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Measuring the fragility of agribusiness value chains: a case study of the South African lamb chain

RESEARCH ARTICLE

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Abstract

The ability to determine the fragility of agribusiness value chains is valuable to agribusines management practitioners and scholars in a context where risk and uncertainty are increasingly pervasive, consequential and unpredictable. The paper argues for determining the fragility of a chain to adverse events rather than trying to predict the probability and impact of such events. The paper specifically proposes a framework to detect and quantify non-linear consequences in response to progressively deteriorating chain fragility factors. The paper's approach is a novel alternative to the traditional value chain 'risk assessment'. Application of the framework to the South African lamb chain reveals that a number of specific factors, like quality and safety performance and cash flow position, have consistently high fragility scores throughout the chain while some factors are uniquely localized to a specific role-player or activity, which highlights the techno-economic uniqueness of individual activities in a chain.

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1. Introduction

The future holds an imminent surge in global uncertainty and complexity and this will come about sooner than expected. Opinion is that many global value chains were not designed for, and are ill-equipped to deal with, this looming uncertainty and complexity (Malik *et al.*, 2011). At the same time, value chains have become sophisticated and essential to the competitiveness of many businesses, even though their interwoven and global nature also makes them increasingly exposed to the challenges that accompany uncertainty and complexity (Deloitte, 2013). The network of value chains that constitute the agribusiness system has also become increasingly connected, complex and volatile (KPMG, 2013; Swinnen, 2015) and mirrors global developments in value chains. Due to these challenges, agricultural value chains are inherently exposed and fragile to adverse events in the economy, the environment, politics, the consumer landscape and the structures that govern these chains (Bode *et al.*, 2013; KPMG, 2013; Neves and Scare, 2010; Wagner and Bode, 2006).

There is compelling evidence that illustrates the impact of value chain fragility, including a loss of shareholder value (Hendricks and Singhal, 2005, 2008), business unit closures (Engber, 2012), profits turned to losses in weeks (Engber, 2012), civil liabilities (Huspeni, 2014), lack of transparency (Linich, 2014) and knock-on effects (Acheson, 2007; Nganje and Skilton, 2011; Williams-Grut, 2015). Consequently, there is a particular need to measure the fragility of value chains in general (Stonebraker *et al.*, 2009) and agricultural value chains in particular. A measure of value chain fragility would reveal the constraints and opportunities in risk management, and inform risk management strategies and appropriate coordination and governance mechanisms in agribusiness value chains.

The purpose of this paper is to advance the argument that fragility, as a concept, provides a further and useful dimension to the uncertainty discourse in agribusiness value chains – especially through its measurement. The development of an approach to quantify agribusiness value fragility will also enable a range of analyses to follow, which would be useful for practitioners and academia. Against this background, this paper adapts and tailors a framework to measure agribusiness-value-chain fragility. As a first attempt to develop such a framework, this paper positions the measurement of fragility in a conceptual landscape, and considers the risk and uncertainty continuum and the link to fragility. The paper also explores some principles and the actual measuring of fragility in the agribusiness context. The paper culminates in the measuring the fragility of the South African Lamb value chain to establish a benchmark for the specific sector and to display the framework and the accompanying concepts. In closing, the implications of the research for the design and management of agribusiness value chains is considered.

2. Conceptual setting

Agribusiness value chains are required to deliver to increasingly complex, nuanced and demanding consumer needs within an environment that is ever more challenging and where uncertainty is inherent to the system (Boehlje *et al.*, 2011; Sexton, 2013). Within the agricultural value chain system, the consequences of adverse events are also increasingly reaching beyond firm boundaries and spilling into value chains (Linich, 2014). Consequently, there is an increasing move towards more coordinated exchanges in value chains in an attempt to manage uncertainty in these chains (Hobbs, 1996; Hobbs and Young, 1999; Sexton, 2013). However, increasingly coordinated exchange in value chains, almost silently, brings about a predicament in pursuing a specific coordination direction. When uncertainties in a chain have predictable probabilities and the payoffs (consequences or outcomes) are simple, increasing coordination brings about high performance value chains. Conversely, when uncertainties in a chain have less predictable or unpredictable probabilities and the payoffs (consequences or outcomes) are complex (due to complex interdependencies, non-linear relationships, etc.), increasing coordination brings about increasingly fragile value chains (Gray and Boehlje, 2005; Taleb, 2009b). Disruption of one or more of the primary flows that constitute value chains, i.e. the flow of goods and services, the flow of information and intelligence and the distribution of retained value exacerbates the exposure of value chains to the consequences of risk and uncertainty. Risk and uncertainty in value chains are, after all, not limited to 'hard elements' like operations and logistics (Christopher, 1998;

Vlajic *et al.*, 2012) but also includes 'soft elements' like trust, transparency and the nature and quality of relationships in the chain (Beulens *et al.*, 2005; Molnar, 2010; Trienekens *et al.*, 2012).

The purpose of this paper is to develop and empirically examine fragility as a concept and to operationalize a method to measure the fragility of agribusiness chains. While the literature is awash with frameworks that measure the performance of agribusiness value chains (Aramyan *et al.*, 2007; Fattahi *et al.*, 2013; Molnar, 2010; Osés *et al.*, 2012), the measurement of fragility of the very same chains is unexplored. The absence of a measure of value chain fragility has also prevented the examination of the trade-off between the juxtaposed objectives of performance and fragility in value chains – the theme which is central to this paper's conceptual setting. A measure of value chain fragility would inform the design, organization, governance and management of value chains and ultimately focus attention on the trade-off between high performance and fragile value chains. Contemplation of this trade-off in value chains is interesting, bearing in mind that value chains are investments where the interplay of revenue, costs and uncertainty drive the attractiveness of the investment.

3. Principles of measuring fragility

Cognizant of the relevance of uncertainty in value chains, the ability to measure fragility is evidently important in exploring all of the extents, dimensions and interactions of fragility and in plotting strategies to manage fragility and its consequences in agribusiness value chains. This section discusses principles in measuring fragility to lay a foundation to propose a metric for value chain fragility.

