Towards Reliable Resilience Metrics in Corporate Settings: Content Validity Considerations

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Abstract

Background: Firm resilience is a critical concept for organisations aiming to navigate disruptions effectively, yet its translation into regularly applicable metrics remains underdeveloped. Thus, existing frameworks often lack systematic validation and fail to capture resilience's dynamic nature across various disruptions, hindering managers' confident implementation of resilience strategies. **Objectives:** This study aims to identify a content-valid and practical metric for measuring firm resilience, applicable across diverse firm contexts and disruptions. **Approach:** The research evaluates and compares existing metrics, based on their alignment with a newly proposed axiom system, to identify the most suitable measure for assessing firm resilience in post-disruption contexts. **Results:** The metric assessment revealed that the *Dominance* axiom posed the greatest challenge, with only two metrics fully satisfying the requirement. The semi-quantitative Likert scales encountered further issues with the *Operationalisation* axiom because of their unsettled interpretation as either ordinal or interval scales, a problem not observed with purely quantitative metrics. **Conclusions:** The BRAVE metric emerged as the most reliable for evaluating firm resilience, owing to its flexibility in accommodating varying time horizons. Future research should test the metric in real-world settings and explore potential simplifications or additional axioms to refine the resilience measurement framework.

Keywords: firm resilience, resilience metrics, content validity, measurement, dynamic capabilities

JEL classification: D21, L20, L21, L29, M10
Paper type: Research article
Received: Dec 14, 2024
Accepted: Sep 5, 2025

Acknowledgements: First, we would like to thank the two anonymous referees for their valuable comments, which helped to improve the paper. We also thank our colleague Marcus Pisch, M.Sc., for his helpful suggestions on the structure, logic and clarity of the manuscript. We further acknowledge the support of the German Research Foundation and the BTU Cottbus-Senftenberg. Finally, it should be noted that this paper extends a preliminary version presented at the ENTerprise REsearch InNOVAtion (ENTRENOVA) conference, held in Dubrovnik, Croatia, September 5–7, 2024, incorporating feedback from the event. The earlier version appeared in the conference proceedings (Schötz, 2024).

Citation: Schötz, E. (2026). Towards Reliable Resilience Metrics in Corporate Settings: Content Validity Considerations. *Business Systems Research, 17*(1), 57-76.
DOI: https://doi.org/10.2478/bsrj-2026-0004

Introduction

The concept of resilience is polarising, as it reflects an existential aspiration shared by individuals and organisations alike – the ability to withstand and adapt to adversity. However, translating the concept into organisational terms, particularly in the context of firm resilience, requires clear, practical guidelines to prevent it from being submerged in the sea of management jargon. To ensure that resilience retains its importance and is not diluted, it must be substantiated by clear, evidence-based metrics demonstrating its economic impact as a motivational driver (Lee et al., 2013). This is especially crucial for Small and Medium Enterprises (SMEs), which have to weather crises independently and do not benefit from the public attention and governmental support that sometimes shield larger companies. Consequently, an expanding body of literature focuses specifically on the resilience of SMEs (Kamalahmadi & Parast, 2016; Saad et al., 2021; Tolner et al., 2021).

The focus on SMEs inevitably highlights a key gap in the existing literature: the measurement of firm resilience remains underdeveloped. Empirical studies often adopt an event-oriented perspective, failing to deliver robust, generalizable metrics. There is considerable ambiguity about whether metrics tailored to specific disruptions can be applied broadly across diverse challenges (Linnenluecke, 2017; Korber & McNaughton, 2018; Saad et al., 2021). Moreover, while theoretical models of firm resilience exist or are being developed, many lack empirical substantiation. The literature increasingly emphasizes the need to test and validate these theoretical findings empirically, with growing calls for well-supported metrics (Annarelli & Nonino, 2016; Linnenluecke, 2017; Conz & Magnani, 2020; Hillmann, 2021) Yet, to the best of the author's knowledge, no previous work has provided a thorough formal set of requirements specifically suited for firm resilience; requirements that both define what resilience metrics must satisfy and that offer a systematic way to evaluate them.

These shortcomings complicate managers' confident implementation of firm resilience strategies. Although qualitative justification may provide partial guidance, for the most part, decision-makers require numerical insights to understand actionable steps and their potential consequences. This underscores the necessity of concrete, evidence-based measures that not only focus on short-term recovery but also capture the long-term, dynamic nature of resilience, particularly in rapidly evolving environments (Cardoso et al., 2015; Annarelli & Nonino, 2016; Hillmann, 2021; Reghezza-Zitt, 2021).

This research addresses the aforementioned gaps in the literature by identifying suitable metrics using guidelines that prioritise precision, reliability, and the capacity for verification (Jones et al., 2021). In particular, content validity has been recognised as a cornerstone for this endeavour and is therefore the focus of this research. While emphasising theoretical formalisation, the paper aims to facilitate the identification of metrics primed for empirical testing and practical application within firm resilience theory.

The vague conceptualisation of resilience results in metrics that, most of the time, attempt to fit an imprecisely defined construct. This leads to uncertainties about their applicability but should not result in imminent rejection (Wacker, 2004). To overcome this, interdisciplinary connections are explored, as resilience engineering already offers a range of performance-oriented measures. Currently, interdisciplinary research on resilience is lacking, leaving the whole idea fragmented across different fields (Rose, 2009; Linnenluecke, 2017; Fraccascia et al., 2018). Hence, this study aims to open the view for cross-disciplinary connections on resilience.

During the investigation into whether metrics exist that can bridge existing gaps while addressing their applicability, this research also examines whether the popular semi-quantitative approaches, such as those used in event studies, truly fit within the firm resilience context.

Following Wacker (2004), a theoretical framework is necessary before even considering measurement to avoid misunderstandings or inconsistencies. Only by building on this foundation can we develop an axiomatic framework that translates conceptual resilience requirements into concrete evaluation criteria.

