An Axiomatic Approach to Evaluating Measures of Firm Resilience

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Abstract

Decision-makers tend to highlight the importance of their companies becoming resilient. The goal nevertheless stays hollow if there is no way to quantify and visualize firm resilience. However current scientific works appear to lack the drive for a robust foundation and empirical evidence, despite the emergence of resilience as a prominent topic in business and management literature. Hence this research is motivated by the specific objective of advancing the theory of firm resilience, addressing the imperative need for measures that capture its dynamic nature by encompassing both absorptive and adaptive firm capabilities. The research presents a grounded view of firm resilience and culminates in a six-part axiomatization, outlining which properties a conclusive resilience measure should possess. Considering the interdisciplinary nature of resilience research, suggestions from engineering disciplines are classified and presented. Their compatibility with the axiomatization is assessed, revealing a clear trend towards quantitative resilience measures. Additionally, a match that inherits all properties is identified. A call for further empirical research on the validity of the metric is emphasized, urging the exploration of other metrics alongside, given that this paper offers substantial guidance for future adjustments to measures of firm resilience.

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Introduction

An emerging topic in business literature focuses on ways companies can become resilient. A goal aimed at, especially in an unstable economic environment that is affected by a broad set of possible disruptions. Although management might be interested in implementing new strategies to achieve or enhance firm resilience, the existing empirical evidence is sparse and lacks common ground (Reghezza-Zitt, 2021). The literature further points out, that a focus on event-oriented resilience has led to a lack of longitudinal studies, resulting in an inability to extrapolate strategies to address a broader spectrum of challenges (Linnenluecke, 2017; Saad et al., 2021). Hence, the extent to which measures against specific disruptions can be applied to a variety of recurring and diverse challenges remains uncertain. For example, resilience characteristics needed for financial crises differ from those necessary for socioeconomic shifts. Additionally, knowledge about the transferability of these measures to different environments and organizations is limited (Linnenluecke, 2017; Korber & McNaughton, 2018). In tradition of the well-known quote that only "what gets measured gets managed" (Caulkin, 2008), these issues can be assigned to a deficit of specific metrics of firm resilience (Erol et al., 2010; Hillmann, 2021). Ruiz-Martín et al. (2018) further emphasize scarcity of literature regarding the measurement of resilience based on its impact on organisational performance. Other disciplines, e.g. engineering, already offer a pool of performance-oriented measures that are usually developed for specific applications. Given the diverse nature of firms, largely generic approaches should be pursued (Henry & Ramirez-Marquez, 2012; Sanchis et al., 2020). Nevertheless, there are distinctive features of theories on firm resilience and the market economy that such a measure should acknowledge.

To investigate whether metrics exist that can serve as a bridge but still remain in obscurity, the paper initially obtains a common understanding of firm resilience. Subsequently, the paper will outline the methodology, including the introduction of some metrics of interest. Then, a system of axioms for firm resilience is established. The research concludes with a discussion of the selected metrics based on their suitability to the axiomization.