3.1 An alternative approach to measuring risk and uncertainty

'Black Swan events' are 'large-scale unpredictable and irregular events of massive consequence' (Taleb, 2012). A Black Swan event (Aven, 2013; Taleb, 2007, 2009a) is characterised by complex payoffs and fat-tailed probability distributions typical of leveraged finance, economic systems, epidemics, catastrophes and the development of the internet, amongst others (Munro and Zeisberger, 2010). Black Swan events are specifically problematic for risk measurement and management because of the impossibility of predicting their occurrence and calculating their impacts (Taleb, 2012). The impossibility of predicting the occurrence and calculating the impacts of Black Swan events relate to a number of epistemological difficulties, particularly dealing with the probability and outcome dimensions as Taleb (2012) notes.

Whereas the typical risk management approach relies on knowledge of the probability and probability distribution of events and the typicality of single events, the approach is evidently severely inadequate, even flawed, in the case of Black Swan events in complex systems like value chains (Taleb, 2009b). An alternative approach is to determine if something is fragile to a 'Black Swan' event rather than to attempt to predict the occurrence of such an event. The reasoning is that fragility can be measured, while risk is not as measurable as is thought, especially in complex systems (Aven, 2015; Taleb *et al.*, 2012). This approach is without a doubt counterintuitive and in opposition to mainstream approaches employed by practitioners and academics to understand and manage the various sources of risk and uncertainty (Ge *et al.*, 2016; Heckmann *et al.*, 2015). Measuring fragility, rather than risk, does, however, solve some very specific shortcomings of the old-style, probability and impact approach, and is the fundamental rationale for the approach in the paper.

3.2 Unit of measurement

Fragility has been positioned as being a measure of the sensitivity to specific risks. In the context of value chains there is, however, not a specific or clear guideline as to which variable or indicator or mix of indicators is recommended in assessing fragility. Value chain fragility could be measured for revenue, costs, margin, gross or net profit, reputation, business continuity, sustainability, volumes, etc.

Examples of the unit of measure include gross profit as a measure to gauge the robustness of value chains (Vlajic *et al.*, 2012). Margin erosion, sudden changes in demand, disruption of physical product flow,

product quality failure, regulatory non-compliance and worker-safety failure and, social responsibility are also considered to be indicators of impact (Deloitte, 2013). A mix of indicators in an indexed fashion has also been employed by considering the impact and probability of an adverse event in relation to a specific variable (Stonebraker *et al.*, 2009). In other cases, market share, reputation, levels of trust, number of casualties or affected people or entities are also indicators of the impacts of adverse events, such as food scandals (Stanciu, 2015).

In developing a framework to assess fragility in value chains, it may therefore be useful to suggest a premise from where fragility is to be considered. Conversely, allowing for some freedom in defining the basis of fragility will possibly permit wider application of such a framework. In this paper, as a generic point of reference, the concept of business continuity is suggested as the lens through which to view fragility. The ISO 22301 standard of 2012 is a generic business continuity management standard that describes business continuity as a position where a business's operations can continue and products and services are delivered at predefined levels, where brands and value-creating activities are protected, and where the reputations and interests of key stakeholders are safeguarded whenever disruptive incidents occur (International Organization for Standardization, 2012).

3.3 What to measure

There is also a significant debate regarding whether risk, and consequently, fragility, should be approached quantitatively of qualitatively. A number of schools of thought exist on the topic (Khan and Burnes, 2007). A concise summary of the schools of thought are that risk can range between a 'techno-scientific perspective, which sees risk as objective and measurable, to a social constructionist perspective, which sees it as being determined by the social, political and historical viewpoints' of stakeholders (Lupton, 1999). In essence, if risk and fragility are assumed to be objective and measurable, then a framework to measure them must consider variables that are objective. Such variables include actual turnover, margin, profit, costs, and frequency of events (assuming that the frequency of past events can predict the occurrence of future events). Alternatively, if risk or fragility are viewed subjectively, then a framework to measure them must consider variables that are subjective – like the perceived impact or probability of an event, the perceived ability to maintain business continuity or the reliability of suppliers or buyers in a chain.

In terms of making a decision about approaching risk and fragility, (Bernstein, 1996) questions the extent to which the past determines the future and how useful past events are in informing a framework for assessing risk and fragility. Although it is increasingly possible to use numbers to scrutinize what has happened in the past, the future cannot be quantified because it is unknown (Bernstein, 1996). Moreover, it is questionable to what extent there should be a reliance on patterns of the past to forecast the future. Bernstein (1996) questions whether the facts as they are seen, or subjective beliefs in what lies hidden in the future, carry more weight when considering risk and fragility and whether the dividing line between the two approaches can be accurately judged. Khan and Burnes (2007) emphasize the point of the on-going debate between those who see risk and uncertainty as objective and those who see it as subjective, noting that the debate is most likely not resolvable. It is, however, important to be aware of the debate and the significant implications for how risk, uncertainty and fragility is seen and managed.

Bounded rationality is a further complication in attempting to produce a framework with which to evaluate fragility. Bounded rationality implies that although people may intend to make rational decisions, their capacity to evaluate accurately all possible decision alternatives is physically limited. This also applies when assessing risk, specifically, where people intend to make rational assessments of risk but their capacity to accurately assess its likelihood and all the possible outcomes and iterations is limited (Hobbs, 1996).

3.4 The scope of measurement

The development of a metric to measure fragility presents significant challenges (Stonebraker *et al.*, 2009). Similar metrics or measures of sustainability (Callens and Tyteca, 1999; Figge and Hahn, 2004; Krajnc and Glavič, 2003; Veleva and Ellenbecker, 2000), robustness (Durach *et al.*, 2015) or resilience (Melnyk, 2014; Vecchi and Vallisi, 2015) of value chains are equally difficult to measure. Citing Stonebraker *et al.* (2009) some of 'the difficulty results from the simultaneous interactivity of multiple variables measured in different units and by different methods for different periods and in different entities. Further, some measures are highly subjective'.