Therefore, the paper begins by providing a thorough definition of firm resilience, grounded in recent literature, and situates it within a contemporary framework by Conz & Magnani (2020). Subsequently, the paper outlines the methodology for assessing the content validity of firm resilience metrics, presenting both semi-quantitative approaches (specifically Likert scales) and four quantitative metrics as key subjects of interest. An axiomatization of firm resilience follows, addressing its distinctive features and its interplay with market-economy dynamics. In doing so, we not only map the theoretical landscape but also deliver an operational tool – via the axiomatic approach – that practitioners and researchers can use to benchmark resilience metrics. This possible application is demonstrated when the research proceeds with a discussion of selected metrics based on their resulting content validity. The paper culminates in a recommendation for a viable metric, practical implications, and directions for future research.

Background

It is important to note that many reviews point out that the concept of resilience remains insufficiently defined at the corporate level. In addition to the lack of standardised definitions and clear distinctions from related concepts, there is a significant absence of widely accepted measures and indicators (Annarelli & Nonino, 2016; Linnenluecke, 2017; Hillmann, 2021; Portuguez Castro & Gómez Zermeño, 2021; Saad et al., 2021). Korber & McNaughton (2018) further criticise that, in the context of entrepreneurship, resilience is often used synonymously with terms such as survival, success, endurance, or optimism. As a result, this does not lead to new insights or ideas.

Nonetheless, the growing importance of resilience is frequently underscored by the multitude of challenges businesses face, driven by micro- and macroeconomic factors and human errors. Many authors indicate that such events are increasing in frequency and intensity (Annarelli & Nonino, 2016; Linnenluecke, 2017; Gligor et al., 2019; Saad et al., 2021). Saad et al. (2021) observe that businesses regularly face multiple disruptions – events or disturbances with destructive effects. These disruptions are characterised by their capacity to destabilise a company's equilibrium or even threaten its foundations (Conz & Magnani, 2020). Sheffi & Rice (2005) provide a structured view by classifying disruptions into random events, accidents, and intentional disturbances. Expanding on this, Sanchis & Poler (2019) identify eleven core sources: corporate finance, customer relations, energy supply, inventory, employee relations, environment, legislation, production, sales, supply chain and technology. Thus, rather than being anomalies, disruptions are an integral part of the business environment, serving as a litmus test for the significance and strength of firm resilience as a vital capability.

Firm resilience, unlike engineering resilience, does not primarily aim to reduce property damage but rather to mitigate the impact of disruptions on production, sales, and other business processes (Dormady et al., 2022). Building on this practical focus, a strong strand in the literature views resilience as an ex-ante state of preparedness that enables organisations to navigate crises effectively (Korber & McNaughton, 2018). This aligns with Annarelli & Nonino 's (2016) description of resilience as an organisation's ability to proactively address disruptions. Schäffer (2020) concisely characterises corporate resilience as the capacity to respond to new challenges and sudden disruptions while adapting accordingly. Portuguez Castro & Gómez Zermeño (2021) emphasise the transformative aspect, highlighting learning, innovation, and reorganisation as key elements while aiming to sustain operational continuity, employment, and income levels. Thematic analyses by Gligor et al. (2019) reveal that resilience encompasses anticipating, avoiding, resisting, recovering from, and adapting to disruptions, as well as accelerating operations. Hillmann (2021) attributes variations in understanding to distinct research perspectives, including ecological, safety, engineering, and management views, each framing resilience through its own lens.

Resilience appears not as a static attribute but a dynamic, evolving quality. Conz & Magnani (2020) argue that firm resilience manifests across all stages of disruptive events – before, during, and after. Saad et al. (2021) expand on this, asserting that resilience is cultivated over time, rather than possessed by a company. Unlike an immutable intrinsic trait, inherent resilience is flexible and adaptive to changing conditions. Rose (2004) introduced a valuable distinction between static and dynamic components of resilience. This differentiation is particularly insightful when considering short- and long-term corporate planning (Rose, 2009). In the very short term, nearly all input factors are fixed. Static resilience reflects a company's ability to manage its scarce resources during a disruption. In the long term, however, all input factors become variable. Dynamic resilience captures the allocation of resources to overcome crises and reverse negative trends, potentially reaching new performance levels.

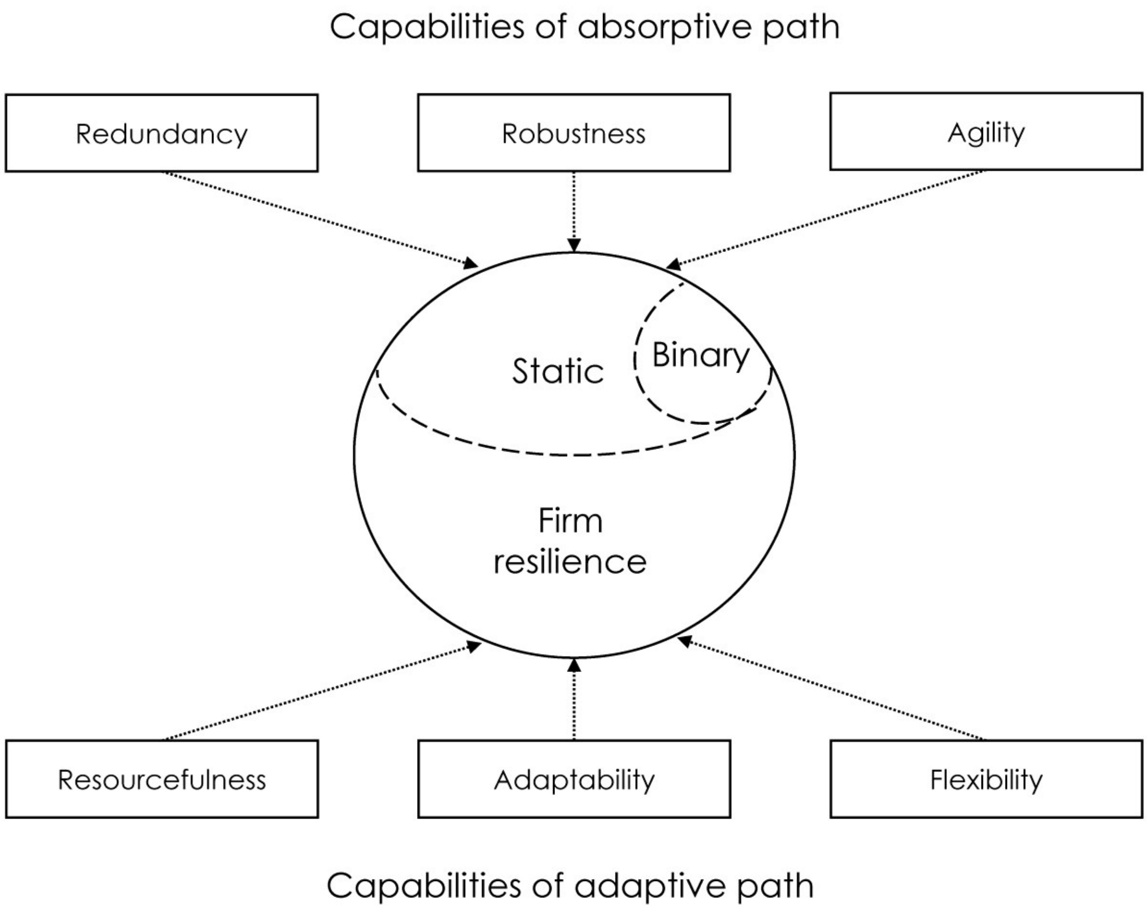
Building on these insights, we derive the following definition of firm resilience for this work:

- **Definition:** *Firm resilience represents an inherent but developable and dynamic attribute of a company, enabling it to sustain business continuity and vitality in an environment characterised by frequent disruptions. Firm resilience is considered static when it reduces the likelihood and impacts of threats. It is regarded as dynamic when it first accelerates the pace of economic recovery to the baseline level and secondly raises the firm's performance to an even higher level.*

Additionally, Conz & Magnani (2020) theorise that firm resilience consists of three phases: a proactive, ex-ante phase before a disruption; an absorbing and/or adaptive phase during the event; and a reactive, ex-post phase afterwards. Disruptions can be managed through two distinct pathways, with different capabilities playing a role in each phase. Redundancy, robustness, and agility aid in the absorptive pathway, while resourcefulness, adaptability, and flexibility characterise the adaptive pathway. Similarly, Saad et al. (2021) classify resilience capabilities as operational and dynamic, while Iftikhar et al. (2021) categorise them into operational and functional types. This dynamic framework by Conz & Magnani (2020) does not prescribe a specific interaction among individual capabilities or mandate their simultaneous presence. In contrast, Iftikhar et al. (2021) argue that prior definitions of resilience have often regarded the elements of both pathways as equally necessary and temporally aligned. Figure 1 illustrates the framework, linking both static and dynamic perspectives of firm resilience as previously defined. While firm resilience involves a static foundation, it ultimately transitions into a dynamic construct. Figure 1 acknowledges the multidimensionality of resilience as a portfolio of attributes and capabilities (Korber & McNaughton, 2018; Hillmann, 2021; Saad et al., 2021).

The absorptive pathway can be understood as a resilience reservoir, mitigating disruptive events through resources such as capital, assets, location, strategies, organisational intelligence, and products or services. This view closely aligns with the resource-based view (RBV), which explains the successes and behaviour patterns of companies in terms of heterogeneous resources and capabilities (Esteve-Pérez & Mañez-Castillejo, 2008; Costello, 2018). The RBV is frequently cited in resilience research as an important theoretical basis (Linnenluecke, 2017; Hillmann, 2021; Iftikhar et al., 2021). Financial factors play a crucial role by enabling firms to draw on resources during disruptions. Robust firms are particularly adept at maintaining legitimacy, diversification, and overcoming financial challenges during crises (Iftikhar et al., 2021; Portuguez Castro & Gómez Zermeño, 2021; Saad et al., 2021).

Figure 1
A Model Representation of Firm Resilience



Source: Author's illustration based on Conz & Magnani, 2020.

The adaptive pathway emphasises innovation capabilities and the effectiveness with which firms manage disruptive events, including the pace of recovery. Adaptability, as a dynamic capability, spans from business model realignment to complete transformation (Korber & McNaughton, 2018; Portuguez Castro & Gómez Zermeño, 2021; Saad et al., 2021). Another dynamic resilience capability identified by Saad et al. (2021) is the ability to capitalise on business opportunities, typically facilitated by flexibility. Flexibility allows firms to proactively adjust to crises and rapidly change configurations, differentiating them from the resource accumulation emphasised in the absorptive pathway despite its ties to the RBV (Iftikhar et al., 2021).

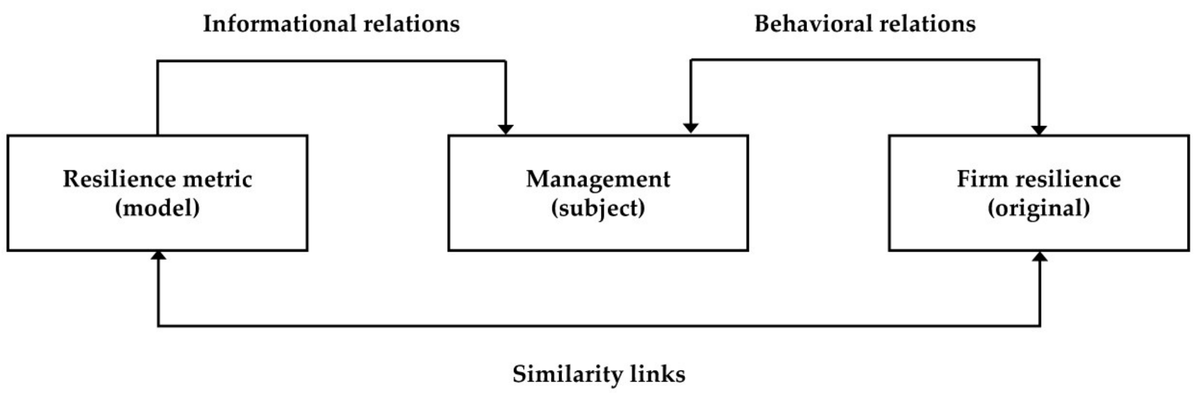
Figure 1 illustrates that absorptive resilience, grounded primarily in static principles, may be examined through binary manifestations that focus on mere survival. However, a more comprehensive metric is needed to assess adaptive resilience, especially its post-disruption dynamics, which include thriving and achieving new performance levels. Additionally, such an approach corresponds with the question raised by Linnenluecke (2017), highlighting that metrics should also address how to handle firms that do not experience recognisable downturns due to disruptions. This leads directly to the methodological search for firm resilience metrics in the following sections.

