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A R T I C L E I N F O

Keywords:
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A B S T R A C T

The costs related to occupational safety or, more precisely, non-safety aspects in the industry represent a moral and economic burden for individuals, employers and governments. Despite the importance of these costs, firms rarely recognize the real cost of non-safety and the opportunity to invest in improving their safety management system. The time and resources needed to collect appropriate, historical data for the evaluation of non-safety costs are indeed a problem for firms, most of all for small and medium enterprises. This paper develops a methodology for an ex-ante evaluation of non-safety costs, with a specific focus on SMEs, based on the collection of easily deducible data. In particular, the different cost items related to non-safety costs and the factors influencing them are identified. The cost functions for each cost item and, subsequently, the shapes of the cost functions are determined; this allows to cluster firms according to the shapes of functions of each cost item, as well as to understand which are the main occupational safety and health factors that distinguish different small and medium enterprises into peculiar groups. An example application of the methodology in a sample of Italian SMEs is proposed. The application paves the way to some remarks for policy and industrial decision-makers and advice for further research.

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Non-Safety Costs: A Novel Methodology for an Ex-ante Evaluation

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Highlights

- ✓ Proposal of a novel methodology for an ex-ante evaluation of non-safety costs
- ✓ Identification of a set of relevant and evaluable non-safety costs items
- ✓ Identification of variables and parameters influencing the shape of cost functions
- ✓ Empirical application in Italian industrial SMEs

Abstract

The costs related to occupational safety or, more precisely, non-safety aspects in the industry represent a moral and economic burden for individuals, employers and governments. Despite the importance of these costs, firms rarely recognize the real cost of non-safety and the opportunity to invest in improving their safety management system. The time and resources needed to collect appropriate, historical data for the evaluation of non-safety costs are indeed a problem for firms, most of all for small and medium enterprises. This paper develops a methodology for an ex-ante evaluation of non-safety costs, with a specific focus on SMEs, based on the collection of easily deducible data. In particular, the different cost items related to non-safety costs and the factors influ-encing them are identified. The cost functions for each cost item and, subsequently, the shapes of the cost functions are determined; this allows to cluster firms according to the shapes of functions of each cost item, as well as to understand which are the main occupational safety and health factors that distinguish different small and medium enterprises into peculiar groups. An example application of the methodology in a sample of Italian SMEs is proposed. The application paves the way to some remarks for policy and industrial decision-makers and advice for further research.

Keywords

Safety costs; Non-safety costs; Ex-ante Evaluation; Small and medium enterprises

1. Introduction

Work-related accidents represent a moral and economic burden for society. The total cost linked to work-related accidents is the sum of the cost for individuals, employers and governments, and it includes a non-financial human cost and a financial cost (HSE, 2018a). From a non-financial human cost perspective, every year about 2.3 million people worldwide die in work-related accidents or from diseases (over 6,000 deaths each day), while 340 million and 160 million persons annually are victims, respectively, of occupational accidents and work-related illnesses (ILO, 2019). In EU-28, the last statistics estimated just over 3.2 million non-fatal accidents and 3,876 fatal accidents per year (Eurostat, 2018a), while Italy accounted for 417,000 cases of work-related accidents, of which 617 were fatal (INAIL, 2018). Small-Medium Enterprises (SMEs) are responsible for 82% of all occupational injuries and 90% of all fatal accidents (European Agency for Safety and Health at Work, 2009). In Italy, SMEs represent 99.9% of the totality of firms, of which 95% is made up of companies with fewer than ten employees (European Commission, 2017). SMEs play a relevant industrial role in Europe and Italy, being considered as the key to ensuring economic growth, innovation, job creation and social integration (Cagno et al., 2011; Eurostat, 2018b); as a consequence, there is a general focus on SMEs and their sustainability, which specifically fosters a growing interest from academia and policy-makers in dealing with occupational safety and health in SMEs (Champoux and Brun, 2003; Fabiano et al., 2004; Sørensen et al., 2007), as a key factor in their sustainability.

The financial impact of work-related accidents, also addressed as non-safety costs, is defined as the cost to the firm that arises from an event – incident or accident – or from non-compliance with safety rules and that would have not been incurred if the event had not taken place (Battaglia et al., 2014; Ibarrondo-Dávila et al., 2015). The non-safety costs can be estimated at around 3.9% of the global Gross Domestic Product (GDP), roughly € 2,680 billion (Battaglia et al., 2014; EU-OHSA, 2017). The cost for Europe is estimated to be 3.3% of the GDP, equivalent to € 476 billion, while for Italy it is around 3% of the national GDP, approximately € 45 billion, associated with the loss of 11 million days of work (INAIL, 2018; Valenti, 2008). According to HSE (2018b), firms are bearing 20% of these costs, leading to an unneglectable economic burden (Jallon et al., 2011). The cost related to non-safety could be avoided by preventing work-related accidents and incidents from occurring (Rikhardsson, 2006): further drivers and incentives for industrial decision-makers towards increased investments in health and safety could come from understanding the actual financial consequences a work-related accident and incident (Feng et al., 2015; Masi et al., 2019; Rikhardsson, 2004).

The evaluation of non-safety costs, therefore, becomes a very critical aspect. Despite research efforts in work-related accidents and incidents costing, with the proposal of diverse methods (Kim, 2018), the evaluation of non-safety costs does not seems to be a common practice among firms yet (Battaglia et al., 2014; Jallon et al., 2011). A proper evaluation of costs, indeed, requires an understanding of all aspects related to safety, beyond the direct and visible financial dimension (Jallon et al., 2011). As a matter of fact, safety and health management contributes in different ways to the success of firms, as not caring about safety and health may lead to costs related to loss of profit, productivity, efficiency, the firm's image and competitiveness (Akcay et al., 2018; Mossink and Greef, 2002). The hidden and indirect aspects must be expressed in monetary terms so to be understood by industrial decision-makers (Jallon et al., 2011; Tappura et al., 2015) but these aspects are difficult to be quantified (Jung and Baek, 2017; Rohani et al., 2015b): tracking the costs of work-related accidents is therefore fundamental for being able to quantify the non-safety costs (Rohani et al., 2015a). However, quantifying economic impact requires resources for the collection of reliable and significant historical data related to past events (López-Alonso et al., 2016), and industrial decision-makers face several barriers to this process (Biddle et al., 2005). The situation becomes even more critical in SMEs, characterized by limited financial and human resources, compared to medium and larger firms (Barbeau et al., 2004; Bonafede et al., 2016; Hasle and Limborg, 2006; McKinney, 2002), and these limited resources negatively influence the firm's capability to evaluate the cost of work-related accidents (Cagno et al., 2014). Moreover, at a single SME's level, the frequency of occurrence of work-related accidents is very low, so historical data is basically not available, given the low frequency of the events, and scarcely reliable, given the lower formal activities initiated after an accident (Rikhardsson and Impgaard, 2004). Additionally, the low work-related accident occurrence makes both industrial decision-makers and workers to feel safe (Masi et al., 2019; Micheli et al., 2018), which, in turn, leads to limited investments in safety and health (Cagno et al., 2013; Hasle et al., 2009).

The non-safety cost evaluation approaches proposed in the extant literature (top-down, bottom-up, local) present strong trade-offs between accuracy and generalizability and between availability and quality of the data (Jallon et al., 2011; Rohani et al., 2015b). Moreover, the proposed approaches are focussing on ex-post evaluation of non-safety costs, meaning that they allow an evaluation of the cost only after an event has taken place and only if proper data are available and have been collected. Additionally, very few of these approaches have been developed considering the necessity of SMEs (Cagno et al., 2013).