On this basis Stonebraker *et al.* (2009) suggest a number of desirable characteristics for supply chain fragility measures. These characteristics include, amongst others, the ability to compare the current state and progress of different units of analysis against a benchmark, standard, target, or goal, the use of cardinal scales in measurement and the ability to measure with absolute, relative and indexed measures.

3.5 A metric of fragility

Variables are not fragile when a linear payoff is observed in relation to a linear disturbance. When the impact of an adverse event remains proportional to the size of the shock, the specific variable is not considered to be fragile. However, when a concave payoff is observed in reaction to a disturbance and the payoff becomes disproportionately larger as the adverse event becomes larger, the variable is considered to be fragile (Figure 1). With particularly large types of events, the difference in harm between a linear and negatively convex payoff can escalate exponentially (Taleb, 2012). This aligns to the principle of Jensen's inequality (Jensen, 1906) which is the basis of non-linear responses.

Such negative convexity effects are recurrent in economic and financial settings and systems. These negative convexity effects typically develop as result of size and as a result of positive or reinforcing feedback effects resulting from complexity and interconnectedness (Taleb *et al.*, 2012). The relevance of negative convexity effects to agribusiness value chains is evident, given the complexity, interconnectedness and oftentimes the

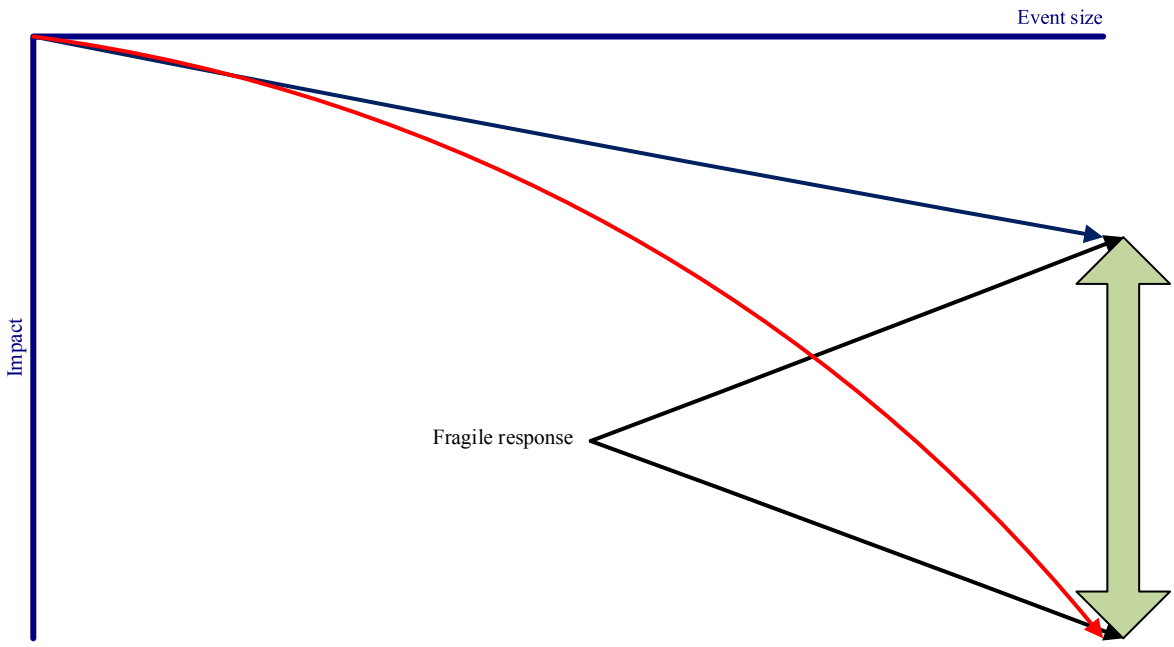

Figure 1. The harm of non-linear impacts (Taleb, 2012).

size of these chains, and the very notable accelerating effects that are frequently observed in instances of food scandals, product recalls, public fallouts, etc.

■ *Detecting fragility*

Identifying fragility in variables has been approached in a number of ways. Using the 'threat level' and 'impact' of specific disturbances, Stonebraker *et al.* (2009) developed the 'The Goldhar-Stonebraker Supply Chain Fragility Index Matrix'. This approach, however, misses the point argued thus far and stays on the course of a typical risk analysis by attempting to understand disturbances rather than the results of the disturbances. A simple point estimate from a conventional risk assessment does not give a sense of the potential for convexity effects and is effectively an estimate of a single or average shock (Taleb *et al.*, 2012) that does not capture the necessary nuances.

An alternative approach, using a heuristic or shortcut, attempts to assess the fragility of a system and not the particular event that will expose that fragility (Taleb *et al.*, 2012). The principle of applying a heuristic to detect fragility was suggested by Taleb *et al.* (2012) in the context of stress testing in the banking sector and involves:

> 'averaging the model results over a range of shocks. When convexity effects are present, the average of the model results will not be equal to the model results of the average shock. The heuristic is a scalar that measures the extent of that deviation, and is calculated as F, where: f(α) is the profit or loss for a certain level α in the state variable concerned, or a general vector if we are concerned with higher dimensional cases (Equation 1).
>
> $$\boldsymbol{F} = \frac{f(\alpha+\Delta)+f(\alpha-\Delta)}{2} - f(\alpha)$$
>
> Where *F = Average shock – Average over a range of shocks*
>
> In this equation Δ is a change in α, a certain multiple of the mean deviation of the variable. The severity of the convexity expressed by F should be interpreted in relation to the total capital (for a bank stress test, or GDP for a sovereign debt stress debt), and can be scaled by it, allowing for comparability of results, and hence an ordinal ranking of fragilities, among similar types of institutions. When F=0 (or a small share of the total capital) the outcome is robust, in the sense that the payoff function is linear and the potential gain from a smaller (by the amount) x is equal to the potential loss from an equivalently sized larger x. When F <0, and significantly so with respect to capital, the outcome is fragile, in the sense that the additional losses with a small unfavorable shock (i.e. compared to a given tail outcome) will be much larger than the additional gains with a small favorable shock.'

