Finance and Economics Discussion Series

Federal Reserve Board, Washington, D.C.
ISSN 1936-2854 (Print)
ISSN 2767-3898 (Online)

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2025-043

Please cite this paper as:
Barth, Daniel, and Stacey Schreft (2025). "Black Swans and Financial Stability: A Framework for Building Resilience," Finance and Economics Discussion Series 2025-043. Washington: Board of Governors of the Federal Reserve System, https://doi.org/10.17016/FEDS.2025.043.

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Black Swans and Financial Stability: A Framework for Building Resilience*

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May 20, 2025

Abstract

This article refines the concept of black swans, typically described as highly unlikely and catastrophic events, by clearly distinguishing between knowable and unknowable events. By emphasizing that black swans are "unknown unknowns," the article highlights that the realization of new black swans cannot be prevented and motivates a need for policies that build the financial system's resilience to unforeseeable crises. The article introduces a "resilience principle" that calls for policies that are adaptable, universal, and systemic. Examples are provided of policies with these features, none of which relies on the official sector being better positioned than the private sector to anticipate the unknown.

Keywords: Black Swans, Systemic Risk, Uncertainty, Financial Stability

JEL Classification: G01, G1, E44, D8, H41

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* This article originated with remarks Schreft delivered at the 2021 Roundtable on Global Risk, Uncertainty, and Volatility and was written while she was on detail to the Board of Governors of the Federal Reserve System. The views expressed are the authors' and do not necessarily represent the views, official positions, or policy of the U.S. Treasury, Office of Financial Research, Board of Governors of the Federal Reserve System, or the Federal Reserve System. Participants at the Federal Reserve Board's Financial Stability Workshop, Ron Alquist, Benjamin Kay, Elizabeth Klee, Anna Kovner, Nicholas Tabor, Stathis Tompaidis, and Ram Yamarthy provided helpful comments.

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I. Introduction

Severe financial crises can have devastating effects that reverberate between local and national economies and the financial system. Past crises share some common features, such as growing vulnerabilities from excessive leverage and limited liquidity, and extensive regulation is in place to mitigate those vulnerabilities. Yet, the future always brings another crisis. Unsurprisingly, new crises generally differ in critical ways from those that preceded it; if they did not, the existing regulatory and supervisory regime would have kept any financial system disruptions from developing into financial crises.

For these reasons, financial crises are often described as being black swans. Nassim Taleb is credited with popularizing the term "black swan" in his book by the same name to refer to an event with two features (Taleb 2010, xxii). First, a black swan event is so rare and outside the realm of expectations that it is unpredictable. Second, the extreme effects of the event can be beneficial or catastrophic, although usually only the black swans with catastrophic effects get attention. At the same time, Taleb considers black swans to be in the eye of the beholder and warns that objectively defining a black swan in a way that is "invariant in the eyes of all observers" would be a mistake. Taleb gives the example of the September 11, 2001, terrorist attacks, which were a black swan for many, but not for those who planned the attacks (Taleb 2010, 78).

Under Taleb's definition, it is easy to see why financial crises are often viewed as being black swans. This article makes the case that a precise and internally consistent definition of "black swan" is more than a matter of semantics. Such a definition is integral to the challenge of designing effective financial stability policies. The article thus starts from Taleb's definition but proceeds to resolve the fundamental tension between events that are *rare* and those that are *unpredictable*. Rarity can only characterize an event within the realm of expectations and known to occur infrequently. Black swans defined roughly as low-probability, high-impact tail events akin to 100-year storms point policymakers toward an emphasis on better prediction tools and risk management. Indeed, if rare events are known and their consequences well understood, management of those risks is possible through private sector contracts or public sector programs. The definition expounded upon in this article instead defines a black swan as fundamentally unknowable, which redirects the policy discussion away from prediction and risk management and toward an emphasis on financial market *resilience*.

Section II begins by putting forth a taxonomy for black swans—and other waterfowl—distinguishing risk, uncertainty, and scale of impact. Specifically, and consistent with common practice dating at least to Knight (1964), this article takes "risk" to refer to known events with known (or estimable) likelihoods. The taxonomy associates these events with white swans and ducks, depending on the magnitude of their consequences. "Uncertainty" is one dimension removed from risk, referring to known events with unknown probabilities. Decision making regarding known unknowns, categorized here as grey swans, is much more

computationally complex than under risk (Norman and Shimer 1994).[3] But the events themselves are still known to be possible. In contrast, this article categorizes the unknown unknown event as a black swan, an event that before its occurrence was not even conceived to be possible.[4] After its occurrence, a black swan is viewed as a rare event. Under this definition, a black swan arises from a deeper degree of uncertainty that is two dimensions removed from risk.

The terms "black swan," "grey swan," and "white swan" are used by others to refer to events somewhere on the continuum from known knowns to unknown unknowns, but their usage lacks consistency and clarity. The COVID-19 pandemic generated many such uses. Ahmad, Kutan, and Gupta (2021), Halliburton (2020), and Winston (2020) consider the pandemic to be a black swan. Ghosh (2020) and van den Heiligenberg (2020) label it a "grey swan," defined as an event without historical precedent, highly unlikely but conceivable. Taleb (2020) calls it a "white swan," defined as something with great impact that will occur with great certainty. The taxonomy presented in Section II rationalizes all these terms to force a clear distinction of unknown unknowns from other events in designing policies to build resilience.

The Appendix complements the taxonomy by providing a diagnostic tool for classifying events in their aftermath, which is the only time previously unknown events can be classified. The tool lists five broad features of an event: official sector intervention, news coverage, cross-jurisdictional coordination, private sector adaptation, and legislative interest. Realizations of different types of events are likely to lead to different manifestations of the features. The tool is not determinative in that often the only diagnosis is one of exclusion: The diagnosis that fits the best may ultimately be the one that checks the most

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[3] A line of research has considered decision-making under uncertainty. Some events, like natural disasters, may be so rare that their likelihood is ignored, but when they occur or when people become aware of the risk, the reaction can be large and threaten financial stability, even in the absence of leverage (Gennaoli, Shleifer, and Vishny 2012). The possibility of disasters can explain anomalies like the equity risk premium, the low risk-free rate, and stock price volatility (Barro 2006; Wachter 2013). A related literature has shown that shocks to uncertainty, measured as the variance of beliefs about fundamentals conditional on available information, can explain short but sharp recessions and recoveries (Bloom 2009). Small changes in information, even in normal times, can lead to big changes in the conditional variance and help forecast real GDP growth one quarter ahead (Orlik and Veldekamp 2022).

Another line of literature has tried to account for how the imperfect knowledge associated with uncertainty alters information use. The behavioral economics literature introduces biases in interpreting information (Laibson 1997; Benabou and Tirole 2003). The learning literature models how people improve their understanding of the true model of the economy over time as new information becomes available (Sargent 1993; Evans and Honkapohja 2001). The rational inattention literature focuses on how people choose the information to pay attention to when processing all available information is costly (Sims 2003). Contagion between financial markets with unrelated fundamentals can arise when, for example, investors who cannot distinguish information about the markets shift their attention from a healthier market to a stressed market (Mondria and Quintana-Domeque 2013).

[4] The phrase "unknown unknown" was popularized by former U.S. Secretary of Defense Donald Rumsfeld, but predates his use.

boxes but not all of the needed boxes. The Appendix puts the diagnostic tool to use to classify a number of past events as black swans or something else. The focus is only on events with negative effects, the ones for which there are benefits to building resilience.

Section III makes the case that adverse shocks are more likely to manifest as black swans in a *complex adaptive system* (CAS), a classification that well describes the modern financial system. Others, perhaps most prominently Haldane (2009), have recognized this feature of the financial system. Section III, in linking the system's CAS nature to unknown unknowns, lays the foundation for designing policies for building resilience in the environments that give rise to black swans.

Battling the unknowable may seem to be an exercise in futility, but this article advocates a way forward, through a focus on promoting financial system resilience. A resilient financial system can weather many threats, even unforeseeable ones. Resilience has received heightened attention in recent years as an objective for policymakers aiming to mitigate the risk of financial crises (Brunnermeier 2021 and 2024; Mester 2023). Section IV proceeds to define "resilience." Specifically, this article defines "resilience" as the ability to withstand a shock without damage that compromises viability. Integral to this definition is the concept of a cliff effect. The cliff is the breaking point beyond which there is no return and the shocked system is too damaged to function. The length of time to recover matters as well. A system that survives a negative shock may eventually recover, but if that recovery takes a century, it would not be viable for many years.

Section V reviews the role for and limits of market mechanisms to build resilience to black swans, as distinct from lesser events, and the resulting role for the official sector to fill the gap. For the known known, markets can reduce risk or transfer risk. For the known unknown, the probabilities or the potential outcomes are not known, resulting in inaccurate risk pricing and imperfect risk transfer. For the black swan, the unknown unknown, no market mechanism can exist to price the event because there is no knowledge that an event needs to be priced, and the risks and consequences of black swans therefore cannot be efficiently shared through financial market transactions. Further, private investment in resilience will be too low, and the disruptions to financial stability from black swans especially damaging, because a resilient financial system is a weaker-link public good. Each market participant's limited investment in its own resilience serves to reduce the returns to others from investing in their own resilience (Cornes 1993), and markets therefore underproduce financial system resilience, making the system more vulnerable to black swans. These market failures create a role for official-sector policy in building and supporting resiliency.[5]

[5] This article takes the view that financial stability and financial system resilience are weaker-link public goods rather than weakest-link public goods (analogous to the distinction made in Anand, Duley, and Gai (2022) regarding cybersecurity and financial stability). With weakest-link public goods, underinvestment in resilience by one market participant could make all others' investments in resilience worthless; with weaker-link public

Policies to build resilience are those that ex ante result in a stronger financial system, one better able to withstand future black swans without extraordinary emergency official-sector intervention to avoid the cliff. Section VI proposes that policies designed for this purpose are consistent with a **resilience principle**, given the complex and adaptive nature of the financial system. Simply stated, the resilience principle calls for policies that are adaptable in response to the changing environment, universal in coverage, and systemic in scope.