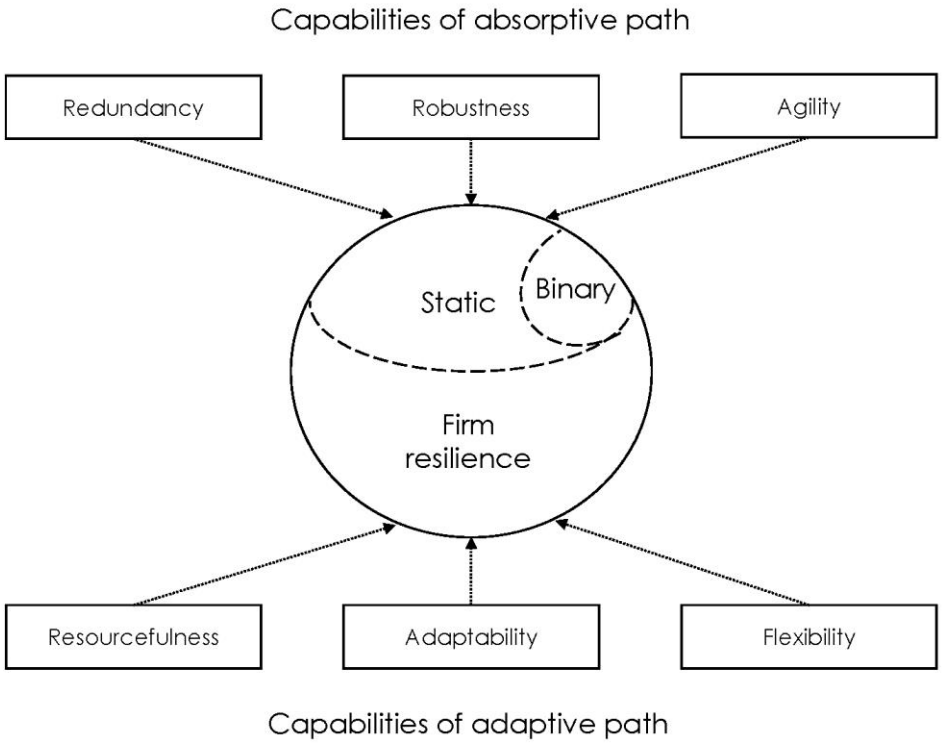
Background

Many reviews on firm resilience explicitly point out that at the corporate level the concept is not satisfactorily defined (Annarelli & Nonino, 2016; Linnenluecke, 2017; Saad et al., 2021). Korber & McNaughton (2018) criticize further 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. Beneficially, Conz & Magnani (2020) specify that resilience is a fundamental characteristic of companies that is inherent in them before, during, and after an event that occurs during their business life. Saad et al. (2021) further clarify that resilience is developed and built. It is not simply possessed by a company. Firm resilience is considered static when it ensures the reduction of the likelihood and impacts of threats. It is regarded as dynamic when it firstly accelerates the pace of economic recovery to the baseline level and secondly promotes the firm to an even higher level (Rose, 2004; Annarelli & Nonino, 2016). According to Sevilla et al. (2023), due to its dynamic nature, resilience on an organisational level cannot be measured ex-ante.

Conz & Magnani (2020) theorize that firm resilience encompasses a proactive phase before the event (ex-ante), an absorbing and/or adaptive phase during the event, and a reactive phase after the event (ex-post). Thus, disruptions can be managed through two pathways, with different capabilities playing a role in each phase. Redundancy, robustness, and agility aid in the absorptive pathway out of the

crisis, while resourcefulness, adaptability, and flexibility characterize the adaptive pathway. The dynamic process does not dictate how individual capabilities work or whether all must be present to a certain extent. Conversely, Iftikhar et al. (2021) emphasize that previous resilience definitions have considered elements of both pathways as necessary and temporally equivalent. Figure 1 provides a presentation of the framework with a link to static and dynamic views of resilience. Thus, while firm resilience encompasses a static component, it overall transitions into a dynamic construct. Figure 1 also considers the multidimensionality of resilience as a portfolio of attributes and capabilities.

Figure 1
A model representation of firm resilience



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

The absorptive pathway, rooted in the RBV (resource-based-view), signifies resilience as a safeguarding reservoir against disruptions. The adaptive pathway highlights factors such as innovation capabilities and places emphasis on the effectiveness of handling disruptive events and the pace of post-event recovery. While absorptive resilience, being predominantly grounded in static principles, might be examined through binary manifestations, a more comprehensive metric is essential for understanding adaptive resilience, including its post-disruption dynamics.