This paper aims to develop a methodology for the ex-ante evaluation of non-safety costs (Rechenthin, 2004; Rikhardsson and Impgaard, 2004), suitable for any firm, with a specific focus on SMEs (Cagno et al., 2013; Jallon et al., 2011; Rikhardsson and Impgaard, 2004), and based on quality and easily deducible data. This methodology would allow firms to evaluate the cost associated with a work-related accident or incident before it occurs, with the final aim of fostering the investment in prevention as well as the adoption of prevention programmes (Feng et al., 2015; Rikhardsson, 2004). The first step is to identify the different cost items related to non-safety aspects and the factors influencing them (Section 2). After this, the cost functions for each cost item are determined, based on estimators derived from the influencing factors, and subsequently, the shapes of the cost functions are identified, and firms are clustered according to the shape of the functions of each cost item (Section 3). The new methodology is then applied to a set of Italian SMEs (Section 4), and discussion on the results, together with limitations and future streams of research, is offered (Section 5).

2. Background analysis

2.1. The cost of non-safety

Non-safety costs have been studied in the literature for quite a long time. The extant literature proposes several classifications, but an agreement on the cost types and definitions has not been met yet (Gosselin, 2004). The main classifications are reported in the following, providing an overview of the complexity of the issue:

- **Visible and hidden costs**: costs are divided in cost easy to identify, isolate and quantify, and costs difficult to quantify or not directly ascribable to the event (Corcoran, 2002).
- **Direct and indirect costs**: direct costs can be directly associated with the event; indirect costs occur after the event but cannot be immediately associated with it (Hinze and Appelgate, 1991).
- **Insured and uninsured costs**: insurance costs are handled through an insurance policy, whilst uninsured costs are borne by the employers and not covered by the insurance policy (Simonds and Grimaldi, 1956).
- **Fixed, variable and disturbance costs**: fixed costs are related to the event but don't depend on the duration of the event; variable costs increase with increasing days of absence; disturbance

costs depend on both the characteristics of the event and the employment position of the injured worker (Rikhardsson and Impgaard, 2004).

- **Internal and external costs**: internal costs are incurred by firms; external costs are attributed to the activity of the firm but not incurred by firms.
- **Tangible and intangible costs**: tangible costs are produced directly by a specific event and can be quantified by conventional calculation methods; intangible costs are not monetary consequences and can be very difficult to measure (Riaño-Casallas and Tompa, 2018).
- **Event-related costs and general injury situation-related costs**: event-related costs emerged as a consequence of a specific event and depend on the characteristics of the event itself; costs related to the general injury situation are related to the general safety situation characterizing the firm.
- **Classification by nature**: costs are classified based on the cause that generates them.

A recent reclassification of costs has been proposed by Micheli et al. (2015), who reclassified all the costs found in literature according to their nature, taking a stand with regards to the discordant aspects of the previous classifications. This reclassification was deemed as necessary by the authors to have a coherent overview of all the possible economic losses incurred by a firm due to work-related accidents, underlying the lack of homogeneity with which the different costs were classified (Rikhardsson and Impgaard, 2004).

An analysis of recently published contributions about non-safety costs has been performed to confirm the cost items identified by Micheli et al. (2015). Table 1 shows the different cost categories with the related cost items, with a detail of the different references addressing the specific cost item, thus basically further validating and confirming the previous research. Here in Table 1, we re-ordered the cost categories proposed by Micheli et al. (2015), listing them in order of occurrence after the work-related accident.

Cost categories	Cost items	Heinrich (1959)	Bird and Germain (1966)	Andreoni (1986)	Laufer (1987)	Leopold and Leonard (1987)	Usi-Rauva et al. (1988)	Miller and Rossman (1990)	Hinze and Appelgate (1991)	Miller and Galbraith (1995)	Aaltonen et al. (1996)	Aaltonen and Miettinen (1997)	Head and Mark (1997)	Holland and Gibbon (1997)	Leigh et al. (1997)	Miller (1997)	Monnery (1998)	Neville (1998)	Riel and Imbeau (1998)	Dorman (2000)	LaBelle (2000)	Leigh et al. (2001)	Reville et al. (2001)	Osterhaudt (2002)	Rikhardsson (2004)	Rikhardsson and Impgaard	Oxenburgh and Marlow (2005)	Leigh et al. (2006)	Sun et al. (2006)	Gavious et al. (2009)	Jallon et al. (2011)	Guimarães et al. (2012)	Battaglia et al. (2014)	Ibarrondo-Dávila et al. (2015)	Rohani et al. (2015a)	Rohani et al. (2015b)	López-Alonso et al. (2016)	Jung and Baek (2017)	Kim (2018)
Medical costs	Medical costs	•	•						•		•					•					•								•	•	•		•	•		•			
Administrative costs	Cost of administrative staff									•												•				•		•	•		•		•	•	•	•	•	•	•
	Cost of internal investigation		•						•			•	•			•						•						•		•	•		•	•	•	•	•	•	•
	Cost of time lost by supervisors and managers								•							•					•	•				•	•	•	•	•	•		•	•	•	•	•	•	•
Insurance costs	Insurance costs						•		•			•				•			•				•	•		•		•		•	•		•	•	•	•	•	•	•
Communication costs	Communication costs								•																	•							•						
Production costs	Cost due to cancellation of orders and penalties							•			•													•						•	•		•	•	•	•	•	•	
	Cost due to reduced productivity of the injured employee								•		•					•		•			•												•		•	•		•	
	Cost of lost production							•	•																				•			•	•	•	•	•	•		
	Cost of time lost by injured employee	•	•		•				•		•		•				•								•	•	•			•				•	•	•	•	•	•
	Cost of time lost by other employees										•			•		•		•							•	•			•		•			•	•	•	•	•	
	Overtime cost															•		•									•				•		•		•	•			
	Strike cost[1]																																						
Costs due to damage to goods and property	Cost due to damage to equipment and machinery		•		•	•			•				•		•			•		•				•	•		•		•	•	•		•		•	•	•	•	
	Cost due to damage to materials																•					•						•		•	•			•			•		
	Cost due to damage to structures																							•			•				•			•			•		
	Cost due to damage to the product		•								•	•				•								•			•		•		•			•	•	•	•		
Costs of turnover	Cost of turnover																										•				•	•							
Replacement costs	Cost due to reduced productivity of the substitute							•	•																	•					•				•	•		•	•
	Recruitment and selection cost												•											•	•	•	•		•	•	•		•		•	•		•	•
	Training cost		•					•	•		•																•				•		•		•	•		•	•
Court costs	Cost of external investigation																								•								•	•	•	•	•	•	
	Cost of fines and compensations										•		•											•	•	•				•			•	•			•	•	•
	Legal cost									•	•							•											•				•	•	•	•	•	•	•
Intangible costs	Cost for decrease of the morale of employees			•																					•		•		•	•	•			•	•	•	•		
	Reputation cost			•					•		•													•						•	•					•			

Table 1. Cost categories and cost items. Detail of the cost categories and the cost items proposed by Micheli et al. (2015), with related literature references.

[1] *Strike cost* was deemed as relevant by the experts taking part in the focus group conducted by Micheli et al. (2015). We included it in Table 1, the exant literature does not identify it.

Considering their limited availability of resources (Cagno et al., 2013; McKinney, 2002; Micheli and Cagno, 2010), SMEs may face several problems in dealing with the identification, evaluation and tracking of the 26 costs reported in Table 1: the effort devoted to the evaluations of non-safety costs is limited, the data and information on which these evaluations based are sparse, and the collection of data is perceived as resources are consumed (Biddle et al., 2005). The literature has thus underlined the need for simple and customizable solutions for SMEs, given their informal culture (Champoux and Brun, 2003; Hasle and Limborg, 2006). In this regard, Micheli et al. (2015) further developed their model reported in Table 1, proposing a reduced list of cost items, selecting them according to *Relevance* (impact of each cost item on the total non-safety cost) and *Evaluability* (accuracy in the definition of the cost amount from a pre-event perspective). The two characteristics were assessed by Micheli et al. (2015) according to the results that emerged from the literature review and a focus group, and recent studies further validating the previous research (Table 2). The selected costs are graphically reported in Figure 1 and described in Table 3.