The discussion takes the official sector as the entity uniquely able to implement policies to build resilience to black swans, but *not* because the sector has a comparative advantage in spotting building vulnerabilities or calculating the probabilities of rare or consequential events. Rather, the official sector's size and its tax and regulatory authority mean that it can absorb the negative consequences of shocks and thus stay farther from the cliff than can any market or private market participant. This does not mean that the official sector will have the will or the support of the public in acting ex ante to build resilience. Too often, major financial legislation is only adopted in the aftermath of a crisis (Conti-Brown and Ohlrogge 2022), and it is usually focused on preventing a replay of what happened rather than meeting the standards of the resilience principle.

Section VII gives examples of three types of policies—automatic stabilizers, buffers, and backstops—consistent with the resilience principle. These examples provide an attractive starting point for discussing and designing policies for resilience. A growing literature identifies ways in which existing financial regulatory and supervisory policies fall short of building resilience (e.g., Tucker 2015; Geithner 2019; Kay and King 2020; Feldberg and Metrick 2021; Metrick and Tarullo 2021; Daníelsson 2022; Mester 2023; Brunnermeier 2024), but it has not proposed principles for policymaking that account for the complex and ever-changing nature of the financial system. In most cases, the literature addresses policy in a world of only known events (known knowns or known unknowns). This article's contribution is in maintaining a focus throughout on unknown and unknowable events in a CAS and the principles of policies to avoid catastrophic outcomes.

Another literature tackles optimal policy design with uncertainty by applying robust control methods. It optimizes with respect to the worst-case scenario across a set of models believed to be approximations to the true model, which is unknown in some way (e.g., Hansen and Sargent 2001; Onatski and Stock 2002; Giannoni 2007). The nearness of all deviations considered from what is believed to be the truth keeps this literature focused on the fine-tuning of existing policies rather than addressing the large-scale deviations that would constitute black swans and considering policies to mitigate that risk.

Section VIII concludes in a sense fitting for an article about unknowable events. A major insight from this article is that many questions remain open about building the financial

goods, the value of others' investments is reduced but not driven to zero. There is disagreement about whether financial stability and financial system resilience are public goods of some kind or a common resource (e.g., Tucker 2015). The distinction is immaterial for this article's conclusions. Whatever the classification, market failures create a role for official-sector policies with certain features.

system's resilience because of a natural tendency to limit thinking to the realm of the known when the greatest risk of harm stems from the unknown. The resilience principle proposed here and the examples of policies that satisfy it will ideally stimulate debate and become part of an ambitious and fruitful research and policy agenda.

II. Distinguishing Swans and Other Events

This section presents a taxonomy that defines four classes of events that differ along two dimensions: their impact and the prior awareness of them (Figure 1). In this taxonomy, the swans—whether black, grey, or white—are large-impact events, with colors that reflect prior awareness. Ducks, in contrast, have smaller effects, although awareness of them may vary.

The taxonomy has three categories of prior awareness: known knowns, known unknowns, and unknown unknowns.[6] The latter two are states of unquantifiable or Knightian uncertainty, while the first category, the known knowns, is a state in which risk can be measured and probabilities estimated (Knight 1964).[7]

[6] Omitted from the taxonomy are unknown knowns, events that people are not aware of but somehow instinctively understand. These events are not relevant for financial stability and not analyzed here.

[7] Knight (1964) distinguished between cases where risk prevails, so that the probabilities of events are known, and cases where uncertainty prevails and probabilities are unknown. Knight does not state whether the set of possible events is known under uncertainty, although he implies that the events are known. In a complex adaptive system, discussed in Section III, the event space can change frequently and in unknowable ways, making the set of possible events unknowable, as well as the probabilities of even previously known events. In the taxonomy, known unknowns correspond to cases where the event space is known but probabilities are not; unknown unknowns, to cases where the event space is unknown and, by implication, probabilities also are unknown.

Figure 1: A Taxonomy of Financial Stability Relevant Events

MAGNITUDE OF CONSEQUENCE	**Extreme**	White Swan	Grey Swan	Black Swan
	High	White Swan	Grey Swan	Black Swan
	Moderate	Duck	Duck	Duck
	Low	Duck	Duck	Duck
		Known Known: Well understood, low probability event. Models and parameterizations remain within tolerances. Consistent with common understanding.	**Known Unknown: Event within realm of human experience but not well understood. Models require significant recalibration or updating of parameters.**	**Unknown Unknown: Event outside human experience. Models of the world are missing or misspecified in critical ways.**
		PRIOR AWARENESS OF THE EVENT		

Source: Authors' analysis.

The Appendix presents a diagnostic tool for identifying after the fact whether an event was a black, grey, or white swan or a duck. The tool lists five event features: official sector intervention, news coverage, cross-jurisdictional coordination, private sector adaptation, and legislative interest. The realizations of different types of events likely lead to different manifestations of each feature. The Appendix also presents examples of each type of event to show how the diagnostic tool can be used, although more attention is given to the black swan examples.

The remainder of this section describes each type of event and lists the examples described further in the Appendix.

Black Swans

Black swans are defined as unknown unknowns with very large and widespread effects. As unknown unknowns, black swans are fundamentally uncertain. They are outside the realm of prior experience, but once observed, they change the common wisdom of what is possible, which is the essence of the analogy to a black swan. When all swans were thought to be white because no other color of swan had been observed, even if someone had imagined swans of different colors, common wisdom was predicated on a world containing only white swans. Observing the first black swan would fundamentally change that world view and raise a host of new questions. What other colors of swans could exist? What other species might differ in color? Do the odd-colored specimens pose new or greater risks? What is the likelihood of seeing such specimens?

A black swan event reveals that the prevailing understanding of the world was fundamentally wrong. The commonly accepted "models" of causes and effects prior to a black swan, whether financial or otherwise, are shown to be wholly inadequate. A black swan may only have seemed rare given existing models of how the world works; with the benefit of hindsight, the black swan may seem to have been all but inevitable.[8] Observation of a black swan leads to the construction of new models or massive reconstruction of existing models.

Defining a black swan event as done here is consistent with and more precise than the original definition while avoiding the subjectivity of a black swan being in the eye of the beholder. Even if someone had contemplated the existence of a particular black swan event, the event's meaning and implications were so misunderstood that when the event occurred, it radically transformed the common perception of what is possible.

This definition also avoids describing black swans in terms of their rarity. A black swan cannot be synonymous ex ante with a tail event or 100-year storm because such characterizations rely on a well-defined probability distribution. By definition, a tail event lies in the tail of its distribution and therefore is an event whose likelihood is well understood. But assessing the likelihood of an event requires a roughly correct model of cause and effect. If the model that supports the common wisdom is wrong, so too will be any judgment of what is likely or unlikely.

Based on the definition, examples of black swans include the first occurrences of a financial crisis and pandemic. Even if contemplated, these events would be entirely outside the range of human experience when they occurred, and their realization would reframe views of what is possible. The Appendix discusses those examples as well as some others identified as black swans: the 2008-09 financial crisis, the COVID-19 pandemic, the 9/11 attack on the World Trade Centers, and the dropping of the atomic bomb in World War II.

Grey Swans

Grey swans in the taxonomy are known unknowns with large and widespread effects. Essentially, black swans spawn grey swans: once a black swan is realized, an entire class of large-impact events—grey swans—are known to be possible. When grey-swan events will occur and what form they will take remain unknown, but their appearance does not make existing models of cause and effect obsolete.[9] Instead, after a grey-swan event, existing models are retained, but their parameters are updated.

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[8] Taleb (2010, p, xxii) describes this as the human tendency to create narratives ex post to rationalize the event and make it seem to have been predictable.

[9] The term "green swan" has been used to refer to climate-related events that could be extremely financially disruptive. Bolton et al. (2020) acknowledges that green swans differ from black swans in that the likelihood of a climate-related risk materializing in the future is known. That makes green swans a class of grey swan in the taxonomy of this article.

Understanding of a class of grey swans grows with the swan's repeated appearance. Vulnerabilities that contributed to the grey swans come to be recognized, monitored, and mitigated.

Examples of grey swans discussed in the Appendix include the savings and loan (S&L) crisis in the 1980s, 1987 stock market crash (Black Monday), collapse of Long-Term Capital Management (LTCM), 2003 SARS outbreak, 1993 World Trade Center bombing, Chernobyl nuclear disaster, and corporate governance crisis that brought the collapse of Enron and WorldCom. In contrast to the examples of black swans, many of the grey swans are near misses as they fall short of having catastrophic effects and thus fail to catalyze major shifts in world views, policies, and behaviors.

White Swans

White swans are known knowns that occur infrequently and have a sizable, large-scale impact. They are aged versions of grey swans and thus sufficiently well understood from analysis of past events that they fit within acceptable tolerances of existing models. Their likelihood can be estimated, and their effects can be dampened. For example, the creation of deposit insurance reflected recognition of coordination failures as a cause of bank runs and made the banking system more resilient. Bank failures still occur, but they are unlikely to cause runs or crises. The exception is if something has changed that results in bank runs possessing new, unknown properties, as was the case with the 2023 failure of Silicon Valley Bank. The ensuing bank runs brought the realization that the growth of online banking and uninsured deposits had altered run risk.