Methodology

The research approach aims at eliminating the existing weaknesses regarding firm resilience by bridging theory and empirical evidence, in order to strengthen the substance of the research field (Shepherd & Suddaby, 2017). Only with such a foundation can the suitability of fitting instruments, in this case various resilience measures, be examined. Therefore, based on the literature review and known

principles from business economics, six axioms are stated that a metric of firm resilience must meet.

The axiomization was applied to a broad range of resilience metrics from different areas of literature (for classifications of measures, see Hosseini et al., 2016; Ruiz-Martín, 2018). Bringing forward the approaches had to be generic enough to fit the context of firm resilience. Compliance with every axiom was checked mathematically and logically. The results have been condensed to the presentation of the following four metrics rooted in engineering, which are deemed most promising.

The pioneering work of Bruneau et al. (2003), which introduced the renwoned resilience triangle, sparked the development of a variety of resilience measures. A derived version of their metric, drawing on approaches from Proag (2014) and Nan & Sansavini (2017), is included as the first subject (following, $P(t)$ marks the performance at time t):

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

Next, 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):

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

The third subject is a metric adapted from Cheng et al. (2022), which incorporates variation in performance cumulatively. A resilient system should thus be characterized by a gradual performance degradation, prompt recovery, and overall high performance levels. Their rather technical formulation involves normalization regarding performance and time, the latter being tailored to a granular assessment. Consequently, a simplified, modified version is used here, still encompassing the three core points mentioned:

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

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

The underlying idea is that resilience values at each measurement point initially represent only a snapshot. An assessment of firm resilience can only be made when multiple observations are combined into a cross-section.

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:

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

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 these four metrics are discussed, and implications for the validity of the axiomization are derived. Further steps for verifying the connectivity with the theoretical framework are suggested in the conclusion.

Axioms of firm resilience measurement

Firstly, transfer into business practice should be a driving force from the outset. The metric has to generate high acceptance internally by a low cognitive barrier as a primary requirement. A concerned decision-maker must be able to grasp and meaningfully process the information, while not significantly impair their scarce time and attention resources (Dalziell & McManus, 2004; Gladen, 2014). Accordingly, economic foundational knowledge, which includes mathematical and statistical basics, should be 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, symbolizing the absence of resilience. This helps exclude constructs that allow negative value ranges. Characterizing nominally negative resilience contradicts the existing theoretical framework and may cause confusion among executives. To avoid potential sources of error, ambiguity of interpretations is excluded. Finally, we address the lack of timeliness, which is characterized by a long period between the end of the analysis period and the time of compilation (Gleich, 2021):

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

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

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 all aspects, this criterion is strongly inspired by the resilience of technical systems, where the system's 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 capabilities, it is advisable to opt for relative measurement. This also opens the possibility to compare firms with a reference group (Ilseven & Puranam, 2021). It is achieved by the following demand:

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:

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

Najarian & Lim (2019) argue that resilience measures should not entail 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. But a precise implementation of this requirement may almost entirely drop the historical perspective. Thus, leading 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 for a strict

division into two concepts for higher meaningfulness, narrowing resilience nominally to recovery capability.

However, as the literature pointed out that resilience was characterized by multiple phases, the strength of the shock must also be considered. Henry & Ramirez-Marquez (2012) emphasize 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 that a consistently dominant performance trajectory leads to a higher resilience rating, they can be omitted:

Axiom 3 (Monotonicity): 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 monotonic if $d \in D$ occurs at t_0 and at t_s it always satisfies:

$$\frac{P_i(t_k)}{P_i(t_0)} \geq \frac{P_j(t_k)}{P_j(t_0)} \quad \forall\, t_k \in T$$

$$\frac{P_i(t_m)}{P_i(t_0)} > \frac{P_j(t_m)}{P_j(t_0)} \quad for\ at\ least\ one\ t_m \in \mathrm{T}, t_m \neq t_s$$

$$\Rightarrow \qquad R_i(t_s) > R_j(t_s)$$

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 a return to the initial level, the performance of market actors is rarely so limited. Hence, the dynamic nature of firm resilience ensures practical proximity. If a company capitalizes 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. This is achieved as follows:

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:

$$\frac{P_i(t_k)}{P_i(t_0)} \geq \frac{P_j(t_k)}{P_j(t_0)} \quad \forall\, t_k \in T$$

$$\frac{P_i(t_s)}{P_i(t_0)} > \frac{P_j(t_s)}{P_j(t_0)} = 1$$

$$\Rightarrow \qquad R_i(t_s) > R_j(t_s)$$

In line with measurement theory, Asheim et al. (2020) assert the existence of a resilience order as 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 concept of 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 utilized 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, determining a baseline and additional measurement points through the resilience measure is required. Only then can the

desired integration of theory with empirical analysis succeed. Overall, this corresponds to nothing else than the motivation for cardinal measurement (Pfanzagl, 1971; Hand, 1996):

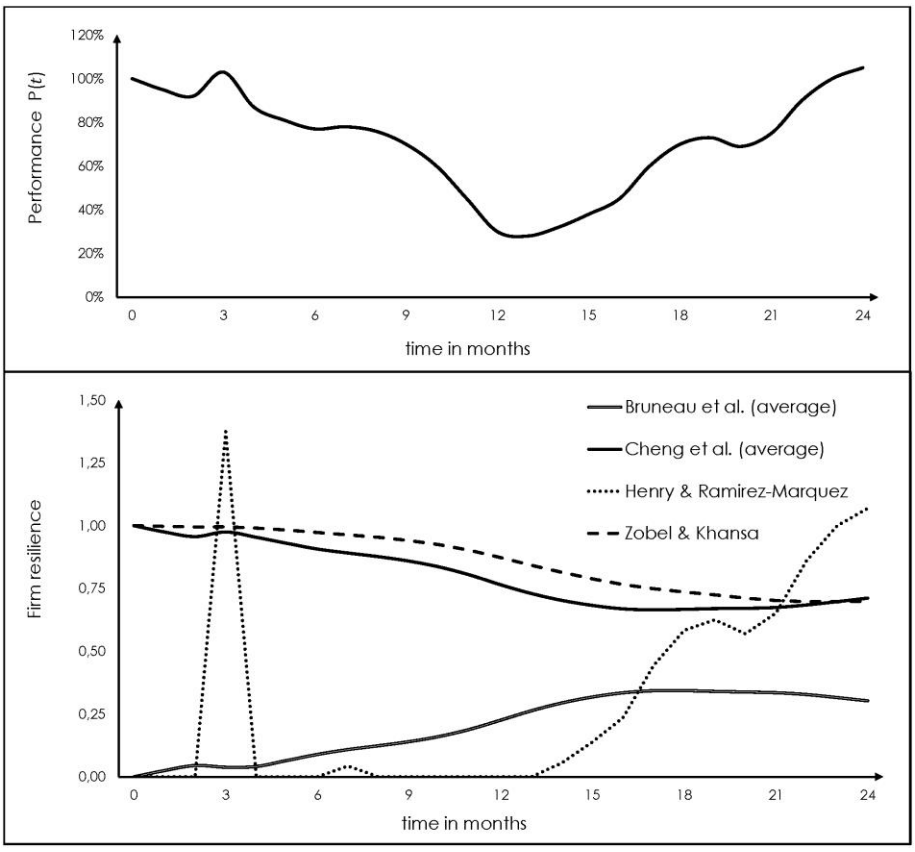
Axiom 5 (Operationalizability): Firm resilience is operationalized through a resilience measure R, if R is at least interval-scaled.

Finally, the question arises: when is a company actually in shallow waters? For technical systems, such states can often be clearly defined and serve as the starting point from which the disruptive event is considered. 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:

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.