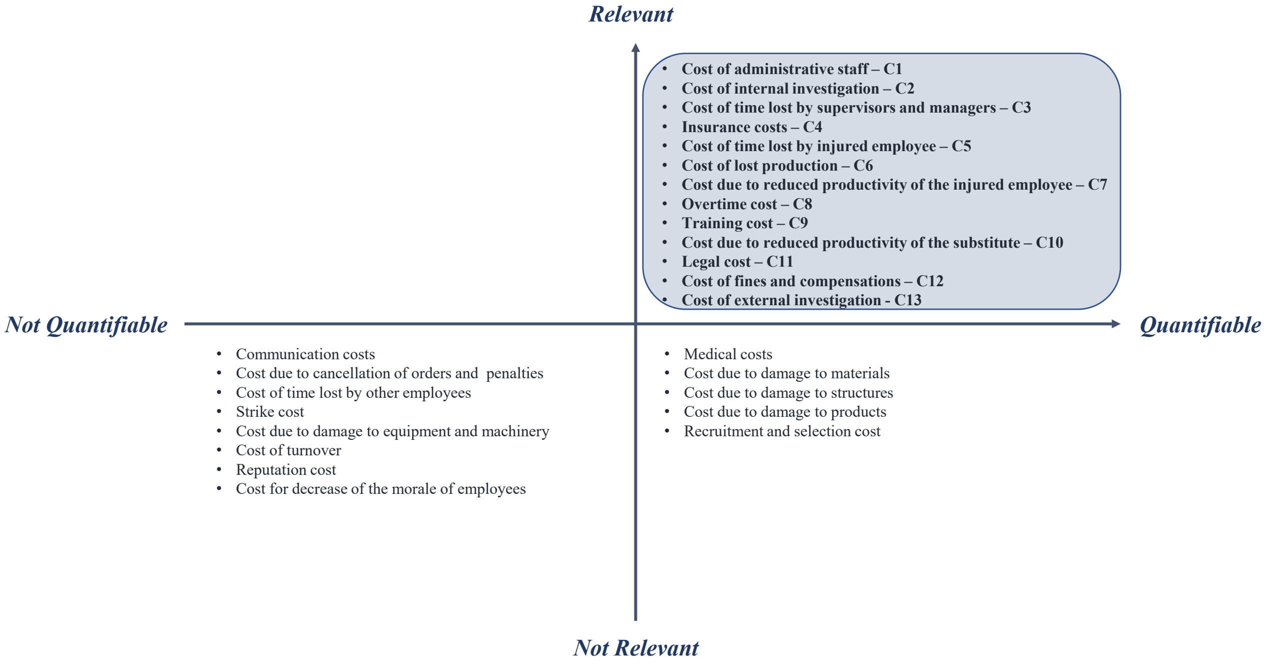
Categories	Cost Items	Relevance			Ex post Evaluability		Ex-ante Evaluability
		Literature (Micheli et al., 2015)	New literature	Focus group (Micheli et al., 2015)	Literature (Micheli et al., 2015)	New literature	Focus group (Micheli et al., 2015)
Medical costs	Medical costs			-	••		••
Administrative costs	Cost of administrative staff	••	Battaglia et al. (2014), Jung and Baek (2017)	•	•		•
	Cost of internal investigation		Battaglia et al. (2014), Jung and Baek (2017)	•	•		•
	Cost of time lost by supervisors and managers	••	Battaglia et al. (2014), Jung and Baek (2017)	•	•		•
Insurance costs	Insurance costs		Battaglia et al. (2014), Jung and Baek (2017)	••	•		••
Communication costs	Communication costs	-		-			-
Production costs	Cost due to cancellation of orders and penalties			°			
	Cost of time lost by injured employee	••		•	••		••
	Cost of time lost by other employees			-	-		-
	Cost of lost production		Battaglia et al. (2014), Jung and Baek (2017)	••			•
	Cost due to reduced productivity of the injured employee	°	Battaglia et al. (2014)	°			•
	Overtime cost	••	Battaglia et al. (2014)	•			•
	Strike cost			°			
Costs due to damage to goods and property	Cost due to damage to equipment and machinery	°	Battaglia et al. (2014), Jung and Baek (2017), Rohani et al. (2015b)	-	•	Ibarrondo-Dávila et al. (2015), López-Alonso et al. (2016) – **based on maintenance costs**	•
	Cost due to damage to materials			-			•
	Cost due to damage to structures	°		-			•
	Cost due to damage to the products	°	Rohani et al. (2015b)	-	•		•
Costs of turnover.	Costs of turnover	••		-	-		-
Replacement costs	Recruitment and selection cost	°	Jung and Baek (2017)	-			•
	Training cost	°		°	-		•
	Cost due to reduced productivity of the substitute		Battaglia et al. (2014), Jung and Baek (2017)	•			•
Legal costs	Legal costs		Jung and Baek (2017) – **in specific cases**	°	•		•
	Cost of fines and compensation		Battaglia et al. (2014), Jung and Baek (2017)	°	•		•
	Cost of external investigation		Battaglia et al. (2014), Jung and Baek (2017)	°			•
Intangible costs	Cost for decrease of the morale of employees	°		-	-	Ibarrondo-Dávila et al. (2015), Rohani et al. (2015a) – **difficult to be estimated**	-
	Reputation cost			°	-	Ibarrondo-Dávila et al. (2015), Rohani et al. (2015a) – **difficult to be estimated**	-

Table 2. Non-Safety cost item relevance and evaluability - amended from Micheli et al. (2015).

Legend:

- **Relevance: -** (*not relevant); • (scarcely relevant); °(relevant in specific situations);* •• (*relevant*)
- **Ex post evaluability**: - (*not evaluable); •* (*disagreement on evaluability / evaluated in papers*); •• (*evaluable)*
- **Ex ante evaluability**: - (*not evaluable); • (limited evaluability)*; •• (*evaluable)*

Figure 1. Selection of the relevant and quantifiable non-safety cost items.



Cost category	Code	Cost Item	Description
Administrative costs	C1	Cost of administrative staff	Cost of time spent by administrative staff on handling the case.
	C2	Time lost by supervisors and managers	Cost of time lost by supervisors and managers to assist the injured worker, re-programme production, hire and train substitutes, attend meetings and report.
	C3	Cost of internal investigation	Cost of the time spent for investigating the causes of the accident, necessary to complete the administrative documentation.
Insurance costs	C4	Insurance costs	Increased insurance premium, i.e. the percentage of increase considering a certain sample of events.
Production costs	C5	Cost due to reduced productivity of the injured employee	The employer loses productivity when an employee works below his/her capacity or is assigned to less demanding activities due to the consequences of an accident. This generates a cost for the firm because the amount of output produced is lower than that of the previous working conditions.
	C6	Cost of lost production	Cost of the slowdown in work and production stop caused by the accident.
	C7	Cost of time lost by injured employee	The employer has to pay the due remuneration to the injured employee in the accident period that is not indemnified by INAIL; this may include salary additions if they are provided by firm policy.
	C8	Overtime cost	Cost related to the employment of extraordinary hours of work so to recover lost production due to the accident.
Replacement costs	C9	Training cost	Cost for the training of the new hire.
	C10	Cost due to reduced productivity of the substitute	Cost related to the time needed by the new hire to achieve full productivity, given their lack of experience.
Court costs	C11	Legal costs	Costs incurred by the firm to defend itself from accusations of liability.
	C12	Cost of fines and compensation	Cost of fines and compensations related to the violations of safety procedures and legislation.
	C13	Cost of external investigation	Cost of time spent by authorities and safety consultants for investigating the causes of the accident.

Table 3. Descriptions of non-safety cost items.

2.2. The evaluation of non-safety costs

The evaluation of non-safety costs is rather challenging, given the complexity of cost allocation and the inadequacy of the available data (López-Alonso et al., 2016; Rikhardsson and Impgaard, 2004), as well as the considerable commitment required from the firm (Battaglia et al., 2014). On the one hand, the analysis of such costs would reinforce the importance of prevention (Battaglia et al., 2014). On the other hand, industrial decision-makers consider cost evaluation to be a lengthy process requiring proper expertise to be carried out (Gavious et al., 2009; Rohani et al., 2015a). The literature has largely underlined the need for a simple (Rohani et al., 2015a) and easy to use (Cagno et al., 2013) methodology for cost evaluation, relying on a collection of data limited to those records already available in the firm (Cagno et al., 2013).