The Appendix describes the March 2020 Treasury market disruption, 1997 Asian financial crisis, 2009 H1N1 pandemic, localized and smaller-scale acts of terrorism, and Fukushima nuclear disaster as examples of white swans.

Ducks

Ducks stand in contrast to the more exotic swans of any color. Their effects are smaller and more localized, lacking the systemic feature of swans. Ducks may vary in the public's awareness of them, but their smaller impact makes any lack of understanding less important. Known ducks are known knowns. New varieties of ducks can arise, constituting known unknowns or unknown unknowns. The localized nature of the new varieties makes learning about them easier, so they can become known knowns rather quickly. Ducks do not bring a risk of pushing the financial system over the cliff, and no systemwide resilience is needed to mitigate their harm. The remainder of this article focuses on ducks that are known knowns.

Sometimes a duck is discovered to be a swan, as in the classic fairytale, *The Ugly Duckling*. What might seem to be a routine virus that will run its course, for example, might instead be the start of a pandemic.

Examples of ducks reviewed in the Appendix include the collapse of Archegos Capital Management, a sovereign bond default by a serial defaulter, the seasonal flu, non-mass shootings, and non-disaster operational issues at nuclear power plants.

III. Complex Adaptive Systems: Conducive Environments for Black Swans

From the preceding discussion, black swans are unknown unknowns; their nature and effect cannot be predicted. As such, black swans cannot be prevented or eradicated, but their harm can be mitigated if the properties of systems or environments that are more likely to experience black swans are understood.

While a variety of environments can give rise to black swans, shocks are more likely to appear as black swans in a CAS, whether the shock is a common shock that hits more broadly within the system or an isolated shock that propagates throughout the system. A CAS is a large network in which the nodes (which can be networks themselves) and links change as a result of their interactions, which can be nonlinear and create amplifying feedback effects. The complex, opaque, and ever-changing nature of a CAS makes it a realm of uncertainty, exactly the kind of environment that is susceptible to unknowable events with extreme consequences—the black swans.

To better understand a CAS, consider the roles of complexity and adaptiveness separately. In a complex but nonadaptive system, more and more of how the system works is figured out over time, enabling the development of better models. For example, quantum mechanics is a complex theory of the behavior of small particles, but it was ultimately discovered because its laws never change. In contrast, in a simple but adaptive system, models are easily developed at a point in time. As the system adapts, the model fit deteriorates, but because the system remains simple, it is straightforward to forecast changes and maintain a current and largely correct model. In a CAS, neither of those outcomes is possible. As knowledge is gained of how the system works at the moment, the system is changing in ways that make that knowledge obsolete in unknowable ways.

Today's financial system fits the description of a CAS well (Haldane 2009). Modern financial intermediation and financial markets create complex financial exposures. Moreover, financial sector firms and their service providers are heavily reliant on digital technologies, if not technology firms outright. Digitization has brought many benefits, including enabling the financial system to intermediate credit, facilitate payments, and provide price discovery on a scale and at a speed not previously imagined. Digitization also has made the financial system an extremely complex network of networks, with financial exposures that change almost continuously and span multiple markets and counterparties. The dense and evolving nature of these linkages make it impossible to know with certainty who is exposed to whom, who is exposed to what, and how quickly those exposures may change.

At the same time, digitization has brought more concentrated market structures, including more single points of failure. It has enabled the trend toward Everything as a Service (EaaS). EaaS reflects how businesses are treating software, platforms, infrastructure, and just about anything else as a service that can be outsourced, customized, and scaled as needed. EaaS adds flexibility to operations while increasing the length and complexity of the supply chain. The trend toward EaaS combined with the increase in market concentration is creating common exposures across the financial system to the same key vendors.

As a CAS, today's financial system forces the acknowledgment that available data and models, and even the human imagination, will fail where black swans are concerned. The nature of a CAS does, however, suggest possible ways forward. The next section considers the concept of *resilience*. A more resilient financial system can better weather the fallout from black swans. Preventing black swans may be impossible, but building a financial system that is better able to withstand their impact is achievable.[10]

IV. What is Resilience and Why is it Needed?

By their very nature a black swan is a fundamentally unknowable and catastrophic event. What hope is there for official sector policies to combat events that cannot be imagined ex ante? This article advocates that, while standard tools are useful for ensuring the efficient allocation of risk across market participants, a new approach is needed to effectively address black swans. This approach is a focus on financial system *resilience*.

Before considering the scope for private markets and the official sector to build resilience to black swans, a definition of "resilience" is needed. Brunnermeier (2021) defines "resilience" as the ability to bend but not break or to recover to a prior state. Brunnermeier (2024) broadens that definition to allow resilience to be a matter of degree; a system can bounce back to some extent (positive resilience), remain at the post-shock damaged state (zero resilience), or deteriorate further (negative resilience).

Clearly, resilience can be viewed as a matter of degree. Because this article focuses on policies to build resilience to catastrophic unknown unknowns, and because resilience is costly to achieve and maintain, this article defines "resilience" as the ability to withstand a shock *without damage that compromises viability*. In other words, it is the ability to bend and possibly remain bent and functional without breaking.

Integral to this definition is the concept of a cliff effect. The cliff is the breaking point, the point beyond which there is no return and a system becomes too damaged to function. Shy of that cliff, a system can continue to function, although perhaps to a lesser degree. For example, insolvency of the financial system as a whole, or at least a substantial part of it, is a cliff for the system. There is an enormous difference between being almost insolvent and insolvent.

The length of the recovery also matters for this definition. Most systems that survive negative shocks can eventually recover, but the downtime during the recovery can itself threaten viability. By analogy, dense forests can eventually return to their average or "normal" state after a high-severity fire, but recovery could take at least a century; this would not be an example of resilience (e.g., Kolb 2020).

[10] The U.S. Army describes the strategic environment as a CAS, where the actors, their strategies, and the nature of the battlefield are everchanging and unpredictable (U.S. Army War College 2019).

In practice, the location or point at which a cliff exists might not be known. Policymakers need to assess the risk that a cliff lies ahead and to weigh the costs and benefits of building varying degrees of resilience. A black-swan crisis reveals an event newly discovered to exist in the tails. When the crisis occurs, the financial system needs to be sufficiently resilient so that policymakers have enough time to figure out how to stabilize the system, assuming the will to do so and a steep learning curve.

The concept of resilience is appealing in a world with black swans because a resilient financial system can withstand a wide range of potential events, including the unpredictable. Whereas policies that fight the last crisis are effective at preventing similar crises from happening again, they are poorly suited to fight new crises. A resilient financial system is not tailored to fight a particular brand of crisis; rather, it is built on principles that ensure it has sufficient armor to endure all manner of unknowable threats.

V. The Scope for Market Mechanisms to Build Resilience

Market-based approaches are a natural place to begin examining how to build resilience. When available, market solutions offer the opportunity to both reduce and redistribute risk, and they are preferable to official sector interventions that bring the possibility of distortions in prices and activity. To mitigate the consequences from the realization of risk, a market-based approach is indeed possible. But to mitigate the consequences from the realization of uncertainty—from former unknowns being revealed, as in the case of black and grey swans—markets solutions are wholly inadequate, creating a role for the official sector to develop and implement a more robust approach. This section reviews the potential and limitations of market solutions before turning to a framework for building resilience in the next section.

One way that markets can reduce risk is through diversification, the act of spreading resources across assets or exposures that are not perfectly correlated to reduce the effect of any one asset-specific outcome. Diversification does not eliminate the variation in asset-specific outcomes, but it does spread the outcomes across more market participants, lessening the consequences for any particular investor.

Another market solution, one that is available through insurance products and derivatives contracts, is the potential transfer of risk from those for whom the risk is more costly to those for whom it is less costly. Consider a wheat farmer whose entire income is determined by wheat prices that can fluctuate widely and expose the farmer to considerable idiosyncratic risk. Through forward contracts in which an investor agrees to buy wheat from the farmer at a future date at a guaranteed price today, the farmer can transfer this risk to the investor, who may be better able to invest across a wide range of risky assets. The farmer will agree to a lower than expected, but guaranteed, price, while the investor will accept the diversifiable idiosyncratic risk of wheat in exchange for a small but positive expected return. In this case, the market has efficiently transferred risk from someone less able to bear the expected cost to someone who can better afford it, although the aggregate risk remains the same.

Likewise, hedging strategies can also transfer risk. For example, investors with a large exposure to a particular idiosyncratic risk may not be able to diversify the risk (e.g., an outsized exposure to a particular currency or the credit risk of a single or small set of firms). However, they can hedge this risk through a variety of financial contracts (such as futures, options, or credit-default swaps). Aggregate, undiversifiable risks such as interest rate risk, inflation risk, or GDP risk, while not reducible, can also be efficiently transferred through the market. Interest rate swaps, for instance, do not eliminate interest rate risk, but can transfer the risk to those better able and more willing to manage it. While hedging does not reduce the risk in the aggregate (the investor supplying the hedge is now exposed to the risk instead of the purchaser of the hedge), it nonetheless serves to efficiently transfer risk.

Various market frictions, such as incomplete information and trading costs, may impede the efficient management and transfer of risk. Policies that reduce these market frictions can make the financial system more resilient, although they are no panacea.

Unfortunately, market solutions are insufficient in a world with black swans. Central to any market mechanism is the establishment of prices. Prices represent the value at which trades can occur, and when markets function well, prices represent the estimated fair value of the item traded. In the context of risk, a price reflects a combination of the probability of an event and the magnitude of its consequence. But the occurrence of a black swan event necessarily implies that the prevailing beliefs about probabilities and outcomes were based on an incorrect model. When prices are based on the wrong beliefs, exposures to outcomes are not properly diversified or shared.