Research approach

This paper addresses current shortcomings in the study of firm resilience by bridging the gap between theory and the empirical application of appropriate metrics – thereby strengthening academic rigour of the field (Diamantopoulos, 2005; Shepherd & Suddaby, 2017).

First, a theoretical foundation is critical for evaluating the content validity of fitting instruments, in this case, various resilience measures. To this end, six axioms are proposed, based on the literature review and established principles from business economics, which a metric for firm resilience must meet. Figure 2 highlights how these axioms represent the necessary similarity links between the theoretical construct and the metrics, embedding them within the context of managerial interactions.

Figure 2
Relation between Model, Subject and Original regarding Firm Resilience



Source: Author's illustration based on Meyer, 2008.

Second, content validity is pivotal in ensuring that the axiomatic logic aligns with the metrics under examination. As Rossiter (2002, 2008) emphasises, content validity is crucial to the practical utility of any measure and is effectively synonymous with construct validity. While other forms of validity – such as convergent and discriminant validity – are valuable, their reliance on other constructs renders them secondary under this premise. This research, however, acknowledges the broader perspective of Lienert & Raatz (1998), asserting that multiple validity perspectives are essential for the overall justification of a measure's utility. While content validity is only one aspect, its significance as a cornerstone of robust metric design is underscored here.

For this purpose, the axiomatization was applied across a wide range of resilience metrics drawn from different strands of the literature (for classifications of measures, see Hosseini et al., 2016; Ruiz-Martín et al., 2018). The approaches selected had to be sufficiently generic to accommodate the context of firm resilience. Compliance with every axiom was checked logically and, in the case of quantitative measures, mathematically. The results have been condensed to the following metrics.

In the literature, semi-quantitative approaches to resilience are widely used (Ruiz-Martín et al., 2018). They typically rely on a series of questions that assign scores to specific indicators. By aggregating these scores, an overall resilience assessment for the analysed object is generated. This aligns with a more static perspective on resilience. A popular method in this context is the Likert scale. Selected indicators are first formulated into statements, known as items, and paired with a consistent set of response options that express varying degrees of agreement or disagreement. It is advantageous to avoid statements that inherently contain moderation or extreme positions (DeVellis, 2009). A well-known example, designed by Lee et al. (2013) to measure organisational resilience, includes 53 items, each rated on a 4-point Likert scale. These items form thirteen indicators grouped into the categories of adaptive and planning capacities. This framework was condensed by Whitman et al. (2013) into a shorter version with thirteen items, which delivered comparable results.

The quantitative metrics begin with the pioneering work of Bruneau et al. (2003), who introduced the renowned resilience triangle, which sparked the development of various resilience measures. A derived version of their metric, hereafter named BRAVE (Bruneau et al. + average), which incorporates approaches from Proag (2014) and Nan & Sansavini (2017), is included as a subject of interest. Furthermore, the assessment logic has been adjusted such that values approaching 1 now signify higher resilience, in contrast to the original formulation, where lower values were indicative of greater resilience (following, at any time t, $P(t)$ marks the performance and $R(t)$ the assessed resilience, t_o marks the time stamp for the initial performance level, t_s refers to the time stamp at which resilience is currently evaluated):

$$R(t_s) = 1 - \frac{\int_{t_0}^{t_s}[P(t_0) - P(t)]dt}{P(t_0) \cdot (t_s - t_0)} = \frac{\int_{t_0}^{t_s} P(t)\, dt}{P(t_0) \cdot (t_s - t_0)} \quad (1)$$

Moving forward, Henry & Ramirez-Marquez (2012) introduced a measure that relates the recovery of a system to the maximum performance loss caused by a disruptive event (t_d marks the time stamp for the lowest performance level achieved):

$$R(t_s) = \frac{P(t_s) - P(t_d)}{P(t_0) - P(t_d)} \quad (2)$$

The next subject is a metric, adapted from Cheng et al. (2022), that cumulatively accounts for performance variation. A resilient system should thus be characterised by gradual performance degradation, prompt recovery, and overall high performance. Their rather technical formulation involves normalisation of performance and time, the latter tailored for a granular assessment. Consequently, a simplified, modified version is used here, still encompassing the three core points mentioned (t_m marks the time stamp for the measurement point, T is the time horizon observed):

$$R(t_m) = 1 + \frac{\sum_{j=0}^{m-1} P(t_{j+1}) - P(t_j)}{P(t_0) \cdot (t_{j+1} - t_j)} \quad (3)$$

$$\bar{R}(t_s) = \frac{\sum_{t_i=t_0}^{t_s} R(t_i))}{|\{t_0, \dots, t_s\} \subseteq T|} \quad (4)$$

The underlying idea is that the resilience values at each measurement point, as calculated by Equation 3, initially represent only a snapshot. An assessment of firm resilience can be made only by combining multiple observations into a cross-sectional view, as in Equation 4.

Finally, Zobel & Khansa (2014) propose a piecemeal approach. Manifestations of the segmented performance trajectory thus form a set of resilience triangles whose overlap leads to resilience assessment ($\bar{X}$ is the average performance lost, T^* denotes the maximum allowed recovery time):

$$R(t_s) = 1 - \frac{\bar{X} \cdot t_s}{T^*} \quad , \qquad \bar{X} \le 1, \qquad t_s \in [0, T^*] \qquad (5)$$

The equation spans indifference curves representing combinations of $\bar{X}$ and T^* with the same resilience assessment. Absorptive and adaptive resilience are thus equally represented here. However, T^* influences the nature of the indifference curves and has to be suitably chosen.