Therefore, as Taleb *et al.* (2012) argue, volatility is undesirable in such a situation; i.e. we can say that an institution for which F is negative is 'fragile' to higher volatility and particularly fragile to the specific event (Figure 2).

An equivalent approach applies to the framework to measure value chain fragility. The approach in the case of value chain fragility is a variation of the basic heuristic proposed by Taleb *et al.* (2012) and Taleb and Douady (2013). Practically, in the case of this specific analysis, this heuristic measures the difference in overall impact between an average shock and the average of a range of shocks per factor to arrive at a measure of fragility.

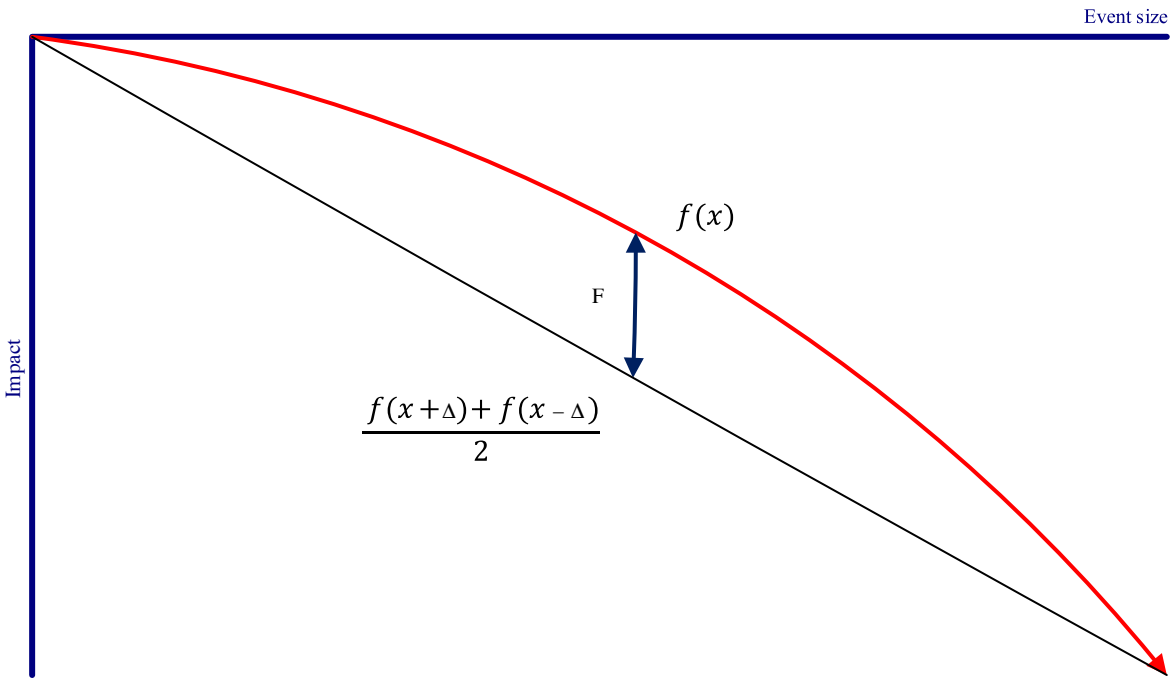

Figure 2. Detecting fragility (Taleb, 2012).

■ *A composite index for chain players and a whole chain*

The fragility tool, adapted as described above, provides a measure of the fragility of specific variables. It does, however, not yet provide for a single measure that encompasses all of the fragility variables identified for agribusiness value chains. The route to a complete value chain tool is to develop a composite index per chain player and then a final score denoting 'value chain fragility', comprised of all the composite indices of each value chain player in the chain being analyzed. Examples of typical composite indices in supply chains include a composite sustainable supply chain performance index for the automobile industry (Gopal and Thakkar, 2014), benchmarking of green logistics performance with a composite index (Lau, 2011), and a collaboration index to a measure for supply chain collaboration (Simatupang and Sridharan, 2005).

Consequently, to arrive at single measure that combines the different dimensions of fragility into a single measure, a polygon is developed with the final sub-index values encompassing the overall fragility of the value chain in question according the approach by Gopal and Thakkar (2014). Employing this approach the fragility measure per chain stakeholder is determined on the basis of the area of the polygon. The point where the axes meet corresponds to a value of 0. The value corresponding to the edges of the polygon is 0.4461. The larger the area of the polygon is, the greater the fragility of the individual stakeholder under analysis is. The area of the polygon is calculated by dividing the total area of the polygon into triangles. Then, using the formula (0.5*a*b*sin(360/17)), the area of each separate triangle is calculated and summed to arrive at a total value for fragility.

The same procedure is then used to combine the individual fragility scores per chain player into a composite index that represents a measure of fragility for the whole chain. A graph is drawn with the each of the values of the links to analyze the overall fragility of the value chain in question. The value chain fragility measure is determined on the basis of the area of the polygon. The point where the axes meet corresponds to a value of 0. Similar to the approach earlier, the larger the area of the polygon is, the greater the fragility of the value chain under analysis is. The area of the polygon is also calculated by dividing the total area of the polygon into triangles. Then, using the formula (0.5 base*perpendicular height) area of each triangle is calculated and

summed to arrive at the overall fragility score for the chain in question. Therefore, in summary, the process to arrive at a composite index of value chain fragility is achieved in three main steps as described below:

1. Determine the fragility to each of the fragility factors for each player.
2. Combine each of the fragility outcomes per fragility factor into a composite index (represented by an area) of fragility for each chain player.
3. Combine each of the fragility outcomes per chain player into a composite index (represented by an area) of fragility for each chain.

In each of these instances, the composite index provides for a combined measure of a number of elements to form a product that is representative of the overall picture of fragility in a chain. While this approach is certainly not without shortcomings, the composite index does provide for a standardized approach and a useful statistical measure to gauge the overall fragility in a chain, having considered the elements that contribute to fragility.