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

Figure 2
Exemplary performance curve and corresponding values of resilience metrics



Source: Author's illustration

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 2 shows the resilience values for an exemplary two-year performance curve. This example induces no negative values, which, however, can occur in the cases of Cheng et al. (average) and the metric derived from Bruneau et al. (2004) – consequently violating non-negativity. 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, always results in a drop to zero when reaching a new performance low.

The second axiom of *Weak comparison* is met by all presented measures since they rely on relative relations. Still, other methods, particularly a Likert scale (see e.g., DeVellis, 2009), may indicate that two companies have parallel crisis trajectories on paper, but their differing subjective perceptions lead to differences in resilience ratings. Similarly, Likert scales violate *Monotonicity* and *Gratitude*.

The demand for *Monotonicity* proves to be the strongest obstacle overall. The measure of Henry & Ramirez-Marquez (2012) only considers a portion of the past time period, allowing for distortions. On one hand, Cheng et al. (average) can potentially omit the history of the performance trajectory using equidistant times. On the other hand, even with the exclusion of these cases, it cannot be universally demonstrated that the requirement is otherwise met. Zobel & Khansa and Bruneau et al. (average) 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

Metric / Axiom	Bruneau et al. (average)	Cheng et al. (average)	Henry & Ramirez-Marquez	Zobel & Khansa
1. Comprehen-sibility	☒ (non-negativity)	☒ (non-negativity)	☒ (interpretation of zero)	☑
2. Weak comparison	☑	☑	☑	☑
3. Monotonicity	☑	☒	☒	☑
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 by non-monotonic measures, basically showing that measures can inherit dynamic character of resilience whilst disregarding absorptive capabilities.

Operationalizability is present in the resilience 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.

The final axiom mainly serves as a safeguard for trajectories not solely of technical origin. The metric of Henry & Ramirez-Marquez (2012) fails in this regard due to initialization issues,

Figure 2 shows that Zobel & Khansa and Cheng et al. (average) exhibit similar trends, although the latter generally shows lower resilience ratings. The former's focus on past performance results in a smoother trend, while the latter can more rapidly and significantly consider amplitudes. Determining the maximum recovery duration T^* proves challenging for Zobel & Khansa, especially when no fixed time is provided, as in the example. Meanwhile, the trend of Bruneau et al. (average) is nearly inverse to that of Zobel & Khansa. Notably, concerning resilience assessment, a reverse logic applies – smaller values are better for this metric, which also causes the violation of non-negativity.

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

Conclusion

Sevilla et al. (2023) noted that, as a dynamic capability, resilience cannot be measured ex-ante. In line with this perspective, the aim here was not to claim the ability to predict a company's resilience before a crisis occurs, but rather to obtain a meaningful measure that can support the effectiveness and validity of strategies post hoc. Although a seemingly appropriate metric was found, it initially only serves as a model representation of reality, with its establishment being merely true or false based on logical foundations (Coombs et al., 1954). Only through application to reality can the reliability as a component of firm resilience theory be demonstrated. This is especially evident considering the multidimensionality shown in Figure 1, which directly calls for proof of relations to the corresponding attributes and phases of resilience. The need to empirically test and validate both existing and future theoretical concepts has been increasingly emphasized in the literature (Annarelli & Nonino, 2016; Linnenluecke, 2017; Conz & Magnani 2020; Hillmann, 2021; Saad et al., 2021).

Furthermore, while the quote in the introduction motivated the research, its extension goes beyond: "what gets measured gets managed - even when it's pointless to measure and manage it, and even if it harms the purpose of the organisation to do so" (Caulkin, 2008). Addressing the need to carefully observe the implementation of resilience metrics in management control processes and track their implications on firms and management behaviour.

Ultimately, the system of axioms, optionally reducible to five items, generates significant implications for the further development and definition of additional and even more suitable resilience metrics. They serve as essential tools for empirical research and the advancement of the field. At the same time, the axiomization calls for a critical debate and consideration of other axioms for firm resilience that may have been inadvertently overlooked.

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