Results for the measures are discussed below, and implications for the content validity of the axiomatization are derived. Further steps for verifying the theoretical framework's connectivity are suggested in the practical implications section.

Axioms of firm resilience measurement

We developed the following axioms to establish a consistent and theoretically grounded framework for assessing firm resilience metrics. While inspired by elements from existing literature, the formalisation and structure of these axioms are original contributions.

Axiom 1 (Comprehensibility): A resilience metric R is called comprehensible if it is

- (a) *visualizable,*
- (b) *non-negative ($R \geq 0$) for non-negative performance trajectories,*
- (c) *uniquely interpretable, and*
- (d) *up-to-date.*

First, Axiom 1 addresses the idea that transfer into business practice should be a driving force from the outset. The metric must achieve high internal acceptance, with a low cognitive barrier as a primary requirement. A concerned decision-maker must be able to grasp and meaningfully process the information without significantly impairing their scarce time and attention resources (Dalziell & McManus, 2004; Gladen, 2014). Accordingly, economic foundational knowledge, including mathematical and statistical basics, should serve as the cornerstone for assessing comprehensibility. Visual perception can be helpful; thus, the measure should be visualizable. Furthermore, it is advisable to integrate a fixed point, symbolising the absence of resilience. This helps exclude constructs that allow negative value ranges. Characterising nominally negative resilience contradicts the existing theoretical framework and may confuse executives if resilience can be less than absent. This necessitates ensuring that a company's performance is measured in non-negative terms or appropriately normalised before calculation. Moreover, to avoid potential sources of error, interpretation ambiguity is excluded. Finally, by requiring timeliness, the axiom addresses the issue of outdated results arising from a long delay between the end of the analysis period and the time of evaluation (Gleich, 2021).

Axiom 2 (Weak comparison): Let R be a resilience metric $D \neq \emptyset$ the set of possible disruptions, and $\{i,j\}$ two companies such that $P_i(t_0) \leq P_j(t_0)$. If $d \in D$ occurs at t_0 Then it must hold:

$$\frac{P_i(t)}{P_i(t_0)} = \frac{P_j(t)}{P_j(t_0)} \quad \forall\, t \in (t_0, t_s] \quad \Rightarrow \quad R_i(t_s) = R_j(t_s)$$

For validity and factual logic, the assessment of firm resilience should yield the same result after a disruption with an identical crisis trajectory. While it may seem practically implausible to be identical in every respect, this criterion is strongly inspired by the resilience of technical systems, where functionality is the focus. Equilibrium states are clearly defined, which are also identically attainable (e.g. D'Lima & Medda, 2015; Yarveisy et al., 2020).

Furthermore, to avoid disadvantaging companies based on their performance, it is advisable to use relative measurement. This also opens the possibility to compare firms with a reference group (Ilseven & Puranam, 2021). This is achieved in Axiom 2 by normalising the performance trajectory through division by the initial value $P(t_0)$. This removes scale effects and ensures that resilience ratings reflect the shape of the crisis trajectory rather than its absolute magnitude.

Axiom 3 (Dominance): Let R be a resilience metric $D \neq \emptyset$ the set of possible disruptions, and $\{i,j\}$ two companies and $T = \{t_0, \dots, t_s\}$ describes the time. R is called dominance-maintaining if $d \in D$ occurs at t_0 and at t_s It always satisfies:

$$\left.\begin{array}{l} \dfrac{P_i(t_k)}{P_i(t_0)} \geq \dfrac{P_j(t_k)}{P_j(t_0)} \quad \forall\, t_k \in T \\[2ex] \dfrac{P_i(t_m)}{P_i(t_0)} > \dfrac{P_j(t_m)}{P_j(t_0)} \quad for\ at\ least\ one\ t_m \in \mathrm{T}, t_m \neq t_s \end{array}\right. \quad \Rightarrow \quad R_i(t_s) > R_j(t_s)$$

Najarian & Lim (2019) argue that resilience measures should not entail an imbalance in assessing capabilities. This primarily concerns the treatment of static and dynamic components of resilience, both of which should be covered by the measure. However, a precise implementation of this requirement may almost entirely drop the historical perspective. This leads to cases in which absorptive or adaptive skills are either undervalued or completely ignored. Accordingly, Cheng et al. (2022) highlight the demanded behaviour as a weakness, while Munoz et al. (2022) advocate a strict division into two concepts for greater meaningfulness, narrowing resilience to recovery capability.

However, as the literature pointed out, resilience was characterised by multiple phases; the strength of the shock must also be considered. Henry & Ramirez-Marquez (2012) emphasise the fundamental issue arising from the mixing of absorptive and adaptive elements of resilience. The difficulty lies in interpreting a single measure that combines both components. While a satisfying solution for the problem remains to be found, it appears clear that resilience measures lacking historical context cannot adequately address this concern. By ensuring in Axiom 3 that a consistently dominant performance trajectory leads to a higher resilience rating, such measures can be excluded from use in firm resilience assessment.

Axiom 4 (Gratitude): Let R be a resilience metric $D \neq \emptyset$ the set of possible disruptions, and $\{i, j\}$ two companies such that $P_i(t_0) = P_j(t_0)$ and $T = \{t_0, \dots, t_s\}$ describes the time. R is called grateful if $d \in D$ occurs at t_0 and at t_s It always satisfies:

$$\left.\begin{array}{l} \frac{P_i(t_k)}{P_i(t_0)} \geq \frac{P_j(t_k)}{P_j(t_0)} \quad \forall\, t_k \in T \\[2ex] \frac{P_i(t_s)}{P_i(t_0)} > \frac{P_j(t_s)}{P_j(t_0)} = 1 \end{array}\right. \Rightarrow \quad R_i(t_s) > R_j(t_s)$$

As Axiom 3 may be interpreted as ensuring the significance of absorptive capabilities, it is evidently necessary to also address the adaptive component. While technical systems are frequently limited to returning to the initial level, the performance of market actors is rarely so constrained. Hence, the dynamic nature of firm resilience ensures practical proximity. If a company capitalises on the minimal effects of a disruption and surpasses its initial level compared to another firm in a similar scenario, a higher resilience rating is desirable. Axiom 4 directly translates this into a formal requirement.