4. Measuring value chain fragility – a case study

The tool to measure value chain fragility was operationalized in the South African lamb value chain to demonstrate its use in measuring fragility and to relate this measurement to the governance mechanism in the chains. The tool also provides the means to interrogate trade-off between coordination intensity and fragility, but this trade-off is not explored herein.

4.1 Overview of the South African lamb value chain

The generic South African lamb value chain encompasses six main activities, from input provision to consumption. Key activities are input supply, production (may also include finishing in a feedlot), collation, value addition, retailing and consumption (Figure 3). A range of variations between the collating and retailing activities is possible, including a trading (wholesale), value addition (packing, processing) and a direct option.

Recent and extensive evaluation of the South African lamb value chain (Spies, 2011; Van der Merwe, 2013; Wilson, 2015) provides encompassing details of its extent, stakeholders, activities, coordination and governance, differentiation strategies, trends, etc. Consequently, and in the interest of conciseness, this paper does not offer another broad narrative of the generic chain, apart from the basic details in relation to fragility and the coordination of the chain.

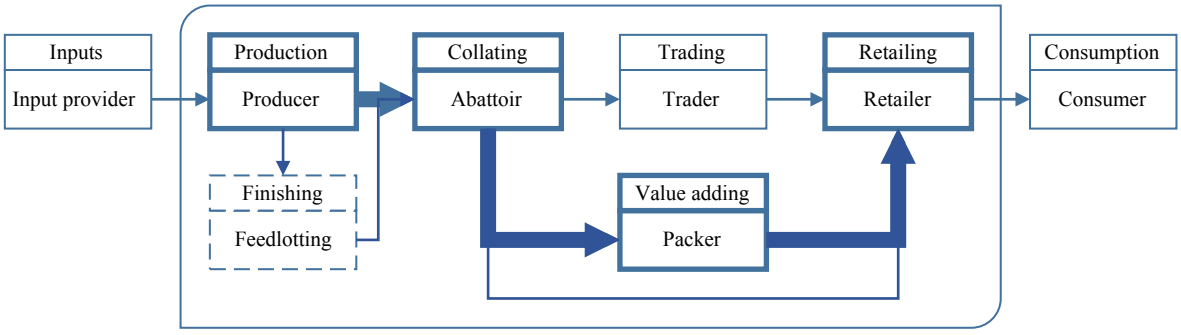

Figure 3. Basic South African lamb chain.

4.2 Overview of the respondents and the specific chains

■ *Respondents*

The survey questionnaire was presented to 200 respondents in selected South African lamb chain configurations, after requesting their participation in the research. Overall, 77 responded to the request with completed questionnaires (response rate 38.5%). In terms of the adequacy of the sample, the 77 responses provide for at least a 90% confidence level and a 10% confidence interval, considering a population of 8,000 sheep farmers, 247 registered sheep abattoirs, 18 meat packers and 2,975 registered meat outlets (n=11,240). Respondents were actors actively involved in the particular chains spread across the typical lamb value chain, from producers through to retailers (Figure 4). A stratified and random sampling approach was employed to identify and source respondents for data collection. The different activities in the chain were the strata and within these strata, respondents were selected randomly.

■ *Methodology and data*

The methodology to measure value chain fragility entailed presenting 17 value-chain-fragility factors to all respondents. These factors were derived from a range of such factors cited in literature and distilled to 17 factors specific to agribusiness chains through dimension reduction techniques (Jordaan, 2017). The approach to the analysis recognizes that several different chains, with different fragilities, may be operational within the overall lamb sector but these potential differences between chains are not explored and the analysis is restricted to the sector level chain. The rationale for this approach is that it establishes a statistically justifiable fragility benchmark at the sector level for the South African lamb chain and against which the fragility of specific lamb chains in the sector are comparable.

In the survey, respondent's reactions were elicited in response to a progressively worsening adverse event, in relation to the specific factor. The extent of adverse events was worsened in 10% increments from a 10% to a 90% event extent and respondents were required to indicate the corresponding impact of the adverse event on business continuity in 10 equally sized incremental categories, ranging from 0-10% to 90-100%. This method is analogous to stress testing in economic systems, including value chains (Amini *et al.*, 2012;

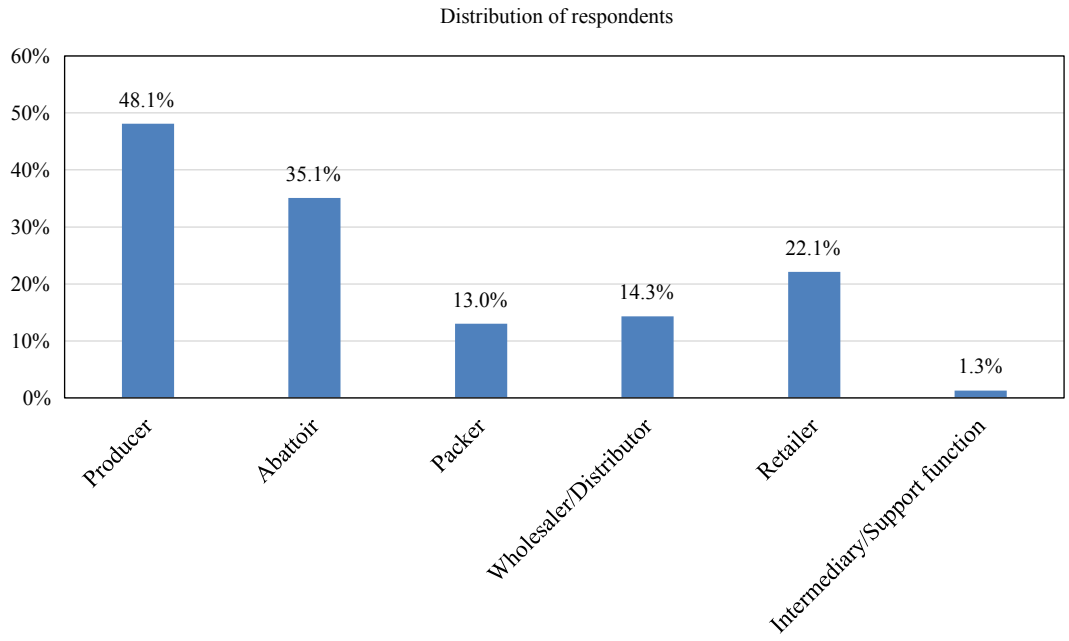

Figure 4. Distribution of respondents across the lamb value chain.