2.2.1. Evaluation approaches

The extant literature proposes three main approaches for the evaluation of costs, namely Top Down, Bottom Up and Local, each of them showing a compromise between time spent on data collection and accuracy and reliability (in terms of correctness, completeness and consistency) of the data and the results (Jallon et al., 2011; Rohani et al., 2015b).

- **Top-Down**: it provides an average cost per worker, using aggregate data and with a strong generalized perspective. The Top-Down approach generally uses data derived from national statistics or results of previous studies and does not require any further data collection. This approach provides decision-makers with an approximate idea of non-safety costs whose validity can be questioned. In particular, the specific characteristics of a firm (e.g., the size) or of an event (e.g., the duration) that might influence the cost are ignored, while it has been largely demonstrated that firms, particularly SMEs, should be addressed by focussing on the specific characteristics of each (Micheli and Cagno, 2010; Trianni et al., 2019). An application of this approach can be found in Thepaksorn and Pongpanich (2014) and in the model developed by INAIL, the Italian National Institute for Insurance against Accidents at Work (Cagno et al., 2013).
- **Bottom-Up**: it provides an average cost for each industrial sector or event type. The data used are local and usually collected through surveys, questionnaires or interviews considering a limited sample. The accuracy of the collected data is very high, but the approach has a limited scope –

since only proactive firms can effectively contribute to the collection of the data – and the generalizability of the method can be questioned, given that the specific firm's non-safety cost may differ significantly from the average costs' estimates. An application of this approach can be found in Battaglia et al. (2014), Feng et al. (2015), Jung and Baek (2017) and Toutounchian et al. (2018).

- **Local**: it allows the single decision-maker to accurately assess the non-safety costs by collecting their data using tables and guidelines. The approach can be used for performing a cost-benefit analysis or for identifying preventive measures. It is based on the examination of the records of past internal accidents. It is very accurate, but rather resource-consuming, and based on the actual availability of historical data. Moreover, the obtained results are limited to a specific firm, so that the cost evaluation cannot be extended to others. Examples of this approach are the ACT method (Aaltonen et al., 1996; Uusi-Rauva et al., 1988), the ABC method (Riel and Imbeau, 1998) or the SACA method (Rikhardsson, 2004; Rikhardsson and Impgaard, 2004).

The main characteristics of the three approaches are reported in Table 4. In particular, the trade-off between accuracy and generalizability of the results can be underlined, as well as the trade-off between the availability of the data and quality of the data. Moreover, interesting to note, all the above-mentioned approaches proposed an ex-post evaluation of the cost, both real-time and post-hoc (Rikhardsson, 2006): they are thus able to provide an evaluation of the non-safety costs only after the occurrence of the event.

	Approach		
	Top-Down	Bottom-Up	Local
Accuracy	Low	Medium	High
Generalizability	High	Medium	Low
Availability of data	High	Medium	Low
Quality of data	Low	Medium	High
Data collection	Ex- post	Ex- post	Ex- post

Table 4. Characteristics of the different approaches for the evaluation of non-safety costs.

2.2.2. Data collection: the ex-ante perspective and the need for estimators

The above-mentioned approaches (Table 4) are all based on the collection of historical data and ex-post evaluation. Firms face several difficulties in gathering historical data related to past events (Lahiri et al., 2005), mainly because of the time required and the level of accuracy needed (Jallon et al., 2011). An easy methodology for non-safety cost assessment should not require more information than what is available at the time of the event (Sun et al., 2006). A shift from the ex-post perspective to an ex-ante one would allow the assessment of non-safety costs without the need for consistent and reliable historical data to properly quantify them (Micheli et al., 2015). Moreover, the extant literature suggested that to understand the real cost of non-safety, it is necessary to calculate the costs of an event that has not happened yet (Rechenthin, 2004; Rikhardsson and Impgaard, 2004).

However, up to now, an ex-ante evaluation has been deemed as impossible (Toutounchian et al., 2018). One of the main issues lies in the fact that being able to quantify ex-ante, means to be able to identify those factors that influence each specific cost. The literature provides some hints regarding the nature of these factors, which can be classified according to two main areas: the characteristics of the accident and the characteristics of the firm (Table 5).

Area	Factor	Reference
Accident	Type of accident	Jallon et al. (2011), Rikhardsson (2006), Rikhardsson and Impgaard (2004), Sun et al., (2006)
	Accident frequency	Feng et al. (2015;), Micheli et al. (2015)
	Accident severity	Battaglia et al. (2014), Carrillo-Castrillo et al. (2013); Jallon et al. (2011), Rohani et al. (2015b)
	Days of absence	Battaglia et al. (2014), Jallon et al. (2011), Micheli et al. (2015), Rikhardsson (2006), Rikhardsson and Impgaard (2004)
Firm	Firm size	Akcay et al. (2018); Feng et al. (2015); Micheli et al. (2015); Rikhardsson and Impgaard (2004)
	Industrial sector	Feng et al. (2015), Jallon et al. (2011), Micheli et al. (2015), Rohani et al. (2015b), Sun et al. (2006)
	Wage structure and salary	Micheli et al. (2015), Rikhardsson (2006), Rikhardsson and Impgaard (2004)
	Specific occupation	Micheli et al. (2015), Sun et al. (2006)

Table 5. Factors that influence non-safety costs, as identified in the literature.

2.2.3. Dependence of the selected cost items on the influencing factors

A preliminary overview of the influence of the factors has been proposed by Micheli et al. (2015). They divided the factors into variables (*Number of events; Length of absence*) and parameters (*Firm size; Manufacturing sector; Salary of the injured worker; Complexity of the job*), and evaluated the dependence of each cost item on both variables and parameters (Table 6). However, how and to what extent the influencing factors affect the specific cost item has not been evaluated yet.

		Cost Items	Variables		Parameters			
			Z_1 *Number of events*	Z_2 *Length of absences*	Θ_1 *Firm size*	Θ_2 *Manufacturing sector*	Θ_3 *Salary of the injured worker*	Θ_4 *Complexity of the job*
Administrative costs	C1	Cost of administrative staff	•		•			
	C2	Cost of internal investigation	•					
	C3	Cost of time lost by supervisors and managers	•					
Insurance costs	C4	Insurance cost	•	•		•		
Production costs	C5	Cost of time lost by injured employee	•	•			•	
	C6	Cost of lost production	•	•				
	C7	Cost due to reduced productivity of the injured employee	•	•	•			•
	C8	Overtime cost	•	•			•	
Replacement costs	C9	Training cost	•	•				•
	C10	Cost due to reduced productivity of the substitute	•	•				•
Court costs	C11	Legal cost	•	•				
	C12	Cost of fines and compensations	•	•				
	C13	Cost of external investigation	•	•				

Table 6. Variables and parameters influencing the non-safety cost items and dependence of each cost item.

2.3. Research objective

The aim of the present work is to to develop an approach for the ex-ante evaluation of non-safety costs that is accurate but also allows generalizability, based on the collection of easily deducible, quality data that is suitable for any firm, with a specific focus on SMEs.

As a proper evaluation of non-safety costs is indeed necessary as often firms are not adequately able to quantify them (Biddle et al., 2005), the ex-ante perspective is necessary to carry out an effective evaluation of non-safety costs (Rechenthin, 2004), also allowing proper budgeting for safety investments (Rikhardsson and Impgaard, 2004). The ex-ante approach does not require consistent and reliable historical data to quantify non-safety costs (Micheli et al., 2015)**,** thus overcoming issues related to the extant cost evaluation methods considered by industrial decision-makers (Jallon et al., 2011), particularly in SMEs (Bonafede et al., 2016; Micheli and Cagno, 2010). On the other hand, an ex-ante evaluation of cost would require the quantification of the factors influencing the different cost items, more specifically the variables related to the characteristics of a specific event, and the parameters related to the characteristics of the specific firm (Akcay et al., 2018; Battaglia et al., 2014; Feng et al., 2015; Rikhardsson and Impgaard, 2004; Rohani et al., 2015b; Sun et al., 2006).