Consider the credit default swaps (CDS) written on mortgage-backed securities (MBS) in 2007. These contracts were written under the assumption that house prices could not fall simultaneously across many U.S. states—a local housing market crash would be a duck for a nationally diversified mortgage lender. This assumption was wrong, and in hindsight the prices of these contracts were laughably low given their exposure to the ensuing housing market crash. For markets to resolve the misallocation of exposures, it must be that the probabilities and consequences of events are known. In a world with unknown unknowns, this is impossible.

More than ineffective, under incorrect (but believed to be correct) probabilities, markets can do more harm than good. Decisions by market participants may create risk that would not exist otherwise. Consider again the CDS on MBS offered by AIG. Because AIG believed incorrectly that the probability of a nationwide housing collapse was small, they sold a tremendous amount of CDS. This created additional exposures to house prices that would not have existed in the absence of the CDS market or if AIG had known the true expected losses on those contracts. In these scenarios, markets can worsen the consequences of black and grey swans when they appear because the total amount of exposures and interconnections in the system are larger.

For some events, rather than incorrectly setting prices, markets will simply fail to exist. One example is when probabilities are not computable. A classic case is long-term insurance. Insurance contracts for medical care and environmental damage are renegotiated annually

because the distribution of events over long periods is too difficult to estimate. Additional examples include insurance for school playground accidents, satellite damage, or new product failures, which were priced prohibitively high or entirely unavailable because the probability of the event or loss given the events were not quantifiable with a sufficient degree of certainty (Cutler 1996; Kunreuther et al. 1993).

For other events, no market mechanism can exist to price the event because the event is unknown. In such cases, no one thinks to price the events, which is a more fundamental problem than knowing about an event but having limited ability to assess its likelihood or consequences.

Arguably the most fundamental source of market failures related to financial stability is that a stable financial system is a weaker-link public good: Its stability arises out of the resilience of all its markets and participants, and each market participant's limited investment in its own resilience can reduce the returns to others from investing in their own resilience (Cornes 1993). In this case, markets underproduce financial stability. Financial market participants take on too much risk relative to their resilience because they do not internalize the full social cost of their actions, namely the threat posed to financial stability. Markets cannot solve this problem because no market participant owns the public good or the right to contract to protect it.

These disparate sources of market failures create a role for official-sector policy in building and supporting resiliency. Such policies will necessarily distort individual entities' incentives. In fact, their goal is to alter incentives. What often is lost in discussions of such policies is the extent to which incentives where not aligned and markets alone were unable to achieve socially optimal outcomes.

VI. A Resilience Principle for Addressing Black-Swan Risk

Most official-sector policies were enacted in response to past events, the white and grey swans (Conti-Brown and Ohlrogge 2022). This is appropriate because policy should at least mitigate the risk of similar events in the future. Such policies will also provide some resilience to black swans. For example, resolution plans for systemically important banks, stress tests, and standards for capital, leverage, liquidity, and counterparty exposures were implemented to mitigate vulnerabilities to events like the 2008-09 crisis. These policies are agnostic to the source of stress, and they did reduce the damage in the COVID-19 financial crisis, although the features that made that event a black swan meant that additional official-sector action was needed. That is not surprising because policies to mitigate white and grey swans will necessarily miss the mark to prevent a future black swan. Accordingly, such policies failed to prevent both the 2022 UK pension stress, when liability-driven investments unraveled, and the 2023 runs on U.S. regional banks.

Mitigating the risk of future black swans requires policies designed not to fight a past war but rather to ensure the financial system is sufficiently resilient to avoid cliff effects. The official sector can uniquely implement policies to enhance resilience to black swans, but *not*

because it has a comparative advantage in spotting vulnerabilities that are building or calculating the probabilities of rare or consequential events. Rather, the official sector's size and tax and regulatory authority means that it can absorb the negative consequences of shocks and thus stay farther from the cliff than any market or private market participant can. It is this special nature of the official sector that creates its critical role in building resilience to black swans.[11]

The remainder of this section proposes a **resilience principle** for constructing official-sector policies that help to build resilience in a complex, adaptive financial system. The resilience principle is analogous to the principles for earthquake-resilient construction in a world with a shifting and obscured network of underground fault lines. Simply stated, the resilience principle calls for policies that are **adaptable**, **universal**, and **systemic**. Resilience-enhancing policies need not have all three features, but policies with more of the features—that more fully meet the resilience principle—are generally better. Each feature is discussed in turn.[12]

- **Adaptable**: Policies to build resilience in a CAS are designed to adapt to the prevailing environment because policymakers recognize that the environment is ever-changing. Simpler adaptable policies are better because they can apply more broadly and across more states of the world. This point has been made by others (e.g., Haldane and Madouros 2012): with highly tailored and state-contingent rules, even ones designed to be optimal, the financial system is more likely to find itself in states to which the rules do not apply. The nature of a CAS means that states are changing in unknowable ways, so policies targeted at known or well-understood states will necessarily miss the unknown states. Policies that are not adaptable would be ineffective in such cases or worse; they could bring about adverse outcomes.

  Adaptable policies adjust at least somewhat automatically to changing conditions, as is the case with automatic stabilizers discussed below, and the bar for modifying them should be high. Delays while legislatures decide to allocate funding or policymakers agree to act pose a risk of catastrophic loss in a world of black swans.

- **Universal**: Policies to build resilience are universal, meaning that they apply widely across markets and entities with few exceptions. Much regulation today lacks this feature, applying instead to a limited set of entities and financial assets (Arseneau et al. 2023). This lack of universality matters for two reasons. First, it creates a regulatory perimeter and an incentive for organizations to adapt business models to move their activities outside that perimeter. Such movement, in turn, sets off a cycle in which regulations are modified to bring more activity inside the regulatory perimeter, followed by more adaptation to escape the grip of those regulations,

[11] Of course, this assumes a well-functioning official sector.

[12] Building resilience to black swans that have a negative impact will not reduce the likelihood of swans with positive consequences as the latter usually come from technological innovations and are realized gradually.

followed by more regulatory modifications (Metrick and Tarullo 2021; Vardoulakis et al. 2021). In contrast, universal policies apply broadly to organizations to avoid the creation of regulatory perimeters or specification of select industries or sectors of the economy as mattering for resilience. They are congruent in the sense of Metrick and Tarullo (2021).

Second, recent crises have shown that Wall Street and Main Street are interconnected, and distress can readily spread between the two. Universal policies are designed to ensure that the economy widely has skin in the game. Critical infrastructure sectors should still be identified and required to meet appropriate sector-specific standards for enhanced resilience, but universal policies avoid presupposing the connections through which distress can spread across sectors.

Systemic: Policies to build resilience also are systemic in that they are designed to enable the financial system as a whole to retain all critical functions and avoid the cliff. Systemic policies account for the complex and everchanging nature of a CAS and for policymakers' inability to foresee how distress may propagate through the system. Whereas universal policies aim to cover a wide range of institutions and markets to limit the migration of risk, systemic policies account for the proliferation of stress throughout the system due to black swans. At the same time, systemic policies do not prevent the harms that can arise from routine events such as firm bankruptcies, financial institution failures, and job losses as part of traditional Schumpeterian creative-destruction dynamics. Instead, systemic policies enable the key functions of the financial system to persist during periods of severe distress.

A key benefit of systemic policies is that they buy policymakers time to understand the nature of the crisis. Because systemic policies create distance from the cliff, in the midst of a crisis more targeted and effective policies can be crafted to restore stability.

Systemic policies are big enough soon enough to build resilience across the complex, adaptive financial system. A risk in policymaking is that policies designed to mitigate the visible stress of the moment could be too limited in effect, requiring additional interventions to be taken later. Before a crisis, debate will inevitably arise over whether systemic policies are too big or too comprehensive. After a crisis, the fact that there is a functional system within which that debate can even occur is proof that the policies succeeded in avoiding the cliff.

No discussion that advocates a role for policy to build financial system resilience to crises would be complete without a discussion of moral hazard. Moral hazard is the possibility that financial system participants intentionally take on more risk because they expect not to bear the full cost of that risk. But how salient is the moral hazard threat from policies that are systemic, as the resiliency principle would stipulate? Bailouts occur in crises, which are the realization of systematic risk, whereas events stemming from non-systematic risks are not bailed out. The moral hazard threat would thus need to inspire financial market participants to take on risk with the intent to capitalize on a bailout, which necessitates loading up on the systematic risk that ultimately is realized in a future crisis. This seems farfetched.

A more likely scenario is that market participants follow the actions of others, even though risk is building, because they fear falling behind competitively otherwise. That is not moral hazard; rather, it reflects short-term decision-making, flawed incentive contracts for managers, or limited liability. If the risk never materializes, the strategy appears successful. If the risk is realized in the extreme, triggering a crisis and broad bailout, the strategy may still seem worthwhile. But if the risk is realized in isolation—without a systemic event or rescue—the resulting harm can be severe. It is this type of herding behavior that has amplified some past financial sector shocks and transformed them into black swan events. Financial sector regulations designed to reduce black swan risk through adaptable, universal, and systemic policies are unlikely to inspire notably more risk-taking than already results from competitive forces.

VII. Examples of Policies Consistent with the Resilience Principle

Much work remains to be done to understand a world with black swans and which policies can build resilience. This section proposes three types of policies—**automatic stabilizers, buffers, and backstops**—that illustrate how the features put forth in the previous section might be put into action. Each type embodies one or more of the desired features.