Falasca *et al.*, 2008; Schmitt and Singh, 2009) which is, in essence, an analysis conducted under a range of adverse scenarios to determine whether the entity under scrutiny is able to withstand the adverse events.

An overall measure of value chain fragility is achieved by determining sequential composite indices across the chain. A composite index of the fragility of each of the 17 factors characterizes the overall fragility of the specific activities in the chain. Moreover, a further composite index of all of the fragility scores of each of the activities in the chain characterizes the overall fragility of the specific chain in question.

Data was collected by way of a structured survey that was either emailed to respondents or completed in person. In some instances the physical completion of the questionnaire was preferred above the electronic completion thereof. Data processing was undertaken in Microsoft Excel.

4.3 Results

- *Fragility of activities*

The primary aim of this paper is to showcase the framework to measure agribusiness-value-chain fragility and to explore the usefulness of the framework through a case study – in this case – selected chains in the broader South African lamb value chain. Considering the results, it is evident that the framework is able to detect non-linear effects in response to progressively deteriorating parameters. These non-linear effects correspond to the fragility of the specific factor, which is ultimately an indication of the fragility of the factor in question to adverse events, specifically, to rare, high impact events (Table 1). Here negative scores indicate fragility (negative convexity effect) and positive scores anti-fragility (positive convexity effect).

Interestingly, there is some divergence and some convergence in the major fragility factors across the South African lamb value chain. It is specifically noteworthy that, for example, the quality and safety performance and the cash flow position of the specific actors rank very highly in terms of fragility across the chain and for most actors. Conversely, the nuances at the different levels in the chain are also evident with specific factors, unique to each activity, emerging as significant dimensions of fragility. Producers are uniquely fragile to buyer and operational reliability, abattoirs to the quality and training of human resources, and the quality and adequacy of infrastructure, packers to regulations and supplier reliability, and retailers to the management information and supplier relationship and alignment.

Table 1. Major fragility factors and scores per chain player.

Producers	Quality and safety performance (-10.46)
	Operational reliability (-8.43)
	Cash flow position (-8.41)
	Buyer reliability (-8.37)
Abattoirs	Quality and safety performance (-14.03)
	Cash flow position (-12.96)
	Quality and training of human resources (-9.10)
	Quality, adequacy of infrastructure (-8.30)
Packers	Cash flow position (-15.52)
	Regulations (-13.29)
	Supplier reliability (-13.20)
	Operational reliability (-12.64)
Retailers	Quality and safety performance (-15.81)
	Cash flow position (-12.40)
	Management information visibility (-10.20)
	Supplier relationship and alignment (-10.20)

Considering the fragility of the respective actors in the South African lamb chain, is it equally noteworthy that while the actors differ in terms of the fragility to specific factors, the overall fragility score per actor is similar (Figure 5). In the context of the South African lamb chain, this observation has a range of interesting implications. The first observation relates to the perennial discussion of which actor is more exposed to uncertainty. In this specific case packers' and retailers' exposure to relatively higher levels of fragility, compared to that of producers and abattoirs is noteworthy. While there are nuances to the sources of uncertainty in the South African lamb chain, the order of overall magnitude of fragility is somewhat similar for most actors (Figure 6).

Therefore, the second observation relates to the differences in the fragility factors per actor and the equal size of the overall fragility per actor. The implication is that large impact, rare events for one actor could foreseeably have a similar impact on another actor, and that such an event would not remotely be on the radar of the second actor. By way of example, given the other players' sequential interdependency with packers in the specific lamb value chain, a change in regulations and compliance requirements at the packer level could, conceivably, have dire spill-over effects for retailers, abattoirs and producers due the golden thread of exposure to quality and safety performance and cash flow uncertainty. While not explicitly analyzed the extent and nature of the sequential interdependency between successive stages of the chain probably explains the phenomenon that the fragility of the individual actors is of a similar magnitude in the particular instance.

