not physical, property, and cybersecurity, will become the dominant risk for the insurance market.

Given the different risk exposures across different types of institutions and imperfect risk-sharing, it is important to note which institutions are risk absorbers and which ones are shock amplifiers. This depends on the institution's exposure and leverage. The key is whether the institution sees a price drop as a cheap buying opportunity or is

[18]This calls for analyzing empirical holding data in addition to asset prices (Koijen and Yogo (2019)).

[19]See Moreira and Savov (2017) for a macrofinance model with shadow banking.

forced to sell into a falling market due to funding constraints. Systemic risk measures, such as ΔCoVaR, try to capture the contribution of a specific institution to the overall riskiness of the financial sector. Analogously to systemic co-risk measures, one can also derive *co-resilience* measures that capture how easily the rest of a financial system can adapt and bounce back after a specific financial institution experiences an adverse shock.

Pension funds and insurance companies with their long-term funding arrangement seem to act as contrarian investors (see Timmer (2018) for Germany). They act as shock absorbers in particular in the short run. However, from a long-run perspective, underfunded pension funds may become a destabilizing factor if they primarily follow a reaching-for-yield and a game-for-resurrection strategy (Novy-Marx and Rauh (2009)). The size of the private pension fund sector depends on the public social security arrangement. Pension funds play a less important role in countries with a public pay-as-you-go (PAYG) system. In contrast, in countries without a public PAYG system, pension funds can absorb a large part of corporate debt. However, if pension funds are forced by regulation to hold only government bonds, the arrangement is like a public PAYG system. Scharfstein (2018) hypothesizes that countries that promote the accumulation of pension savings also promote the development of the capital market, including the corporate bond market, and affect household finance, banking, and the size of the overall financial sector. If pension funds can hold a large fraction of corporate debt, large corporate firms with access to capital markets can substitute away from bank credit to corporate bonds. This substitution frees up capital for banks that can lend to small firms with no access to the bond market.

Overall, macrofinance models with many financial subsectors are more challenging to solve globally since they involve many state variables. The net worth share of each subsector is a state variable. Novel techniques that explore neural networks and deep learning algorithms, as developed in Gopalakrishna, Gu, and Payne (2024), open up new pathways to push the frontier in this direction.

C.5. Resilience of Financial Market

In most of the macrofinance literature, financial resilience is compromised if a particular entity or a critical sector is undercapitalized. Financial crises can also arise if financial markets and infrastructure are dysfunctional. For example, markets may break down and trading activity might freeze when intertemporal trading frictions dominate. A prominent example are flash crashes. A market is resilient if it can be easily restarted after a market breakdown.

Markets plagued with asymmetric information lead to a potential market breakdown. Less informed agents do not want to trade an asset with better informed agents like insiders if gains from trade are not sufficient. Akerlof (1970) market for lemons problem might kick in. A centralized market structure with better information revelation through the price is less prone to a market freeze. Trading activity can bounce back as soon as some of the private and asymmetric information is made public and available to most market participants. In other words, the resilience of trading activity depends on the nonresilience of asymmetric information.

Assets that suddenly become more informationally sensitive are a prominent example of market freezes due to asymmetric information. Debt contracts are typically not very informationally sensitive because their payoff is mostly constant and does not depend on information about the performance of the creditors. However, this changes when the probability of default increases, possibly due to an adverse shock. In the event of default, the payoff of a debt contract varies with the performance of the creditor, (Gorton and Pennachi (1990); Gorton, Lewellen, and Metrick (2012); Gorton and Ordoñez (2023)). In short, as default becomes more likely, asymmetric information about the creditor's performance matters, and consequently the trading activity of the bond market may freeze. Extending a government guarantee in times of a crisis that limits the default of a bond can therefore restart bond market trading.

Financial intuitions are also crucial in the functioning of financial markets. Often, buy and sell orders do not arrive at the same time. Financial institutions that take on the role of market makers bridge the gap that arises from the random asynchronicity between buy and sell orders. When there are more sell orders, they step in temporarily and buy the asset until buy orders arrive. Market makers provide some market liquidity. To do so, they have to take on some risk, and hence need to be sufficiently capitalized. If they do not have enough net worth and cannot assume the role of improving market liquidity, then prices are depressed and price volatility increases, which in turn makes it more challenging for market makers to obtain the necessary funding liquidity for market making (Brunnermeier and Pedersen (2009)). Liquidity and market functioning bounce back as soon as market makers can improve their net worth.

When market making breaks down, the central bank can step in as the market maker of last resort to ensure the resilience of the market. A prominent example occurred in March 2020 with the outbreak of Covid19 in the United States. The U.S. Treasury market trading activity was lopsided. All foreign investors wanted to sell, and only a limited number of buy orders came in, threatening the safe asset status of U.S. Treasuries. To stabilize U.S. Treasury market making, the U.S. central bank bought large parts of U.S. government debt. Duffie and Keane (2023) argue that financial regulation reduced the willingness of private U.S. banks to dedicate risk-bearing capacity to market-making activity of the U.S. Treasury. As the U.S. central bank increasingly assumes the role as a market maker of last resort, it affects the size and composition of its balance sheet.

IV. Conclusion

In this paper I review macrofinance models with frictions from a resilience perspective. I introduce a new resilience measure emphasizing the importance of adaptation and adjustment, and I advocate for a shift towards resilience management that goes beyond traditional risk management. Resilience critically hinges on the adaptability and adjustability of the economy. Adjusting can lead to a timelier recovery compared to a zero-resilience benchmark, making the resilience measure positive in such cases. However, adjustability can also exacerbate initial shocks and lead to further divergence, for example, through adverse feedback loops, resulting in a negative resilience measure. The resilience measure is applicable to first-generation macrofinance models with an approximate log-linearized solution around a steady state, assuming deterministic recovery by agents. Second-generation models involve concepts like tipping points, traps, vulnerability regions, and rich volatility dynamics. The final part of the paper relates resilience to key macrofinance concepts. Liquid safe assets enable agents to adjust portfolios and share idiosyncratic risk in incomplete markets. Government debt, particularly if it holds an exorbitant privilege, provides additional fiscal resilience. While monetary policy enhances macroeconomic resilience, it faces the monetary policy-resilience dilemma. In contexts involving financial sectors and fractional reserve banking, monetary policy also influences risk premia. Macroprudential regulation helps balance price and financial stability, though it may also induce financial repression. Recent methodological advances facilitate studies in which the financial sector is divided into subsectors, such as banking, shadow banking, insurance companies, and pension funds. The interactions among these sectors affect overall economic risk-sharing and macroeconomic resilience. Lastly, the design and structure of financial markets themselves influence market function and resilience.

The concept of resilience applies to far more fields in economics than covered in this article. For example, in international finance and macroeconomics, the insights, modeling techniques, and metrics in this paper can be used to analyze the resilience of national economies, the global financial framework, and the entire international monetary system. Other relevant areas include shifts and transitions such as the green transition, and the transition due to rapid technological innovations driven by artificial intelligence.

In summary, resilience, a relatively new concept in economics and finance, is central. Recent continuous-time modeling techniques and numerical methods, including deep learning and neural networks, address vital issues and provide key insights for policymakers, aiming to ensure a swift recovery after setbacks to improve societal well-being.

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