Automatic Stabilizers

Automatic stabilizers are rules-based policies that adapt in size and scope in response to some key indicators of potential instability. The value of system stabilizers seems self-evident, and the value of an automated rule is critical. A black swan may be developing, unseen and unimagined. Early signs of stress may appear gradually and seemingly without cause, but be known to signal underlying developments that could push the system closer to the cliff. Automatic stabilizers are designed to respond to these developments without active recognition or intervention by policymakers.

Automatic stabilizers must operate largely free from human intervention. While the desire to fine-tune policies may be expected, particularly during periods of stress that transmits differently than in the past, the aim should be to institute policies that can remain fairly static and yet still adapt to the environmental changes to which they apply.

In financial markets, rapid growth in participation, trading volumes in specific assets, and profits in particular sectors can be early indicators of building vulnerabilities. For instance, prior to the 2008 financial crisis, the growth in MBS issuance was unprecedented. LTCM averaged 30% returns per year during its first four years of operation. The roaring 1920s foreshadowed the Great Depression. Between August 1921 and September 1929, the Dow Jones Industrial Average increased from 63 to 381, which is a more than 500% cumulative return.

As these indicators suggest, automatic stabilizers need to be scale-independent, such as pegged to relative quantities like returns or other ratios, and not to the level of variables (i.e.,

prices). They also need to be difficult to soften, with high bars in place to prevent changes in the direction of being less stabilizing or stabilizing in fewer states of the world. This ex ante commitment is crucial, as a weakening of the stabilizer when it is most needed can shake the faith of markets and households. Because the presence of the stabilizer alone may contribute to stability, reforms to stabilizers during periods of stress and volatility should be avoided.

Automatic stabilizers are already in use to a limited extent, Examples include:

- **Progressive income taxes and unemployment insurance**. When the economy slows, personal and corporate income falls, and unemployment rises. At the same time, taxes owed fall, and more people qualify for unemployment benefits. In this way, the government automatically injects more funds into private businesses and households, stimulating economic activity. The reverse happens when the economy grows.

- **Market-wide circuit breakers in financial markets**. Circuit breakers are triggered based on ex ante rules to halt trading and thus disrupt a rapid sell-off of assets that may disrupt financial system stability. For example, the SEC imposes trading halts when the S&P 500 index experiences losses within a single day that eclipse certain thresholds set ex ante: 7% (Level 1), 13% (Level 2), and 20% (Level 3). Level 1 and Level 2 circuit breakers stop trading for 15 minutes if they are triggered within about 30 minutes of the normal close of trading. Otherwise, they along with Level 3 circuit breakers stop trading for the rest of the day.

- **Mutual fund swing pricing**. Historically, a mutual fund's investors could transact (i.e., buy or sell shares) at a price equal to the net asset value of the fund's assets, regardless of whether the transactions themselves could dilute the fund's value for the remaining investors through transaction costs and depleting liquid assets. Under swing pricing, swing "factors" are imposed that pass these costs on to the transacting investors and are based in part on the fund management's expectation of transaction costs. During periods of heightened transaction costs, such as times of deteriorating liquidity, the first-mover advantage to running is greater, and the swing factor will be larger.

For resilience to black swan events, there is the potential for a considerable expansion of the set of automatic stabilizers. For example, during quarters of significant contractions in credit, covered financial institutions' earnings distributions could be limited. Existing research has demonstrated that during periods of stress, banks will scale back their credit provision to maintain their dividend payments and share buyback programs (Acharya et al. 2011). In the wake of the COVID-19 crisis, the Federal Reserve imposed distribution limitations on banks to facilitate the growth of capital buffers (discussed below) and to incentivize the continued provision of credit. This intervention was seemingly successful: Research has found that bank capitalization rose in jurisdictions that restricted capital distributions, and the additional capital was more likely to support lending in those jurisdictions (Hardy 2021). Transforming that policy into an automatic stabilizer offers potential benefits.

The supplemental leverage ratio (SLR) is also potentially dynamic; it is already somewhat automatic. The SLR determines the amount of common equity capital U.S. banks must hold relative to their total leverage. During the episode of Treasury market instability in March 2020, the Federal Reserve Board removed Treasury securities and reserves (deposits held at Federal Reserve Banks) from the denominator of the SLR. The goal was to limit any disincentive banks might have to provide intermediation services in Treasury markets. That is, the SLR was temporarily modified to avoid contributing to market instability, and research shows that it achieved this (Favara et al. 2022). The SLR could serve its desired purpose yet adjust automatically. During periods of reduced Treasury market liquidity, Treasury exposures could receive lower weights in the SLR denominator.[13] In fact, such a principle could apply more broadly. Heightened illiquidity in any broad asset class could correspond to lower weights in the SLR denominator, better positioning banks to supply liquidity to markets when liquidity is scarce. Of course, such an automatic adjustment of the SLR would require ready measures of market liquidity.

In identifying potential automatic stabilizers, policymakers should look carefully at the interventions that worked well during previous bouts of stress and assess which can become rules-based and automated.

Buffers

Buffers are required amounts of typically liquid funds that can be drawn on in dire circumstances. Whereas automatic stabilizers support resilience under predetermined conditions, when they are insufficient, buffers can provide additional support in avoiding cliffs. Buffers also mitigate the externality from private actors undervaluing financial stability and underinvesting in their own resilience. They serve as a required form of self-insurance. To be available in bad times, buffers need to grow or be replenished in good times. This adjustment feature could be automated.

Many kinds of buffers can build resilience. For example, capital and liquidity buffers have long been used in the banking sector to build bank and financial system resilience and to reduce the moral hazard associated with government-provided deposit insurance. Perhaps the most well-known buffer for systemic purposes is the countercyclical capital buffer (CCyB), which was introduced by the Basel Committee on Banking Supervision as part of its Basel III regulatory framework (Bank for International Settlements 2010). Under the CCyB, countries set a positive countercyclical buffer during periods of elevated systemic risk, requiring large, internationally active banks to hold additional capital during those periods; in downturns, countries ease the requirement, allowing the buffers to be released. As implemented, however, CCyB rules fail to live up to their promise. Bank regulators must actively decide to increase the buffer, and any increase goes into effect with a 12-month lag. They also must actively decide to lower the buffer, a decision that takes effect quickly but relies on data about a slowing economy that are available with a lag. The CCyB could be

[13] In its current form, the SLR does not include risk weights. All exposures are treated equally regardless of their safety or liquidity.

designed differently to overcome these drawbacks. It could increase (decrease) automatically by small amounts, perhaps 0.10% per quarter, when profits are rising (falling), with each change taking effect within six months. With this modification, the CCyB would share the defining benefit of an automatic stabilizer.

Even with these proposed changes, the CCyB would apply only to sufficiently large banks. A universal buffer could be introduced that is similar to the CCyB but requires holdings of liquid assets by *all* firms subject to limited liability, not just by banks and other financial companies. The universal buffer would allow individual firms to provide a backstop for themselves in dire circumstances. It also would offset some of the excessive risk-taking that can result from the moral hazard associated with limited liability or from the government serving as a backstop in a crisis.

The universal nature of this buffer is key. The downside of typical buffers is that they apply to a limited set of institutions, which creates a regulatory perimeter, as discussed above. Non-universal buffers also view stress too narrowly, failing to cover the broad array of firms that can propagate shocks. Recent crises have shown that distress can spread quickly and unexpectedly. Further, stress can be magnified by impairments to a large number of small firms, none of which are individually consequential to the system, but whose correlated troubles can have substantial macroeconomic effects. A universal buffer could avoid these common downsides.

The universal buffer could be analogous to a 401(k) plan with automatic enrollment at 1% of income, a contribution rate that increases by 1% of income annually up to a maximum percentage, and with withdrawals allowed for certain hardships. For the universal buffer, any business entity with limited liability would be automatically enrolled in a buffer capital program. Contributions to the buffer could start at 1% of any positive profits based on the prior year's taxes. They could increase by 1% of profits in any year when profits are positive until hitting a maximum percentage. When profits are negative, no contribution is required. When profits are positive again, contributions resume at the previous contribution rate and continue to climb 1% in future years with positive profits. Profits for the purposes of calculating the buffer could be defined simply and at a high level (e.g., as gross profits) to limit the scope for accounting manipulation. Contributions could be made quarterly. Buffers could be tapped for certain emergencies—swan events—set by statute or declared by the government, and they would have to be exhausted before any government support could be received during a crisis. When businesses are allowed to tap their buffers, additional contributions could be waived. If a business is acquired, the buyer would receive the buffer as an addition to its historical buffer, without any credit toward that year's buffer contribution. Bank regulators could still choose to use a CCyB for large banks in addition to the universal buffer.

Backstops

A backstop is an official-sector policy or authority that supports or preserves the critical functions of a CAS when a black swan event pushes the system toward the cliff. It can support

any side of a market, serving as a demander or supplier of last resort anywhere along any supply chain, or as a guarantor for the value of some asset or product value.

The need for an official-sector backstop as a necessary tool but also a last resort has been recognized before. Judge (2019), for example, has proposed a standing Emergency Guarantee Authority that would authorize the U.S. Treasury Secretary to provide an emergency guarantee of financial claims as a last resort to halt a crisis. Judge's proposal has its potential pitfalls (e.g., Cecchetti and Schoenholtz 2019), but it clearly articulates the need for and potential shape of a backstop to build financial system resilience. When all other policies have been insufficient to avoid a catastrophic outcome, government must provide a safety net.