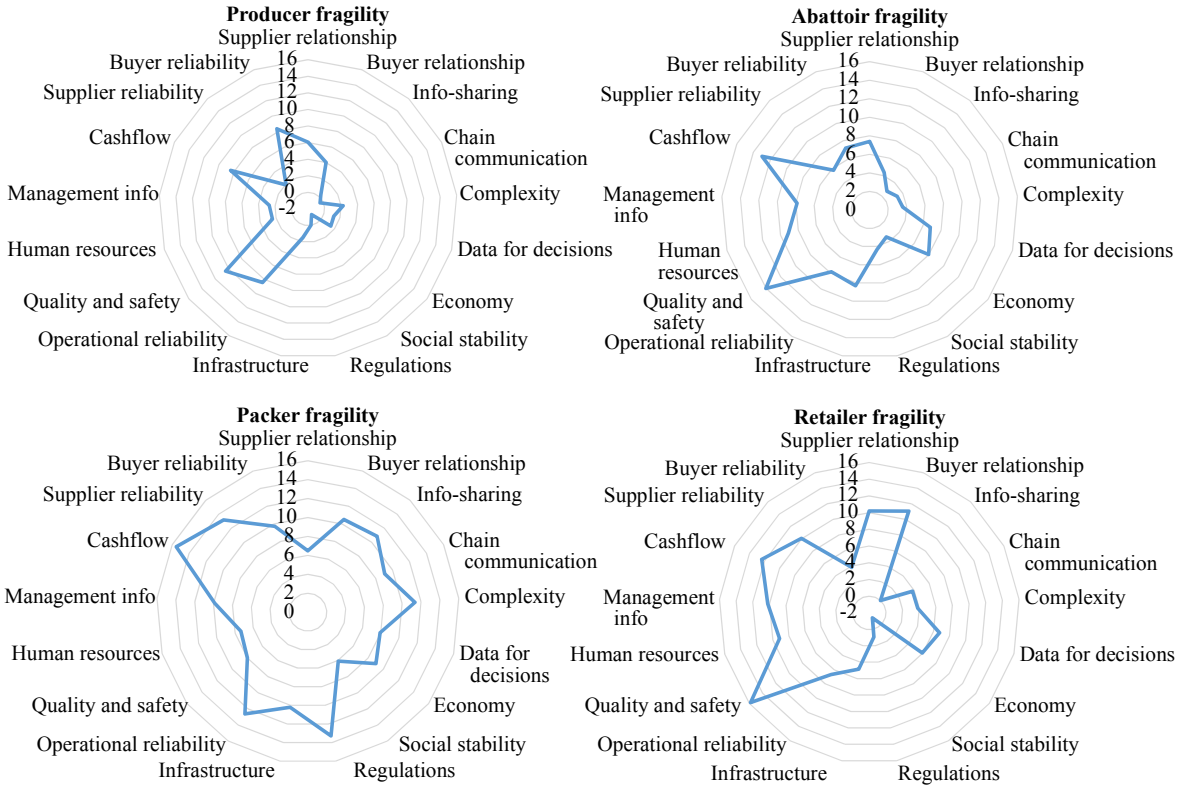

Figure 5. Fragility, per actor, in the typical South African lamb value chain.

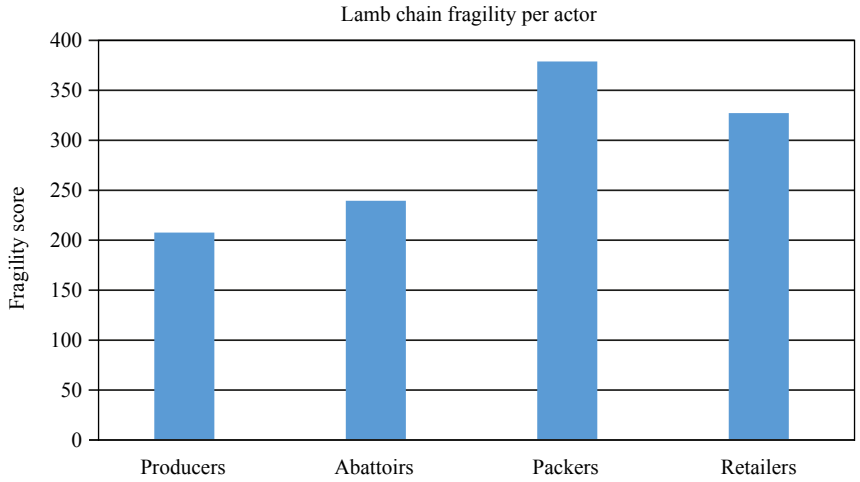

Figure 6. Overall fragility, per actor, in the typical South African lamb value chain.

■ *Value chain fragility*

The ultimate outcome of the fragility analysis is to arrive at metric for value chain fragility. As contemplated, the framework developed in this paper provides a vector for fragility that stretches from the factor to the chain level. In the context of the specific value chain, the vector for the South African lamb value chain amounts to a nondescript value of 166 215, which corresponds to the area of the polygon (Figure 7 below), assembled from the fragility scores of the component parts of the particular chain.

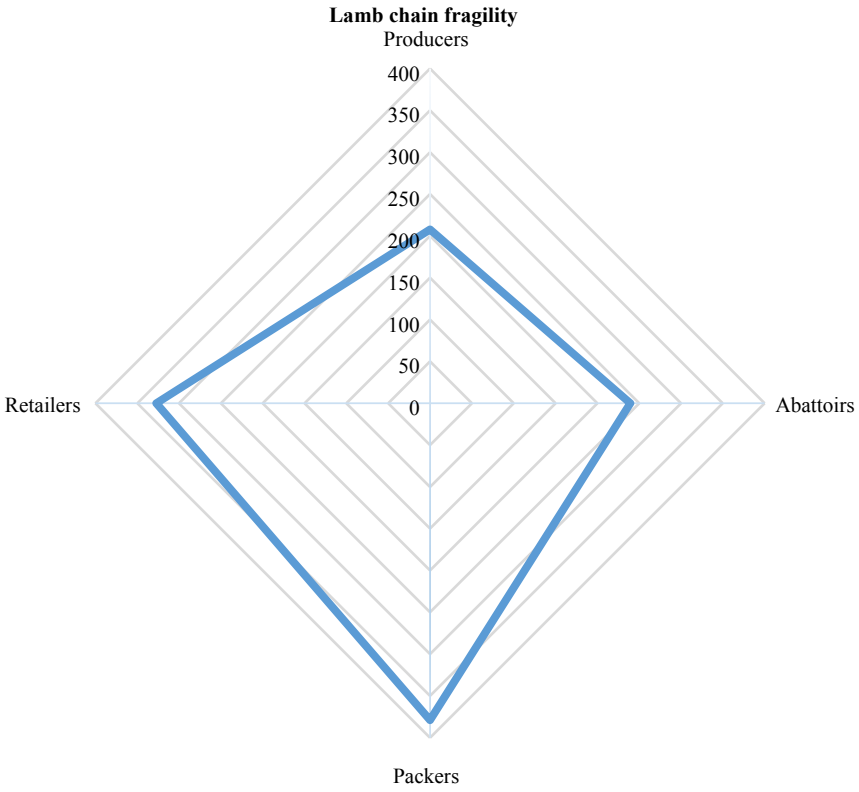

Figure 7: Fragility of the typical South African lamb value chain

While this single outcome of the framework with regard to value chain fragility does not generate an interesting value per se, it does display the process to arrive at a measure for fragility. The outcome is also akin to a sector level benchmark for the overall sector chain. Analogous to the approach used in stress testing and risk analysis, the fragility measure only really comes to fruition through comparative analyses against the benchmark, or of the same entity over time, or of different entities, players or factors at the same time.