The identification of estimators for each factor and the evaluation of the extent to which each factor influences the cost items would allow the characterization of each cost item with a cost function, whose shape will change according to the different values of variables and parameters. Given the dependence of the shape of the cost functions on variables and parameters, it would be possible to identify clusters of application for each specific cost function, allowing an ex-ante evaluation of the non-safety costs, based on data easily available within firms. We deem such a methodology to provide results easy to interpret and representative of the specific business reality, based on available data, and customizable, based on the needs of different firms.

3. Developing an ex-ante methodology for the evaluation of non-safety costs

3.1. The development of the cost functions

According to Micheli et al. (2015), each cost item C_i can be represented as a function of different independent variables Z_m - with *n* indicating the number of the variable, particularly (see Table 6) *n*=1, 2 - and parameters θ_n - with *m* indicating the number of the parameter, particularly (see Table 6) *m*=1,2, 3,4 - as expressed by (1).

$$C_i = f(Z_m, \theta_n) \quad (1)$$

Variables and parameters have already been identified (Table 6), but it is now necessary to define an estimator to represent each of these factors – variables and parameters – influencing the cost items. Basing on the factors identified by Micheli et al. (2015), the following estimators are proposed:

- ***Z_1* = number of events.** The number of events represents the number of accidents and incidents. This number can be considered according to two different perspectives: i) the **number of events (n)**, allows us to evaluate the total dimension of a cost based on how many events we are considering; ii) the **frequency index (FI)**, defined as the number of events over the total of worked hours, allows us to compare different situations, given that the occurrence of an event has a different impact on firms with different characteristics.
- ***Z_2* = Duration of absence.** The duration of the absence can be considered according to two perspectives: i) the **average duration (AD)** of the event, that can then be further specified in $AD_{replacement}$ (days of absence that make it convenient to get a replacement) and $AD_{reference}$ (average reference duration, assumed to be 15 days); ii) the **severity index (SI)**, defined as total

days of absence over total hours worked, allows us to compare different situations, given that the occurrence of an event has a different impact on firms with different characteristics.

- ***Θ_1 = Firm size.*** The firm size can be evaluated based on the number of employees or turnover. In this research the **number of employees** has been chosen, representing the availability of personnel of the firm.
- ***Θ_2 = Manufacturing sector***. The impact of the manufacturing sector can be estimated based on **sector insurance costs**. The sector insurance cost is defined according to the level of risk associated with a specific manufacturing sector, considering the type of industry as a predictor that can give an account of the major differences in terms of benefits and policies.
- ***Θ_3 = Salary of the injured worker.*** The parameter can be identified using the **gross daily pay**.
- ***Θ_4 = Complexity of the job.*** The complexity of the job can be evaluated based on the **training days**. These are related to the days needed for the substitute worker to learn and properly perform the activities related to the role of the injured worker. The underpinning assumption is that the more complex the job, the greater amount of time for training will be required.

After identifying the estimators, it is now possible to define the cost function for each of the 13 cost items, i.e. to understand how and to what extent each influencing factor affects the specific cost.

As previously acknowledged, cost functions are necessary for achieving a realistic assessment of the cost items, allowing the industrial decision-makers to estimate the economic impact of an event before it occurs. The cost functions were identified with the help of a focus group.

A focus group is a team approach, in which an appropriate number of specialists discuss the subject matter in a group conducted by moderators. This method is characterized by structured meetings, which allow members to recreate a situation similar to ordinary opinion focusing and information exchanging in a free-like communication style. The group is composed of an expert panel, which includes a meeting facilitator and a few informal participants, with the necessary in-depth knowledge about the SME environment.

The purpose of the discussion addressing each of the 13 relevant-quantifiable cost items, is twofold: i) highlighting the estimators – variables and parameters – to be considered; ii) identifying the shape of the functions.

Following relatively recent methodological directions (as in Newnam et al., 2019; Sandelowski, 2004; Weber et al., 2018), 6 people were involved in the focus group, in addition to a facilitator. Specifically, 2 Owners of SMEs (approximately 10 and 20 years experience), 2 Responsibles for OSH in SMEs (approximately 4 and 15 years experience), 1 senior researcher in Industrial Engineering (approximately 10 years experience) and 1 SMEs consultant for OSH (approximately 15 years experience). They were recruited on a voluntary basis, after sharing the scope of this research through local (Lecco area, Northern Italy) Associations of SMEs Owners. The total amount of time that spent in meetings is approximately 25 hours, split into 5 comparable meetings. The participants were instructed before the meeting, and the facilitator (a researcher in Industrial Engineering with approximately 4 years experience) used to recap the past meetings whenever a new one started. The first meeting was comprehensive if compared to the remaining 4; these 4, instead, were specifically devoted to the cost functions. A couple of junior researchers were in charge of taking notes, which were then distributed and validated before every next meeting.

The results of the focus group in terms of estimators involved in the definition of each cost item and the proposed cost functions are reported in Table 7.

Cost category	Cost items	C	Cost functions	Unknown vector
Administrative costs	Cost of administrative staff	C1	$C_1 = \alpha_{pa} * n * \theta_1$	$\boldsymbol{\alpha_{pa}}$
	Cost of internal investigation and time lost by supervisors and managers	C2 ; C3	$C_{2+3} = \alpha_{tsi} * n$	$\boldsymbol{\alpha_{tsi}}$
Insurance costs	Insurance costs	C4	$C_4 = \alpha_a * FI * SI * \theta_2$	$\boldsymbol{\alpha_a}$
Production costs	Cost of time lost by injured employee	C5	$C_5 = \alpha_{ti} * n * AD * \theta_3$	$\boldsymbol{\alpha_{ti}}$
	Cost of lost production	C6	$C_6 = \alpha_{mp} * n * AD^2 * (\theta_1)^{-1}$	$\boldsymbol{\alpha_{mp}}$
	Cost due to reduced productivity of the injured employee	C7	$C_7 = \alpha_{rpi} * n * AD * \theta_4$	$\boldsymbol{\alpha_{rpi}}$
	Overtime cost	C8	$C_8 = \alpha_s * n * AD * \theta_3$.; for $AD \leq AD_{replacemnet}$	$\boldsymbol{\alpha_s}$
Replacement costs	Training cost	C9	$C_9 = \alpha_{as} * n * AD^2 * \theta_4$; for $AD \geq AD_{replacemnet}$	$\boldsymbol{\alpha_{as}}$
	Cost due to reduced productivity of the substitute	C10	$C_{10} = \alpha_{rps} * n * AD * \theta_4$; for $AD \geq AD_{replacemnet}$	$\boldsymbol{\alpha_{rps}}$
Court costs	Legal cost, Cost of fines and compensations, and Cost of external investigation	C11; C12 ; C13	$C_{11+12+13} = \alpha_g * n * (AD/AD_{reference})^2$	$\boldsymbol{\alpha_g}$

Table 7. The identified cost function for each selected cost item.

As it can be inferred from Table 7, every cost function presents an unknown vector α that depends on the context in which the event takes place and on the event's characteristics. The α makes the different functions vary in terms of the relevance of the different variables and parameters, determining the shape of the single cost function. Firms with similar characteristics, in which similar events take place, might thus have the same shape of cost functions, characterized by a close value of the unknown vector α. This would make it possible to cluster together firms characterized by the same value of α for the specific cost items. Identifying their own characteristics, firms would be able to select the right shape of the cost functions so as to perform an ex-ante evaluation of the non-safety costs.

3.2. Development of the shape of the cost functions

3.2.1. Estimation of the α

In order to define the shape of the cost functions, the value of the unknown vector α must be identified. The process is composed of 4 steps, explained below.

- *Step 1: Data acquisition.* In this step, the value of the different variables and parameters needed for the evaluation of each cost item (as reported in Table 7) are identified within the firm. Data acquisition can be carried out through interviews with employers and the safety managers, asking them to economically quantify an event significant to their firm, according to each cost item, in order to so to create a dataset consisting of input estimators for each cost function (n, AD, FI[2] ,

[2] *FI – Frequency index*: the data can be obtained from INAIL web database.