Axiom 5 (Operationalizability): Firm resilience is operationalised through a resilience measure R, if R is at least interval-scaled.

In line with measurement theory, Asheim et al. (2020) argue that a resilience order is a necessary condition for the measurability of resilience. However, this alone does not give it numerical, quantitative significance, but merely enables the formation of sequences. For practical significance, higher levels of measurement are required. Here, the previous definition of firm resilience as an inherent but adaptable quantity comes into play – it must be changeable through activities within the company. In this way, it can be utilised as a comparative measure, whether in operational or temporal comparison (Gladen, 2014). While there is an extensive strand of qualitative research proposing how a company should position itself before, during, and after a disruption to increase its resilience, there is a lack of predominantly comprehensive validation (Reghezza-Zitt, 2021). For this purpose, baseline and additional measurement points for the resilience measure are required. Only then can the desired integration of theory with empirical analysis succeed. Overall, this corresponds to nothing other than the motivation for cardinal measurement (Pfanzagl, 1971; Hand, 1996), enforcing the need in Axiom 5 for interval-scaled metrics.

Axiom 6 (Multimodality): Let R be a resilience metric $D \neq \emptyset$ the set of possible disruptions, i resembles any company, and $T = \{t_0, \dots, t_{n-1}, t_n, t_{n+1}, \dots, t_s\}$ describes the time. If $d \in D$ occurs at t_0 and $\exists\, t_n \in T$ such that $P_i(t_n) > P_i(t_{n-1})$ and $P_i(t_n) > P_i(t_{n+1})$. Then R is called multimodal if $\forall\, t_k \in T, t_k > t_n \Rightarrow R_i(t_k)$ is defined.

Finally, the question arises: when is a company actually in shallow waters? In technical systems, such states can often be clearly defined and serve as the starting point for considering the disruptive event. However, Cheng et al. (2022) note that performance curves can exhibit fluctuations. In some cases, there may even be points where such a curve is not differentiable. On the other hand, the business of a market economy company is generally subject to fluctuations, which are reflected in various performance metrics. An appropriate resilience measure should be able to handle this and work in all situations, which is encapsulated in the *Multimodality* Axiom.

The six established axioms form the basis for evaluating various resilience measures in the following section. In doing so, the authors' names are occasionally used synonymously with their corresponding metrics.

Results

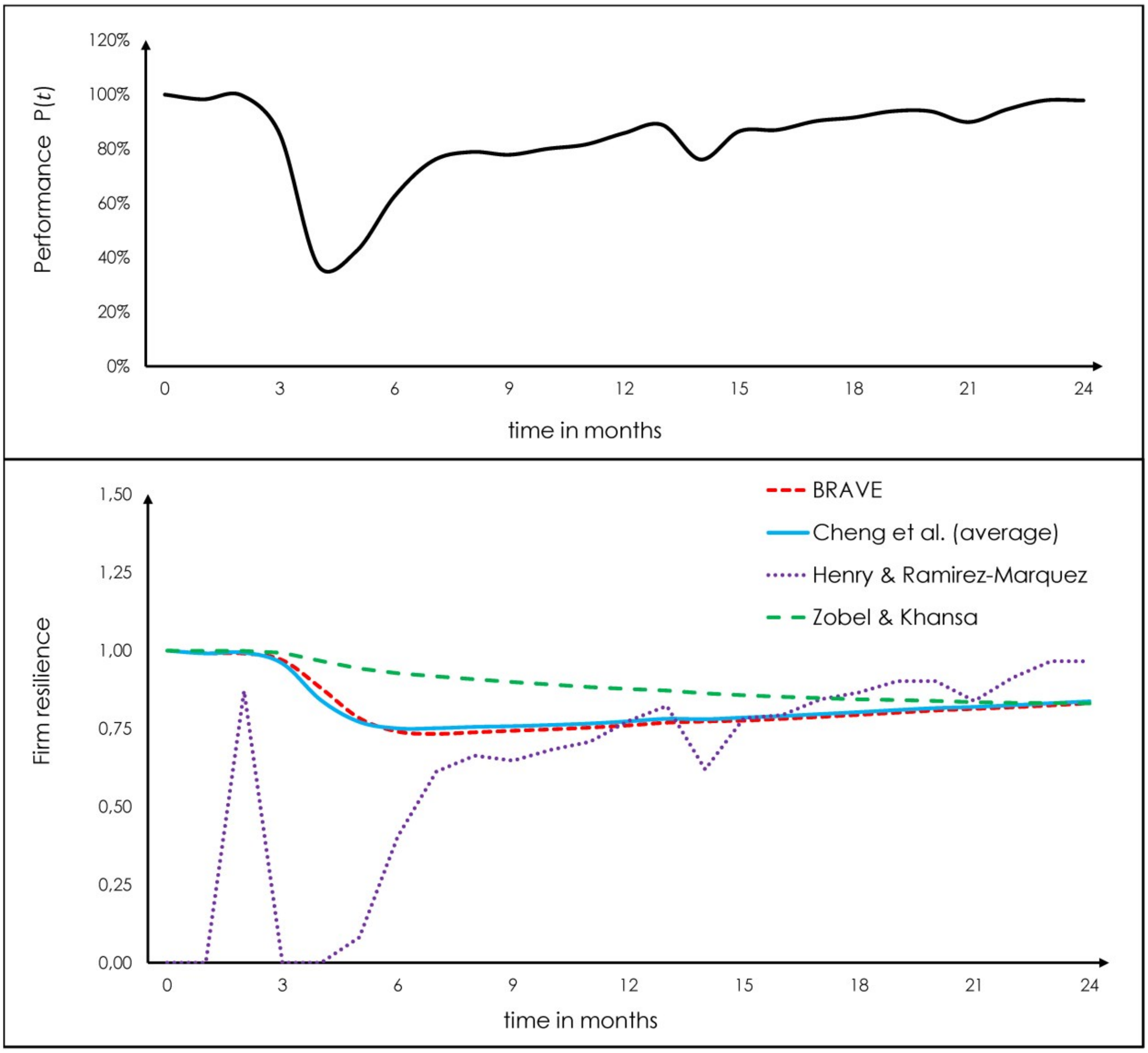
Comprehensibility is based on several sub-criteria, with timeliness and visualizability proving to be the weakest and being met by all tested metrics. Regarding the latter, Figure 3 illustrates both the underlying performance curve and the resulting resilience values derived from it using the respective metric formulas (Equations 1-5). The used performance data stem from the U.S. Federal Reserve's Industrial Production Index (Macrotrends, 2024), which captures real output in the U.S. manufacturing, mining and utilities sectors. To facilitate comparison and interpretation, the exemplary two-year data were normalised: the performance curve was rescaled to start at 100%, with all subsequent values expressed relative to this baseline. The chosen period – from December 2019 to December 2021 – includes the disruptive effects of the COVID-19 crisis. As such, the performance curve reflects a typical dynamic of shock and recovery often used in resilience studies (Erol et al., 2010; Klimek et al., 2019). The resulting resilience curves thus visualise how each metric captures that disruption and the subsequent developments.