The need to tap a backstop does not mean that the less-extreme public policies in place failed. Existing policies might have built resilience, reducing the size and scope of the backstop needed to preserve the core functioning of the financial system, and they might have turned potential black swans into white or grey ones instead. Despite these efforts, the need for an all-else-has-failed backstop remains, and the backstop must be in place ex ante to be consistent with the resilience principle.

Backstops can be financial or operational.

Financial Backstops

Commonly used financial backstops include steps a central bank or government takes in fulfilling its lender-of-last resort or market-stabilizer roles. Deposit insurance, discount window loans, and the use of other central bank and Treasury emergency lending facilities, like the Temporary Foreign and International Monetary Authorities (FIMA) Repo Facility (Board of Governors of the Federal Reserve System 2023), are examples. So are guarantees of financial asset values, such as when the U.S. Treasury opened its Temporary Guarantee Program for Money Market Funds in September 2008, guaranteeing a stable share price of $1 after the Reserve Fund broke the buck (U.S. Treasury 2008). These examples illustrate the benefits of the official sector having flexible and broad authority to support markets and sectors of the economy as a last resort on short notice and with relatively little bureaucracy. The Dodd-Frank Act's limits on the Federal Reserve's 13(3) authority, the U.S. Treasury's ability to use the Exchange Stabilization Fund, and other elements in the emergency policy arsenal (Alvarez et al. 2020; Geithner 2019) run counter to this ideal.

A standard practice after the official sector has deployed a financial backstop should be to consider whether the backstop or other policies can be introduced as automatic stabilizers on an ongoing basis to make the financial system more resilient to future black swans. The Federal Reserve did this after the COVID-19 pandemic crisis by making its FIMA Repo Facility a standing facility to backstop dollar funding markets (Board of Governors of the Federal Reserve System 2022). It also introduced the Standing Repurchase Agreement (Repo) Facility as a standing backstop source of financing to its counterparties (Board of Governors of the Federal Reserve System 2021). In normal times, these facilities may receive little use; during periods of market stress, market participants can turn to these facilities and obtain

additional liquidity, stabilizing markets without the need for decisive action by policymakers.

Operational Backstops

Similar to financial backstops, operational backstops provide support to ensure that critical operations continue. The official sector can provide operational backstops directly or through public-private partnerships. Examples of operational backstops from outside the financial sector are the U.S. strategic oil reserves and the Svalbard Global Seed Vault, also known as the Doomsday Vault for its mission to backup other seed banks and protect the genetic material needed to protect the world's food supply in a disaster.

Operational backstops are especially important in a highly digitized and digitally interconnected system, like the financial system, where malicious and benign cyber incidents can disrupt operations. For example, financial trade repositories collect and store electronic records of financial transactions. These emerged from the 2008-09 financial crisis to provide timely and reliable access to data on transactions in a standardized way (Commodities Futures Trading Commission 2022; International Organization of Securities Commissions 2022). Another example is the Federal Reserve's operation of Fedwire, a U.S. electronic funds settlement system. By routinely operating Fedwire, the Fed and participating banks are ready to use the system if private-sector systems are down.[14]

Unlike financial backstops, operational backstops cannot quickly be introduced in an emergency. Especially as the financial system and broader economy continue their digital evolution, it is imperative that policymakers identify additional operational backstops that could prove critical in ensuring system resilience to future black swans.

VIII. Conclusion: A Path Forward

This article starts by defining a black swan more rigorously than in the past, and in doing so, it illuminates the need for policies that build financial system resilience. The article defines a black swan as a large-impact event that emerges from the unknown part of the event space—an unknown unknown. The complex and ever-adapting nature of the financial system means that black swans can never be eradicated. The best course of action, then, is to improve the system's ability to withstand whatever might come.

The article proposes a resilience principle for constructing effective official-sector policies up to that challenge. The principle is analogous to those for earthquake-resilient construction in a world with a shifting and obscured network of underground fault lines. The resilience principle calls for policies that are adaptable, universal, and systemic. Adaptable

[14] Fedwire differs from the Clearing House Interbank Payments System (CHIPS) in that the latter is privately owned by the financial institutions that use it, whereas Fedwire is owned and operated by the 12 Federal Reserve Banks. Another difference is that Fedwire settles gross payments, while CHIPs allows payments to be netted. Nevertheless, in a major outage of CHIPS, Fedwire could serve as a backup.

policies are designed to naturally adjust to changes in the environment. Universal policies apply widely, across entities and markets, with few exceptions. Systemic policies are designed to enable the financial system to retain all critical functions and avoid the cliff, the point beyond which the system becomes too damaged to function. Resilience-enhancing policies need not have all three features, but more features are generally better.

Three types of policies—automatic stabilizers, buffers, and backstops—are described to illustrate the resilience principle at work. Automatic stabilizers are rules-based policies that adapt in size and scope based on the value of some key indicators of activity associated with potential financial system instability. Buffers are liquid funds required and available for emergencies when automatic stabilizers fall short. Backstops are policies or facilities that can serve as a demander or supplier of last resort anywhere along any supply chain, or as a guarantor for the value of some asset or product value.

The resilience principle and example policies arguably require a heroic view of the official sector as willing and able to act to build resilience to the unknown. The policies are proposed with the understanding that the official sector is no better positioned than the private sector to anticipate the unknown. The examples are neither exhaustive nor conclusive. Resilience involves myriad complexities, and the discussion here is intended to inspire discussion and stimulate an ambitious and fruitful research and policy agenda.

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Appendix: A Diagnostic Tool

Section II presented a taxonomy of events distinguished by the collective prior awareness of the event and the magnitude of the consequences. Naturally, events can only be identified by information available *after* the event has occurred. Once the smoke has cleared, a black swan may, in hindsight, appear to have been inevitable. Prior to its realization, it would have seemed virtually impossible.

Figure A1 presents a diagnostic tool to apply the taxonomy to identify after-the-fact whether an event was a black swan or something else. It identifies five broad categories of outcomes from an event: official sector intervention, news coverage, cross-jurisdictional coordination, private sector adaptation, and legislative interest. The realizations of different types of events are likely to lead to different responses within each category. For instance, after a black swan event, official sector interventions are likely to be substantial and wide-ranging. Treasury departments may unveil large-scale fiscal programs; central banks may alter monetary policy; and other government agencies may dramatically revise their operating practices (such as the expanded efforts of the Transportation Security Administration after the terror attacks of 9/11). For swans of lighter colors, these interventions may be more targeted. For ducks, there are likely no interventions.

There are three considerations to keep in mind when using this framework. First, no condition outlined in Figure A1 is necessary or sufficient. Any event may meet some, but not all, of the criteria. In that sense, black swans can have some grey feathers. For example, a black swan may result in considerable official-sector action, but not private-sector adaptation. A white swan may inspire significant news coverage but be accompanied by little legislative attention or official sector action. A gray swan may not set off many cross-jurisdictional efforts, despite attracting notable news coverage and a fair bit of private-sector adaptation. Thus, identifying a duck or type of swan in many cases may resemble, to borrow a term from the medical community, a "diagnosis of exclusion." The diagnosis that fits the best may ultimately be the one that checks the most boxes, but not necessarily all of them.

Second, the vagueness of the conditions for each type of event or swan is a feature, not a bug. Figure A1 provides a roadmap for evaluating the consequence and surprise of an event in its entirety. The conditions in Figure A1 are intended to be evaluated relative to one another rather than against a rigid, quantitative benchmark.

Lastly, when applying the diagnostic tool outlined in Figure A1, it also is important to view the conditions within the appropriate historical context. For example, news coverage may have been in a local newspaper before there were national news sources or by word of mouth before the printing press.

Figure A1: A Diagnostic Tool

	Black Swan	Grey Swan	White Swan	Duck
Official Sector Intervention	Large-scale interventions	Targeted interventions	Minimal intervention, adjusting rules implementing laws and closing enforcement gaps	No intervention
News Coverage	Near 24/7 pervasive across media outlets for an extended period; includes deep dives and documentaries	Extensive coverage across many outlets of "big event, reminiscent of the last time" for shorter period; fewer "deep dives"	Brief coverage, likely the most significant of the month, perhaps the quarter, but not the year	Lead segment for a week or so
Cross-Jurisdictional Coordination	Major new agreements and initiatives from interagency and international public-sector organizations, including creation of entirely new bodies	New but targeted adjustments to interagency and international agreements and initiatives	Limited adjustment of existing interagency agreements and implementation	None
Private-Sector Adaptation	Reorganization of industries; birth of new subindustries; new risk management practices/structures	Introducing new and adapting existing products and services to better hedge newly salient risks	Updating of practices but generally business as usual. Reallocation of risks at the margin.	Business as usual
Legislative Interest	New and far-reaching legislation	Legislation to address deficiencies in or changes that came about in the aftermath of earlier legislation	Interest, but no new legislation. Outreach to public sector agencies to ensure that oversight and enforcement adapt	Little to no interest; perfunctory hearings

Source: Authors' analysis.

The remainder of this Appendix presents some examples of black, grey, and white swans, as

well as ducks, to show how the diagnostic tool classifies events. The discussion of black swans is more extensive, given the focus of this article. Most of the examples concern financial sector events because the focus of the article is on building financial system resilience to black swans, but examples from other sectors are included to show the broader applicability of the framework.