SI[3] , θ_1 , θ_2[4] , θ_3[5] , θ_4) and the related cost value ($C_{j.}$). A significant event can be identified through the Risk Evaluation Document (RED). This document provides a complete picture of the risk distribution for a firm and allows the identification of the risks associated with the different tasks performed, providing the level of likelihood and the level of consequences for each task.

- *Step 2: Multivariate cluster observation.* To identified firms with similar characteristics, in which similar events take place, a hierarchical clustering should be applied, by using (having no clues whether different distances might perform better) for example the Euclidean distance as a metric. Cluster analysis is a data investigation tool for separating a multivariate dataset into natural groups, i.e. the clusters. As a starting point, each observation is put in its distinct cluster. The distance among all the clusters is computed and the two closest clusters – the ones for which the value in terms of Euclidean distance matrix is the lowest – are coupled into a new cluster. It then computes all the distances between all the observations and couples the two closest ones to obtain a new cluster. The procedure continues until a further level of similarity cannot be reached anymore. Based on the clusters obtained, it is possible to evaluate the common input variables and parameters for each cluster, potentially pinpointing the most impacting factors on the

[3] *SI – Severity index*: the data can be obtained from INAIL web database.

[4] *Θ_2 - Manufacturing sector:* from INAIL the rate (%) associated to the firm sector can be retrieved.

[5] *Θ_3 - Salary of the injured worker:* weighted average of the daily net salary of workers classified as *skilled worker* (15.74 €/day), *qualified worker* (13.65 €/day) and *general worker* (11.57 €/day). Given the number of workers for each class:

$$\theta_3 = (\#\,skilled\ worker * €_{skilled\ worker} + \#\,qualified.worker * €_{qualified.worker} + \#\,general\ worker * €_{general\ worker})/(\#\,skilled\ worker + \#\,qualified.worker + \#\,general\ worker)$$

division. In this way, an analysis of similarities among firms in the same cluster and of differences among firms in different clusters can be performed.

- *Step 3: α computation.* Once identified the clusters *j* to which the generic firm *p* belongs, it would be possible to compute the value of the unknown vector $\alpha_{I,j}$ for each cost function *i,* assuming a linear relationship between the dependent variable C_i and the independent variables $Z_{m,p}$ and $\theta_{n,p}$, respectively the variables *m* and the parameters *n* characterising each firm *p*, as expressed in (2).

$$C_i = \alpha_{i,j} * f(Z_{m,p}, \theta_{n,p}) \quad (2)$$

  The unknown vector α can be computed by applying a multiple regression (MLR) in each cluster for all the cost functions. MLR can be indeed used to forecast the value of a dependent or result variable subjected to the value of two or more independent or predictor variables. Some key assumptions must be met in order for the MLR to be applied: (i) a linear relationship must exist between the outcome variable and the independent variables; (ii) the variables are normally distributed; (iii) the number of observations must be greater than the number of predictors. If a cluster has only one observation, i.e. only one firm is composing the cluster, the multiple regression is not applied and the α value is computed by inverting the cost function.

- *Step 4: Post regression data check.* The reliability of the statistically significant effect can be assessed by analysing the statistical values emerging from each MLR, checking that $p\_value < 0.05$ and $R^2 . \geq 80\%$. If either of these two conditions no longer holds, significant outliers in the cluster are identified, removed and individually inserted into different clusters, for each of which the p_value and R^2 will be evaluated to choose the best fit. If none of the already developed clusters meets the threshold values, a new cluster would be created, including just the individual outlier.

3.2.2. Update and convergence of the α

The acquisition of new data should be properly included in the already developed clusters, particularly identifying the suitable cluster for each cost item C_i. As a new set of data is acquired, to choose the right cluster, the set of data should be added to each cluster and MLR should be applied to each cluster, so as to evaluate a new value for the unknown vector α. Once obtained values from regression, both p_value and R^{2} need to be checked. Three cases are then possible: (i) no cluster has a p_value <0.05 and $R^2 \geq 80\%$: a new cluster is created for the cost item under evaluation; (ii) only one cluster has a p_value <0.05 and $R^2 \geq 80\%$: the new data is included in this cluster and the value of the unknown vector α is updated considering new observation; (iii) more than one cluster has a p_value <0.05 and $R^2 \geq 80\%$: the right cluster should be the selected "qualitatively". Selected qualitative analysis of the specific characteristics of each cluster allows the new data to be included in this cluster and the value of the unknown vector α is updated considering new observation.

To update the unknown vector α, previously evaluated based on the cluster composed of k data rows, it is necessary to insert the k + 1 line of data, obtaining a new α, named α_{k+1}. If the difference between α_k and α_{k+1} is less than 5%, the new α can be considered arrived at convergence. Conversely, if the result is larger than 5%, new data should be added until convergence is reached.

4. Application of the developed methodology

The empirical application was conducted in the Italian manufacturing sector, given the relevance of the sector in the specific area and the still high number of accidents at work (European Commission, 2018; Eurostat, 2018b; Manyika et al., 2012; Nenonen, 2011). Data were collected from 10 firms, whose information is reported in Table 8.

Firm #	Manufacturing sub-sectors	Nace code	Number of employees	Firm's size
N1	Manufacture of electrical equipment	C27	20	Small
N2	Manufacture of machinery and equipment	C28	24	Small
N3	Manufacture of electrical equipment	C27	15	Small
N4	Manufacture of machinery and equipment	C28	68	Medium
N5	Manufacture of motor vehicles, trailers and semi-trailers	C29	50	Medium
N6	Other manufacturing	C32	90	Medium
N7	Manufacture of basic metals	C24	20	Small
N8	Manufacture of machinery and equipment	C28	70	Medium
N9	Manufacture of motor vehicles, trailers and semi-trailers	C29	13	Small
N10	Manufacture of basic metals	C24	120	Medium

Table 8. Detail of the sample of firms investigated.

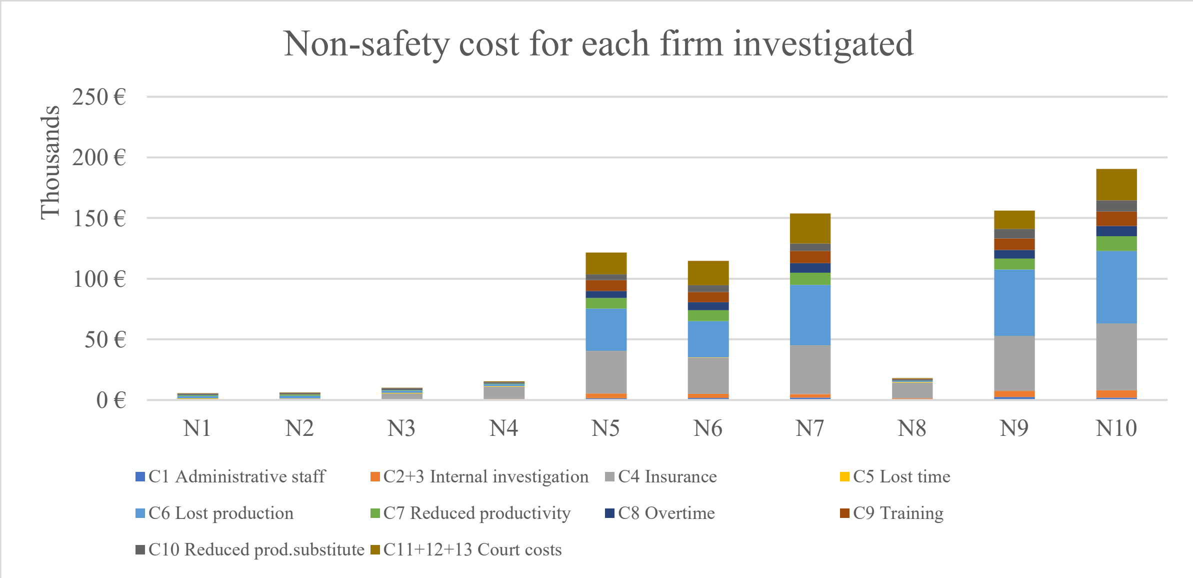
For each firm, the RED was used to identify the tasks that impact more in economic terms. Providing a complete overview of the risk distribution among all the different activities, the RED can help in estimating the non-safety costs related to the riskiest tasks. Assuming that the riskiest tasks are those that generate higher costs, this selection allowed the preservation of the firm's resources in terms of time and staff needed to gather information without negatively affecting the significance of the evaluation. Once tasks were selected, all the needed data were acquired from the firms, apart from FI and SI that were retrieved by INAIL database crossing the sector and the size of each firm. The data represents an average of the last 5 years. The predicted costs were assessed by asking each firm to guess a possible scenario for the next 10 years. This timespan can reasonably be considered appropriate to have a likely occurrence of an event, also in relatively small firms. Moreover, the input data has been classified in three different grades according to the percentile: *Low*: data included in the lowest percentile (34%); *Medium value*: data included between the lowest and the highest percentile (34%-67%); *High:* data included in the highest percentile 67%).