Although this example does not reflect the behaviour of individual firms, which are the actual target of this work, it serves as a stylised and illustrative case for comparing the behaviour of resilience metrics under real-world economic shock conditions. Notably, while some resilience loss occurs, the metrics settle at a moderately lower level and then appear to stabilise. This is partly due to the rapid recovery and the absence of prolonged downturns, resulting in an overall relatively stable trajectory across the second half of the observed period. In this sense, the results indicate that the industrial sector demonstrates a degree of resilience – at least as viewed through the depicted metrics.

The example shown yields no negative values, whereas the average of Cheng et al. (2022) can yield negative values, thereby violating non-negativity. On the other hand, Likert scales yield non-negative values, even without normalising the performance curve. Furthermore, the uniqueness of the zero point poses a problem when the evaluation by the metric depends directly on a fixed point of the chosen period. Hence, applying Henry & Ramirez-Marquez continuously results in a drop to zero whenever a new performance low is reached. This continuous resetting can distort the resilience profile by masking actual recovery progress and resilience capacity. As a result, firms experiencing volatile performance with multiple declines may be systematically undervalued for their resilience, limiting the metric's ability to differentiate among recovery trajectories over time.

All quantitative measures meet the second axiom of *Weak comparison* since they rely on relative relations. Meanwhile, using a Likert scale may suggest that two companies appear to follow parallel crisis trajectories on paper, while subjective perceptions differ, leading to differences in resilience ratings. Similarly, Likert scales would violate the principles of *Dominance* and *Gratitude*. These violations, taken together, complicate comparability across firms, as subjective assessments may not align with objective performance data. Consequently, decisions based solely on Likert-scale evaluations risk bias, especially in crisis management contexts.

Figure 3
Exemplary Performance Curve for Industrial Production and Corresponding Values of Quantitative Resilience Metrics. Source data before normalisation: mean 97.42, SD 4.29.



Source: Author's work

The demand for *Dominance* proves to be the strongest obstacle overall. The measure by Henry & Ramirez-Marquez (2012) considers only a portion of the past time period, which can lead to distortions. On one hand, the average of Cheng et al. (2022) can potentially omit the history of the performance trajectory using equidistant times. On the other hand, even after excluding these cases, it cannot be universally demonstrated that the requirement is met. Zobel & Khansa and BRAVE can meet the criterion. The foundation for compliance is the resilience triangles, which are not newly formed but overlap. As a result, a consistently poorer performance curve can never surpass a better one.

Table 1
Properties of the Metrics (☑ = criterion met, ☒ = criterion not met)

Metric / Axiom	Likert Scale	BRAVE	Cheng et al. (2022) (average)	Henry & Ramirez-Marquez (2012)	Zobel & Khansa (2014)
1. Comprehen-sibility	☑ (for all performance trajectories)	☑	☒ (non-negativity)	☒ (interpretation of zero)	☑
2. Weak comparison	☒	☑	☑	☑	☑
3. Dominance	☒	☑	☒	☒	☑
4. Gratitude	☒	☑	☑ (for equi-distant times)	☑	☑
5. Operational-izability	☒	☑	☑	☑	☑
6. Multimodality	☑	☑	☑	☒ (until $t_k \in T$: $P_i(t_0) > P_i(t_k)$)	☑

Note: Proofs available from the author upon request

Gratitude is implied if the previous axiom is met and therefore potentially expendable. The relevance of the requirement stems from its conformity with non-dominance-maintaining measures, basically showing that measures can inherit the dynamic character of resilience whilst disregarding absorptive capabilities. This reflects a focus on advantages present only within the selected measurement period, potentially overlooking vulnerabilities or strengths outside this timeframe.

Operationalizability is present in the quantitative metrics, as they all induce interval scales. However, using a binary variable for resilience assessment based on company survival would not meet the requirement. This essentially corresponds to a nominal scale with two equivalence classes, although under special circumstances, it can be interpreted as an ordinal scale. In the Likert scale, each item is initially ordinal. However, by assuming equal intervals between the options of the items, it is sometimes used as an interval scale. Some scholars clearly reject this approach, citing the larger, more difficult-to-overcome distance to the extreme options and the potential for nonsensical interpretations of mean values (Jamieson, 2004; Bishop & Herron, 2015). On the other hand, it is argued that this issue applies only to the individual items, while their aggregation, which constitutes the actual Likert scale, can be regarded as interval-scaled (Norman, 2010; Bishop & Herron, 2015). Norman (2010) also demonstrates that Likert scales behave robustly when converted into another point-Likert scale. Nevertheless, Bishop & Herron (2015) caution that alternative methods should be explored before using a Likert scale to avoid the risk of obtaining non-interval data. As a result, the axiom is conservatively considered as not being fully met.