Black Swans

Based on the taxonomy of Section II, examples of black swans include the first occurrences of a financial crisis and pandemic. Even if someone contemplated them, these events would be entirely outside the range of human experience when they occurred, and their realization would reframe views of what is possible. The first financial crisis cannot be identified with certainty, but records trace financial crises to 33 A.D. (Thornton and Thornton 1990). By one account, the crisis of 33 A.D. marked an early use of quantitative easing (Taylor 2013). Likewise, the date of the first pandemic is unknown, but there were pandemics accompanied by quarantines and financial instability going back at least to the bubonic plague in the 6th century (Piret and Boivin 2021; Horgan 2014; Tyson 2004; Livius.org 2020).[15] Limited recordkeeping makes it hard to apply the diagnostic tool to episodes so far in the past, but these firsts or near-firsts appear to have had the news coverage, official-sector intervention, and public-sector adaptation needed to meet the criteria above for a black swan.

Once outside the realm of never-before-experienced events, distinguishing black swan events from others is more difficult. Arguably, the 2008-09 financial crisis was a black swan. There had been earlier financial crises, and some, like the Great Depression, were extremely severe. Nevertheless, the 2008-09 crisis forever altered understanding of how the financial system works and how to build system resilience (The Financial Crisis Inquiry Commission 2011). For example, it elevated interconnectedness among financial institutions and financial markets as a major vulnerability in the financial system. Although risks from interconnectedness existed earlier, financial innovation along with changes in market structure and technology had dramatically changed the number, complexity, and opaqueness of financial system linkages in ways that had not been realized (Haldane 2009). At the same time, although housing market corrections were a part of previous crises, the extent to which banks shifted mortgage risk off the balance sheet amplified the scale and scope of the housing correction beyond what had been previously imagined. Fraud in mortgage issuance contributed to a foreclosure crisis that magnified the macroeconomic effect of the dislocation that hit the financial sector (Piskorski et al. 2015). For these reasons, the 2008-09 financial crisis meets the definition of a black swan.

The criteria for a black swan in Figure A1 are also largely met. Federal Reserve and Treasury Department interventions are well documented. An entire Division of Financial Stability was created at the Board of Governors of the Federal Reserve System. The collapse of risky asset

[15] The first formal city-state quarantine to slow a pandemic appears to date to the second bubonic plague pandemic of 1347-1351, but government actions to limit the movement of possibly ill individuals date back at least to the early part of the first bubonic plague in 541-549, and self-isolation predates that (Horgan 2014; Livius.org 2020).

prices, housing bust, and sharp rise in unemployment were frequent topics on the nightly news for months. The Dodd-Frank Wall Street Reform and Consumer Protection Act (DFA) was enacted into law in 2010 (U.S. Congress 2010). DFA brought about a sweeping overhaul of the U.S. financial regulatory system to promote financial stability. Among the changes was the creation of the Financial Stability Oversight Council to monitor and mitigate risks to financial stability proactively. DFA also required that publicly traded bank holding companies above a certain size, as well as nonbank financial companies supervised by the Board of Governors, had to establish a risk committee responsible for enterprise risk management (U.S. Congress 2010, section 165). In addition, considerable private-sector adaptation occurred as a result of DFA because clearing organizations were designated as systemically important and subject to heightened oversight, and standardized derivatives contracts had to be centrally cleared (U.S. Congress 2010, Titles VII and VIII). At the international level, the Financial Stability Board was created in 2009 to monitor the global financial system and mitigate vulnerabilities (Financial Stability Board 2024).

Similarly, the COVID-19 pandemic was a black swan. There were earlier pandemics, and experts had long warned of the potential for a global pandemic. However, the COVID-19 pandemic dramatically altered understanding of the global speed of transmission and supply chain interdependencies. Business and economic modeling changed in response. The Coronavirus Aid, Relief, and Economic Security Act (CARES Act) became law within days of the dramatic reduction in economic activity that followed the implementation of social distancing measures (U.S. Congress 2020). The CARES Act included funding for the Treasury to provide emergency lending facilities created by the Board of Governors of the Federal Reserve System. Other stimulus packages followed. National health departments coordinated globally and with the World Health Organization (2022), albeit with limited success, while domestic and international travel was limited or altogether halted. News coverage was pervasive, with many media outlets publishing real-time case and death counts. Private-sector firms uprooted long-established norms by allowing employees to work from home and instituting new safeguards for both clients and employees. Medical breakthroughs through unique and global private-public partnerships resulted in vaccines being available in record time. The significance of these activities suggests that COVID-19 lands squarely within the black swan category.

In the same vein, the 9/11 attack on the World Trade Center (WTC) was a black swan. It transformed thinking about the terrorism threat on U.S. soil, as well as views of what constitutes critical infrastructure that must be protected (The 9/11 Commission 2004). This is true even though the event fulfilled a vision the planners had in waging the attacks. Within days of the attack, the Office of Homeland Security was established within the White House. One month later, the USA Patriot Act was passed to dramatically strengthen national security (U.S. Congress 2001). A year after that, the Homeland Security Act created the Department of Homeland Security (U.S. Congress 2002b). International travel was forever altered, as was the way in which U.S. intelligence agencies interact with one another and with their counterparts in other countries. The United States led a global war on terror, which included unprecedented coordination and information sharing across jurisdictions. Progress in that effort has continued to make headlines. Although the counterterrorism campaign aimed to dismantle the Taliban and al-Qaeda and included the ill-fated war in Iraq, the advances made

in global cooperation persist. The private sector adapted, too. Vulnerable targets, such as popular public attractions, sports arenas, and other forms of public transportation dramatically increased their security protocols. Subindustries arose that developed or applied the latest technology to create new security and surveillance tools.

The dropping of the atomic bomb in World War II was another black swan. It forever changed the face of war and approach to national security. It led to a nuclear arms race during which ever more powerful nuclear bombs became part of many countries' arsenals. Previously unknown risks of radiation were revealed. The bomb also led to efforts to reduce the risk: the International Atomic Energy Agency was created to promote the safe use of nuclear energy, and nuclear nonproliferation treaties were signed. Knowledge of radiation risk improved safety protocols in nuclear energy production. News coverage was worldwide.

Grey Swans

Examples of grey swans include the savings and loan (S&L) crisis in the 1980s, 1987 market crash, the collapse of LTCM, 2003 SARS pandemic, 1993 World Trade Center bombing, Chernobyl nuclear disaster, and the corporate governance crisis that brought the collapse of Enron and WorldCom.

When the S&L crisis occurred, the risk of bank runs and bank failures that result from imperfect coordination were well understood thanks to the experience of the Great Depression. Congress created the Federal Deposit Insurance Corporation (FDIC) in 1933 and the Federal Savings and Loan Insurance Corporation (FSLIC) in 1934 to provide deposit insurance. For more than 40 years, this seemed to prevent U.S. banking crises, suggesting the underlying model of runs on depository institutions was largely correct. A toxic mix of high inflation, high interest rates, caps on the interest rate paid on deposits, and S&Ls' focus on mortgage lending combined to create the worst financial crisis since the Great Depression in terms of the number of failed financial institutions. The FSLIC became insolvent in trying to resolve a large fraction of S&Ls that were themselves insolvent. While this event did not inspire the same level of response as the Great Depression, legislative reforms were substantial. Congress ultimately enacted the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 (U.S. Congress 1989), which merged the FSLIC into the FDIC and reshaped the S&L industry and its oversight. These reforms, however, unlike reforms in the Great Depression, largely preserved the rationale and foundations of financial regulation, and instead largely resolved failed institutions and reorganized the financial regulatory structure. News coverage of the event was substantial and protracted, but were commensurate with the severity of the crisis, which paled in comparison to the Great Depression (e.g., the unemployment rate peaked at 10.8 percent in the S&L crisis vs. 24.9 percent in the Great Depression). Nonetheless, the event highlighted a whole new and unappreciated set of financial system vulnerabilities that required a significant rethinking of the financial regulatory landscape.

The 1987 market crash and the failure of portfolio insurance (Rubenstein 1988) was a grey swan. The crash received considerable media attention and constituted the largest single-day stock market decline since World War II, signaling that existing views of what was

possible in stock markets were wholly incomplete. However, this was not a black swan because market crashes were not unprecedented, and public-sector interventions were relatively limited, as was cross-jurisdictional coordination.[16] Private-sector adaptation was significant, but business models and organizational structures were not entirely uprooted.

The 1998 collapse of LTCM also was a grey swan. LTCM was a large relative-value hedge fund that relied on a highly leveraged and quantitative strategy focused on foreign currencies and bonds. LTCM was already experiencing losses by mid-August 1998, when Russia devalued its currency and declared a moratorium on the repayment of its foreign debt. The ensuing flight to quality resulted in further increases in credit and liquidity spreads in global financial markets that were beyond the range of historical experience on which LTCM had relied on positioning its portfolio. LTCM's near-collapse brought to light that many banks and pension funds all had large investments in a single fund, exposures that had not previously been realized, as well as significant outstanding credit, which posed a risk to financial stability more broadly. The Federal Reserve Bank of New York organized a privately financed bailout of LTCM comprising credit forgiveness and an infusion of capital from many of LTCM's counterparties. If LTCM had been a bank, its failure likely would be a white swan. The creation of the Federal Reserve, deposit insurance, and real-time gross settlement had been introduced to mitigate the risk of such events. But LTCM was a nonbank financial institution (NBFI) that was interconnected with the banking system, and existing policy tools were not designed for such a case. LTCM brought a new awareness of the risks from NBFIs. Regulatory agencies introduced new reporting requirements for private investment vehicles, and banks and broker-dealers retooled their risk management practices around leveraged NBFI's. The GAO and Congressional Research Service commissioned post-mortem reports about LTCM's demise.