The collected data for each firm is displayed in Table 9, Table 10 and Figure 2.

			N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
Input data	n	Number of events	2	3	2	2	10	9	12	5	13	10
	AD	Average duration	6	4	4	5	20	21	20	4	15	25
	FI	Frequency index	15.21	26.82	14.12	27.17	37	33.92	41.63	27.17	38.41	48.2
	SI	Severity index	1.25	1.66	0.97	1.69	2.08	1.9	3.4	1.69	3.92	3.24
	θ1	Firm size	20	24	15	68	50	90	20	90	13	120
	θ2	Manufacturing sector	25	32	21	35	45	40	80	35	90	130
	θ3	Salary of the injured worker	16	14	16	19	13	15	18	14	20	16
	θ4	Complexity of the job	40	30	45	60	30	50	60	20	80	42
Predicted costs in 10 years	C1	Cost of administrative staff	200 €	150 €	130 €	180 €	1,500 €	1,600 €	1,900 €	600 €	2,600 €	2,000 €
	C2+3	Cost of internal investigation and time lost by supervisors and managers	500 €	450 €	300 €	800 €	4,000 €	3,500 €	3,000 €	820 €	5,000 €	6,000 €
	C4	Insurance cost	8,000 €	500 €	5,000 €	10,000 €	35,000 €	30,000 €	40,000 €	13,000 €	45,000 €	55,000 €
	C5	Cost of time lost by injured employee	600 €	450 €	490 €	530 €	6,000 €	6,300 €	8,000 €	480 €	9,100 €	9,500 €
	C6	Cost of lost production	2,000 €	2,100 €	1,800 €	1,500 €	35,000 €	30,000 €	50,000 €	1,000 €	55,000 €	60,000 €
	C7	Cost due to reduced productivity of the injured employee	850 €	900 €	700 €	650 €	8,500 €	9,000 €	10,000 €	400 €	9,000 €	12,000 €
	C8	Overtime cost	400 €	350 €	280 €	360 €	6,000 €	6,500 €	8,000 €	400 €	7,000 €	8,500 €
	C9	Training cost	300 €	320 €	420 €	300 €	9,000 €	8,500 €	10,000 €	500 €	9,500 €	12,000 €
	C10	Cost due to reduced productivity of the substitute	450 €	600 €	700 €	650 €	4,500 €	5,600 €	6,000 €	350 €	8,000 €	9,000 €
	C11+12+13	Court cost	250 €	260 €	400 €	350 €	18,000 €	20,000 €	25,000 €	500 €	15,000 €	26,000 €
		Total cost	13,550 €	13,080 €	10,220 €	15,320 €	127,500 €	121,000 €	161,900 €	18,050 €	165,200 €	200,000 €

Table 9. Collection of data. The table proposes an overview of the different data collected for each firm in the investigated sample.

Figure 2. Visual representation of the predicted selected non-safety cost items in 10 years for each firm in the sample.



	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
n	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	High
AD	Medium	Low	Low	Low	Medium	Medium	Medium	Low	High	Medium
FI	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	High
SI	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	High
θ1[6]	Low	Medium	Low	Medium	Medium	Medium	Low	Medium	Low	Medium
θ2	Low	Low	Low	Medium	Medium	Medium	Medium	Medium	Medium	High
θ3	Medium	Low	Medium	Medium	Low	Low	High	Low	Medium	High
θ4	Low	Low	Medium	Medium	Low	Medium	High	Low	Medium	High

Table 10. Classification of the input data for each firm in the sample.

4.1. Identification of the clusters and estimation of the α

4.1.1. Detailed procedure for C1

Based on the previously identified cost function, C1 can be determined $C_1 = \alpha_{pa} * n * \theta_1$. In Table 11, the data needed for the evaluation of C1, as well as the predicted cost in 10 years are reported for each firm investigated.

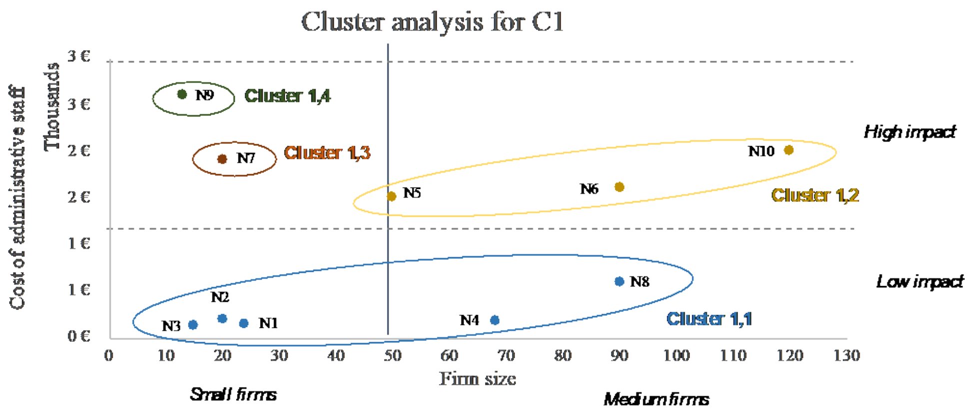
		N1	N2	N3	N4	N5	N6	N7	N8	N9	N10
n	*Number of injuries*	2	3	2	2	10	9	12	5	13	10
θ1	*Firm size*	20	24	15	68	50	90	20	90	13	120
C1	*Cost of administrative staff*	200 €	150 €	130 €	180 €	1,500 €	1,600 €	1,900 €	600 €	2,600 €	2,000 €

Table 11. Data needed for the estimation of the α for C1. The table reports, for each firm of the sample, the perceived cost C1 in 10 years and the value of the estimators necessary for the evaluation of the C1.

[6] The distinction among low, medium and high firm size is not, of course, overlapped with the distinction among Small, Medium and Large Enterprises. The low, medium and high values are assigned focusing on SME dimensions.

Using the statistical software MiniTab, we performed the multivariate cluster observation for cost item C1. In particular, the clusters are reported in Figure 3.

Figure 3. Graphical representation of the results of the cluster analysis for C1.



After determining the clusters, it is necessary to compute the value of the variable α for the different identified clusters, applying MLR. For each cluster, we checked the statistical values coming from the MLR (R^2 > 80% and p_value < 0.05). The values were satisfied for clusters 1,1 and 1,2, while the MLR could not be applied to clusters 1,3 and 1,4, since they both include only one observation. For these clusters, α values are evaluated simply inverting the cost functions. The results of this procedure are reported in Table 12. Looking at the firms in the different clusters, it is possible to spot common characteristics shared among firms belonging to the same clusters, and different characteristics among firms belonging to different clusters, as better described in Table 14.

Cluster	Firm	n	Θ1	C1	α	R^2 (≥80%)	p_value (≤0.05)	Check
1,1	N3	2	15	130 €	1.387	85%	0.02	✓
	N2	3	24	150 €				
	N4	2	68	180 €				
	N1	2	40	200 €				
	N8	2	70	600 €				
1,2	N5	10	50	1,500 €	1.895	90%	0.02	✓
	N6	9	90	1,600 €				
	N10	10	120	2,000 €				
1,3	N7	12	20	1,900 €	0.13	-	-	-
1,4	N9	13	13	2,600 €	0.07	-	-	-

Table 12. α values computation and statistical check for C1.