5. Discussion

The purpose of the analytical component of this paper was to explore an approach to measure value chain fragility and to use this systematic approach to analyze the design and management of agribusiness value chains. The foray to measure fragility in agribusiness value chains materialized in the context of the South African lamb value chain, and stakeholders in this chain were required to consider specific dimensions of a range of value-chain-fragility factors in their specific context. The process entailed applying the fragility framework to individual factors, then combining these individual factors into composite indices to portray measures of fragility for individual stakeholders and eventually for chains.

5.1 Detection

The development of an operational framework to measure value chain fragility enables the detection of the presence and the extent of fragility at a range of levels in value chains, including for specific variables, stakeholders and chains. Considering the results of the South African lamb value chain case study, it is evident that the framework to measure value chain fragility is capable of detecting non-linear responses following progressive deterioration in the range of fragility factors.

Equivalent to the broad approach of a traditional risk analysis, the fragility analysis evidently accentuates fragility at the variable, stakeholder and chain level, which enables the pinpointing of specific triggers of fragility at whichever level is of interest. Moreover, the measurement of fragility at these different levels of the chain enables comparisons between variables, stakeholders and chains. Such comparisons are useful for identifying and tracking the extent of fragility, on the one hand, and to craft strategies aimed at addressing fragility for specific factors, stakeholders and governance of chains, on the other.

A commentary is also made of the plausible need to explore the initial fragility factors in more depth, particularly the distinction between catalysts and causes of fragility. This distinction is a further layer in the fragility puzzle and Taleb (2012) specifically notes that catalysts are often confused for causes of fragility, focusing the attention on the catalyst rather than the cause. Considering the extent and the nature of the range of value-chain-fragility factors in the successive stages of the South African lamb chain, the fragility of, for example, quality and safety performance, operational reliability, cash flow position, and human resources, raises the suspicion that these factors may well be catalysts rather than causes of fragility in the particular chains.

5.2 Measurement

The results of the analysis also point to the ability of the value-chain-fragility framework to attach a quantified value to the fragility of the component parts and the overall fragility in a chain. Whereas detecting fragility is an important first step, the quantification of fragility is an equally important and logical second step to the whole fragility approach to uncertainty and the exposure to it.

Self-evidently, the framework provides a similar type of outcome to a traditional risk analysis, albeit from a different point of departure, by classifying specific priority factors, actors, etc., based on the extent of their fragility. The ability to measure fragility therefore enables the prioritization of factors for purposes of strategic decision-making at a range of levels in the chain. The key outcome, as in the case with traditional risk analysis, is for chain players and the chain as a whole to be cognizant of the hazard of potentially

devastating uncertainties and to reinvent and manage entities within the chain and the chain itself, mindful of the exposure to these uncertainties.

In the case of the South African lamb value chain, the overarching priority factors are evidently the quality and safety performance and the cash flow position in the chain, given these factors' high ranking fragility scores throughout. Thereafter, activity-specific nuances influence the priority factors for the respective activities in the chain, as determined by the unique attributes of the different activities. These very specific outcomes of the analysis point to the importance for the whole South African lamb chain to limit exposure to adverse events related quality and safety performance and cash flow position so as to manage the fragility of the overall chain. Specific stakeholders are equally tasked with managing exposure to activity-specific fragilities that could cascade into the rest of the chain due to sequential interdependencies in a typical chain.

6. Conclusions

The ability to measure fragility is essential to the domestication of fragility as a phenomenon in the uncertainty landscape. It is arguably easier to determine how fragile (or anti-fragile) a complex system, like an agribusiness value chain, is rather than trying to predict the probability and impact that any of a range of events could have on the system (Aven, 2015; Taleb, 2012). The framework and approach detailed in this paper specifically enables the detection of non-linearity and the quantification of the extent of the non-linearity at the factor, actor, and chain level in response to progressively deteriorating value-chain-fragility factors. This approach is akin to stress-testing (Amini *et al.*, 2012), albeit if for multiple factors and actors aligned in a chain of interdependencies. Ultimately, the framework to measure agribusiness-value-chain fragility provides an entirely alternative, and perhaps more appropriate and elegant, approach to the traditional value chain 'risk assessment' (Jaffee *et al.*, 2008). The ability to measure value chain fragility is particularly valuable in a context where risk and uncertainty are more pervasive, consequential and unpredictable (Aven, 2015; Taleb, 2012), and the responsibility to defend chain durability is more pressing.

Considering the fragility results of the South African lamb chain case study, a number of specific conclusions are noteworthy. The first is that a number of very specific factors, like quality and safety performance, and cash flow position, have consistently high fragility scores, from the production level through to retailing. The second is that while a golden thread does, indeed, pass through the chain, a range of fragilities is also uniquely localized to a specific role-player or activity, which highlights the techno-economic (Dorward *et al.*, 2009) uniqueness of individual specific activities.

In closing, it is pertinent to note that detecting and measuring fragility as demonstrated in this paper is merely the first step for agribusinesses to deal with the fragility phenomenon in value chains. The development and implementation of strategies to avoid or address fragility is the essential second step to fortify value chains in an environment where the consequences of uncertainty are increasingly prevalent, influential and unpredictable. A combination of structural and managerial strategies should address fragility in complex systems like value chain (Taleb, 2012; Taleb and Martin, 2012). A subsidiary approach with decentralization of control with optimal, rather than total, integration in the coordination of activities is the primary structural recommendation while developing and maintaining plain operating procedures, accepting some uncertainty and ensuring that all stakeholders in the chain have metaphorical 'skin in the game' are the primary managerial recommendations to address fragility in chains. Practically, the recommendations suggest that fragility in the South African lamb chain is easier to deal with in a less integrated chain structure with basic procedures and institutions across the chain where all stakeholders are exposed to the losses and benefits that flow from their participation and action in the chain.

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