The SARS pandemic of 2002-2003 was caused by a strain of the severe acute respiratory syndrome coronavirus. A different strain would later cause the COVID-19 pandemic. Although the underlying viruses for the SARS and COVID-19 pandemics were genetically similar and both originated in China, the scale and scope of the pandemics were very different. This is largely attributed to their different transmission mechanisms (Wilder-Smith et al. 2020; Keshta et al. 2021; Liu et al. 2020; LeDuc and Barry 2004). SARS was most infections in its second week, whereas COVID-19 was most infections before or soon after symptoms appeared. Moreover, when COVID-19 appeared China was much more interconnected with the global economy and when international travel was much more common. For example, Statista (2025) reports 698 million international tourist arrivals in 2002 compared with almost 1,465 million in 2019. Consequently, within one year, COVID-19 had affected about 120 million people across almost all countries and killed more than 2 million, a 1.6% mortality rate. SARS lasted about nine months and is known to have infected about 8,000 people, primarily in Asia, of which fewer than 800 died. That amounts to a 10% mortality rate. Because SARS was most infections well after symptoms arose but had a higher mortality rate, it was eventually contained with what might be called targeted

[16] Financial market circuit breakers were first introduced after the 1987 crash.

interventions—the halting of human transmission by strictly isolating those with symptoms. COVID-19's faster and wider transmission made that degree of containment unrealistic. News coverage of SARS was initially quite extensive initially but died down in the United States once it became viewed as largely contained to Asia. Much adaptation in public health practices occurred during the SARS pandemic, and lessons from the event helped inform the response to the COVID-19 pandemic. Overall, although SARS was initially thought to be a black swan when it appeared, its small scale makes it a grey swan.

The 1993 World Trade Center bombing was a terrorist attack intended to topple the North Tower and have it fall onto and bring down the South Tower (Federal Bureau of Investigations 2022). A large bomb exploded in a van in the parking garage of the North Tower, creating a 100-foot-wide hole through four levels of the concrete garage. It killed six people that were in the garage at the time; more than a thousand people were injured. The location of the van within the garage relative to the north tower and the tower's construction are attributed to the blast failing to achieve its bigger, more deadly goal of destroying the towers. The limited scope of harm makes it a grey swan.

The 1986 Chernobyl nuclear disaster was a grey swan as well. Many risks associated with nuclear power plants had been identified and modeled. But the accident happened during a routine safety test that proved to be anything but routine (Budjeryn 2021). Operator error and design flaws increased the likelihood that the reactor would explode under the conditions obtained during the test. Today, about 35 years later, models of risks from nuclear power plants are still being adjusted based on lessons from Chernobyl. The event required swift international coordination and was the subject of heavy and prolonged news coverage. It also dramatically altered the appetite for nuclear power (World Nuclear Industry Status Report 2025). Each of these would be of sufficient consequence to put Chernobyl in the black swan category; however, relatively little new information was learned from the catastrophe. The consequences of radiation poisoning were well-established from Hiroshima and Nagasaki, although were less certain in the meltdown scenario of Chernobyl, and ultimately the main adaptation was additional fail-safes introduced into nuclear power plants around the world. Rather than a global catastrophe, the Chernobyl event was closer to a near miss. Ultimately, the model for nuclear safety was largely correct, and all that was needed was a more careful implementation of safety protocols.

A different type of implosion, the crisis in corporate governance and two largest U.S. bankruptcies at the time (Enron and WorldCom), was also a grey swan. Audited financial statements had long been required to mitigate the known risk of loss from lax corporate governance. Not understood was the degree to which deceptive and even fraudulent accounting practices could persist and have occurred with the involvement of Enron's auditor, Arthur Anderson. The Sarbanes-Oxley Act of 2002 (U.S. Congress 2002a), a significant legislative intervention, sought to close gaps in corporate governance that could occur under law. It created the Public Company Accounting Oversight Board to oversee the audits of public companies and SEC-registered brokers and dealers. Yet, the consequences were largely contained to those connected, directly or indirectly, to the firms involved in the governance scandal. No severe recession followed their failures, and no official-sector bailouts were provided. The model of large firm safety and soundness needed recalibration

but not a dramatic reinvention.

White Swans

Examples of white swans include the March 2020 Treasury market disruption, Asian financial crisis, 2009 H1N1 flu, localized and smaller-scale acts of terrorism, and Fukushima nuclear disaster.

During March 2020, global sovereign bond markets, including the market for U.S. Treasury securities, experienced severe disruptions. A large amount of sales from a variety of investors, including foreign official accounts, mutual funds, and hedge funds combined with limited dealer willingness to intermediate caused a dramatic spike in bid-ask spreads and stress in Treasury cash and repo markets. The significance of these disruptions led the Federal Reserve to intervene through large-scale purchases of Treasury securities, expanded repo facilities, and more. While this episode of Treasury market instability was worrisome, it was not entirely unfamiliar. Treasury markets experienced protracted stress during the 2008 financial crisis and the flash rally in 2014, and repo markets experienced turmoil in 2019. Significant selling via a "dash for cash," rather than in a "flight to safety," and limited dealer appetite to buy additional Treasuries may have been new, but the notion that safe government bond markets could face bouts of stress was not. Further, while the March 2020 turmoil inspired many post-mortems (e.g., Inter-Agency Working Group on Treasury Market Surveillance 2021; Group of Thirty 2021), the recommendations have so far been closer to fine-tuning than a wholesale rethinking of U.S. Treasury market structure.

The Asian financial crisis of 1997-1998 is also a white swan. It was preceded by the Latin American debt crisis of the 1980s, which had enveloped not just Latin America but also many other developing regions and took almost a decade to resolve. The Latin American debt crisis, on the other hand, was a grey swan.[17] There were earlier Latin American debt crises and other regional debt crisis, but the crisis of the 1980s led to a sufficient rethinking of the effects of common exposures to sovereign debt. With lessons from the Latin American crisis in mind, market participants, bank supervisors, and international organizations recognized the warning signs sooner and reacted faster. As a result, the Asian crisis was much narrower in breadth and shorter lived than the Latin American crisis.

In 2009, the World Health Organization declared the H1N1 flu to be a pandemic (Centers for Disease Control and Prevention 2019; Fineberg 2014.). Although a novel strain of the H1N1 virus was involved, H1N1 pandemics had occurred twice before. As a result, many people aged 60 and older had some immunity to the 2009 strain, while children were most susceptible. In the end, the number of deaths was comparable to the number observed in a typical flu season. Expecting a worse outcome, a major public health response was launched. Once it became known that the trajectory was more like that of a typical flu virus, the

[17] The Latin American debt crisis of the 1980s was not the first Latin American crisis or the first regional debt crisis. We do not evaluate them all to determine whether the Latin American crisis qualifies as a black swan, but it led to a sufficient rethinking of the effects of common exposures to sovereign debt to be a grey swan.

response to it became normalized as well, making it a white swan.

The 2011 Fukushima Daiichi nuclear disaster was the worst such disaster since Chernobyl in 1986 (Wikipedia 2025b; Budjeryn 2021). In dealing with Fukushima, recalibrated models and a response toolkit were used that had been designed to incorporate the lessons from the Chernobyl disaster. Of course, there were lessons learned and standards for construction and operations were altered. For example, nuclear power plants today have backup power systems that can operate longer in the event of a power outage. But the possibility of a nuclear meltdown, as well as its consequences, were well understood, and the consequences of the Fukushima event generally unfolded as expected.

Ducks

Examples of ducks include the collapse of Archegos Capital Management, a sovereign bond default by a serial defaulter, the seasonal flu, and non-disaster operational issues at nuclear power plants.

Archegos was a highly leveraged family office that held concentrated total return swap positions. Archegos had borrowed heavily from a number of large banks that were unaware of the credit that had collectively been extended. When Archegos failed to make margin calls, some of the banks offering prime brokerage services to Archegos started selling the stocks underlying the total return swaps, causing the stocks' prices to fall sharply and forcing more margin calls on Archegos. The banks that moved fastest to close their positions with Archegos suffered fewer losses than Archegos' other lenders, which lost an entire quarter's profit. Archegos is often compared with LTCM. Before Archegos' collapse, family offices had not been recognized as possibly being sufficiently large or leveraged to pose a risk to multiple large banks at once; however, aside from the management of outside capital, a family office is essentially a hedge fund. Archegos' failure caused only minimal disruptions and, because of its structure, had no effect on external investors. Affected stocks' prices recovered quickly, and standard risk management practices, if adhered to, would have limited Archegos' the buildup of Archegos' synthetic leverage and banks' losses.

Some countries are serial defaulters on their debt, and their defaults are ducks. Argentina is an example (Bartenstein et al. 2020). A default by the United States today could easily be a black swan: although a default has been contemplated at times, the market for U.S. debt is so massive that a default would be far outside the range of human experience and current models of the financial system. In contrast, a default by a serial defaulter is to be expected and is by now well understood (Faria et al. 2021). Markets price in the risk of default, and sovereign credit default swaps offer insurance against the event. Disruptions from a serial defaulter would be expected to be largely contained.

Flu season is another duck. It is expected to occur annually and even to be of the strain of virus observed in countries that experience the annual episode earlier in the year. Mitigating the event is business as usual. Flu shots are developed in anticipation, and the public is educated about the need to get the vaccine (Centers for Disease Control and Prevention 2024).

Routine operational incidents at nuclear power plant are also ducks. The Davis-Besse Nuclear Power Station in Oak Harbor, Ohio, for example, has had numerous incidents (Wikipedia 2025a). In the worst of them, severe corrosion forced the reactor to be shut down for two years while repairs were made. These kinds of events are briefly the lead segment in the local news and may result in after-action reports or regulatory investigations. Repairs are made to fix the cause of the incident. Bigger underlying problems may persist. Those are telltale indicators of a duck.