The final axiom primarily serves as a safeguard to ensure that resilience metrics adequately capture performance trajectories that are neither solely monotonic nor purely technical in origin. It requires that if a firm's performance temporarily improves after a disruption, thus creating a local peak, the metric must continue to provide meaningful resilience values for all subsequent times. This axiom reflects real-world scenarios where companies often experience ups and downs during recovery rather than a steady return to normal. The metric of Henry & Ramirez-Marquez (2012) fails to satisfy this axiom due to initialisation issues, thereby limiting its ability to accurately capture these complex, multi-phase recovery patterns. Therefore, it is less suitable for measuring resilience when performance shows such variability after disruption.

Figure 3 shows that the resilience trends of BRAVE and the average of Cheng et al. (2022) closely resemble each other, both generally showing lower resilience ratings than those of Zobel & Khansa (2014). The latter's emphasis on past performance yields a smoother trend, while the former two metrics are more sensitive to rapid, significant fluctuations. In contrast, the metric developed by Henry and Ramirez-Marquez (2012) takes time to stabilise, but once it does, it appears to align with the trend of the performance curve.

Determining the maximum recovery duration T^* proves challenging for Zobel & Khansa (2014), especially when no fixed time is provided, as in the example. The other metrics offer greater flexibility and can accommodate uncertain time horizons, allowing for more dynamic assessments of resilience.

A summary of the results is shown in Table 1, exhibiting BRAVE and Zobel & Khansa (2014) as the candidates compatible with all of the proposed axioms.

Practical implications

Resilience metrics, as discussed here, could be incorporated into strategic performance measurement systems. Since many consulting firms have so far focused primarily on static aspects of resilience (Korber & McNaughton, 2018), a broader application of these metrics may help ensure that future consulting practices reflect a more balanced perspective by systematically accounting for dynamic resilience factors.

A detailed cost-benefit analysis of establishing such metrics within companies was beyond the scope of this study. However, the practical utility remains evident, as addressing the *Comprehensibility* axiom deliberately limited complexity, supporting real-world application. Careful observation of how firm resilience metrics are affected by management control processes and firm behaviour is essential. Such tracking could reveal competitive advantages by reliably linking actions and processes to resilience outcomes.

Essentially, the reliability of the BRAVE metric as a component of firm resilience theory can be established only through its application to real-world data. As depicted in Figure 1, the multidimensional nature of resilience demands further empirical validation to confirm and explore the relationships between resilience attributes and phases. This need aligns with the increasing focus in the literature on testing and validating both existing and future theoretical concepts of firm resilience (Annarelli & Nonino, 2016; Linnenluecke, 2017; Conz & Magnani, 2020; Hillmann, 2021; Saad et al., 2021). Thus, future studies could employ firm-level panel data to examine how specific resilience capabilities (e.g., redundancy or adaptability) influence BRAVE values over time and whether these relationships align with theoretical expectations or yield new insights. In addition, researchers may explore how BRAVE responds to different types of economic disruptions, such as financial crises or supply shocks, to assess its generalizability. Further investigations should also evaluate whether BRAVE provides a more accurate prediction of firm survival compared to established indicators.

Beyond the metrics identified here, the axiom system also carries significant implications for the development of even more suitable resilience metrics. These metrics are an essential tool for advancing empirical research and theory in the field of resilience. Therefore, the axioms should serve as future benchmarks for assessing resilience metrics in subsequent studies. Consequently, metrics should be evaluated for their suitability by default, especially if additional developments are pursued in the studies, as overlooking key axiomatic properties could lead to misinterpretation of resilience outcomes or flawed comparisons across contexts.

While Likert scales do not fulfil most of the axiom requirements, they may still yield valuable insights into resilience in event studies. However, they must be paired with metrics that adhere to the axioms and capture the temporal dynamics of resilience. This dual application could yield a richer understanding of how subjective perceptions of resilience relate to objective performance-based measures. Ultimately, this should lead to an investigation of the potential links between them – testing for convergent validity could prove fruitful, especially when both measurement approaches are applied within the same empirical context. Such analyses may help bridge the gap between perceptual and behavioural dimensions of resilience. Otherwise, qualitative measures like those proposed by Lee et al. (2013) might offer complementary, alternative perspectives, particularly in capturing dimensions or capabilities of resilience that are difficult to quantify but relevant for further understanding.

The axiom system explored here, through its optional reduction to five items, reflects a pattern seen in decision theory: broader axiomatizations can be simplified without losing their core explanatory power, e.g. the Neumann-Morgenstern axioms (Schneeweiß, 1963). These reductions highlight the inherent strength of axiomatic approaches and their adaptability to specific application domains. Future research on the firm resilience axioms presented here should similarly explore whether further simplifications are feasible or necessary. Conversely, it is also essential to consider other potentially overlooked axioms that could enrich the understanding of firm resilience.

Conclusion

The goal of this research was to obtain a content-valid and thus meaningful metric to evaluate the effectiveness and utility of resilience strategies post hoc. While an earlier draft identified Zobel & Khansa's (2014) metric as the only one fully satisfying the axiom system (Schötz, 2024), slight modifications of the classic Bruneau et al. (2003) metric into BRAVE now provide a comfortable scenario with two apparently usable measures for firm resilience.

The fact that only these two in particular fit underscores the significance of resilience triangles in constructing a measure for firm resilience – or even resilience in general. The resilience triangles uniquely preserve the dominance of performance trajectories, resolving issues in simultaneously assessing the static and dynamic dimensions of resilience. At the same time, some argue for separate measurements of these dimensions (Munoz et al., 2022) or may call for greater emphasis on large recovery efforts, which risks overlooking a firm's ability to withstand disruptions. The *Dominance* axiom was designed to offer a balanced perspective, enabling diverse measurement approaches while maintaining crucial logical traits. In this regard, future research should investigate whether the resilience triangle approach is indeed the only method to satisfy this axiom or if alternative methods, not considered in this study, could emerge.

Although both metrics meet the content validity requirements, other shortcomings suggest a preference for the BRAVE metric. Its flexible time horizon makes it less prone to manipulation. It removes the need to define a maximum allowable recovery time, as required by Zobel & Khansa's metric (2014). This robustness makes it more practical.

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