4.1.2. Results obtained for all the cost items

After repeating the process applied for cost item C1 for the other cost items, it is possible to identify the clusters for each of the cost items. As for C1, it is possible to identify, for each cluster, common characteristics related to the estimators on which the cost items depend (among the firms included in the specific cluster), that identify the cluster itself. The results of the analysis are reported in Table 13.

C	Cost items	Cluster	Firms	Characteristics of the firms in the cluster (according to estimators)	α value	R^2 (≥80%)	p_value (≤0.05)	Check
C1	Administrative staff	1,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium firm sizes	1.39	85%	0.02	✓
		1,2	N5, N6, N10	Medium number of injuries; medium to high firm sizes	1.90	90%	0.02	✓
		1,3	N7	High number of injuries; low firm sizes	0.13	-	-	-
		1,4	N9	High number of injuries; low firm sizes	0.07	-	-	-
C2+3	Time lost by supervisors and managers	2,1	N1, N2, N3, N4, N8	Low to medium number of injuries	188.00	87%	0.006	✓
		2,2	N5, N6, N7	Medium to high number of injuries	330.80	95%	0.02	✓
		2,3	N9	High number of injuries	384.60	-	-	-
		2,4	N10	Medium number of injuries	600.00	-	-	-
C4	Insurance costs	4,1	N1, N2, N3, N4, N8	Low to medium FI; low to medium SI; low to medium sector insurance cost	7.05	90%	0.004	✓
		4,2	N5, N6	Medium FI medium SI; medium sector insurance cost	10.65	99%	0.044	✓
		4,3	N7, N9	High FI; high SI; high sector insurance cost	3.41	99%	0.019	✓
		4,4	N10	High FI high SI; high sector insurance cost	2.71	-	-	-
C5	Cost due to reduced productivity of the injured employee	5,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence; low to high salary	2.49	92%	0.002	✓
		5,2	N5, N6	Medium number of injuries; medium to high days of absence; low salary	2.26	99%	0.012	✓
		5,3	N7, N9, N10	High number of injuries; medium to high days of absence; medium to high salary	2.16	98%	0.006	✓
C6	Cost of lost production	6,1	N2, N3, N5, N7, N9	Low to high number of injuries; low to medium days of absence; low to medium firm size	237.10	95%	0.001	✓
		6,2	N1, N4, N6, N8	Low to medium number of injuries; low to high days of absence; low to high firm sizes	680.00	99%	0.001	✓
		6.3	N10	Medium number of injuries; high days of absence; high firm sizes	9.60	-	-	-
C7	Cost of time lost by injured employee	7,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence; low to high training days	1.52	89%	0.004	✓
		7,2	N5, N6, N7, N9	Medium to high number of injuries; medium to high days of absence; low to high training days	0.75	88%	0.049	✓
		7.3	N10	Medium number of injuries; high days of absence; low to high training days	1.14	-	-	-
C8	Overtime cost	8,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence; low to high salary	1.80	97%	0.001	✓
		8,2	N5, N6, N9	Medium to high number of injuries; medium to high days of absence; low to high salary	2.04	98%	0.008	✓
		8.3	N7, N10	Medium number of injuries; medium to high days of absence; medium to high salary	1.98	99%	0.044	✓
C9	Training cost	9,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence; low to high training days	0.15	87%	0.02	✓
		9,2	N5, N6, N7, N9	Medium to high number of injuries; medium to high days of absence; low to high training days	0.04	94%	0.006	✓
		9.3	N10	Medium number of injuries; high days of absence; low to high training days	0.05	-	-	-
C10	Cost due to reduced productivity of the substitute	10,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence; low to high training days	1.20	91%	0.003	✓
		10,2	N5, N6, N7	Medium to high number of injuries; medium to high days of absence; medium to high training days	0.50	94%	0.026	✓
		10,3	N9, N10	Medium to high number of injuries; medium to high days of absence; medium to high training days	0.62	93%	0.05	✓
C11+12+13	Court costs	11,1	N1, N2, N3, N4, N8	Low to medium number of injuries; low to medium days of absence	1302.00	88%	0.006	✓
		11,2	N5, N6, N9	Medium to high number of injuries; medium to high days of absence	1089.90	99%	0.002	✓
		11,3	N7, N10	Medium number of injuries; medium to high days of absence	1024.00	98%	0.05	✓

Table 13. Clusters identified for each cost items.

4.2. Update and convergence of α

After defining the cluster, a new data-set from firm N11 is acquired. Information about N11 and the collected data from N11 are reported in Table 14 and Table 15 respectively. The inclusion of a new data set is necessary to assess the inclusion of the new data in the already developed clusters, particularly to identify the best cluster for each cost item and then update the related α value.

Firm #	Manufacturing sub-sectors	Nace code	Number of employees	Firm's size
N11	Construction of various instruments and appliances	C33	70	Medium

Table 14. Information of N11

			N11
Input data	n	Number of events	4
	AD	Average duration	5
	FI	Frequency index	21
	SI	Severity index	1.15
	θ1	Firm size	70
	θ2	Manufacturing sector	21
	θ3	Salary of the injured worker	18
	θ4	Complexity of the job	35
Predicted costs in 10 years	C1	Cost of administrative staff	400 €
	C2+3	Cost of internal investigation and time lost by supervisors and managers	900 €
	C4	Insurance cost	8500 €
	C5	Cost of time lost by injured employee	730 €
	C6	Cost of lost production	3500 €
	C7	Cost due to reduced productivity of the injured employee	850 €
	C8	Overtime cost	540 €
	C9	Training cost	450 €
	C10	Cost due to reduced productivity of the substitute	850 €
	C11+12+13	Court cost	550 €
		Total cost	17,270 €

Table 15. Data of N11

4.2.1. Detailed procedure for C1

Stemming from the previously identified clusters for C1 (Table 12) the new observation related to N11 is added to each cluster. MLR was then applied and the statistical values $R^{2\cdot}$ and p_value evaluated, according to the procedure explained in 3.2.2.

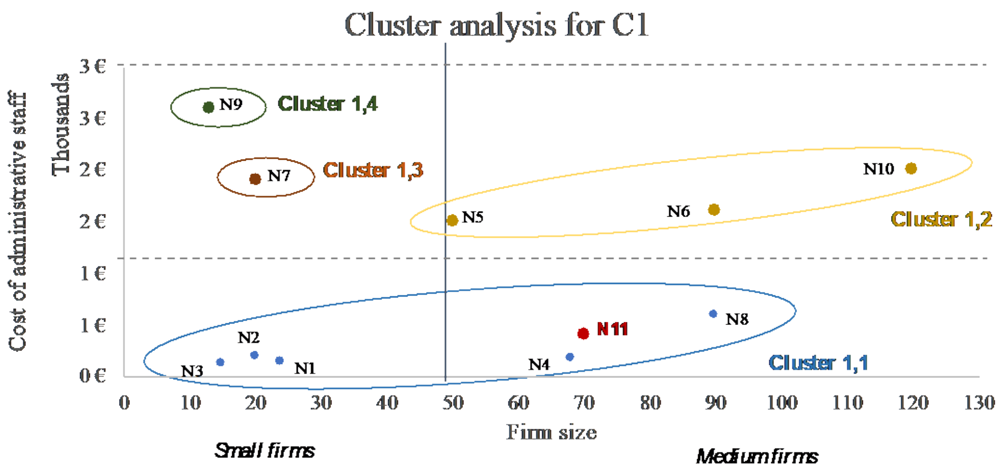
As detailed in Table 16, the addition of N11 meets the conditions only inserted in the Cluster 1,1.

This result could have been reached also qualitatively. Indeed, according to Table 14, Cluster 1,1 is characterized by the presence of firms of all sizes with a more stringent characteristic of a low number of injuries, that is perfectly met by N11, as can be inferred from Table 15 and Table 16. The inclusion of the observation related to N11 in Cluster 1,1 is graphically represented in Figure 4.

Cluster	Firm	n	Θ1	C1	α VALUE	R^2 (≥80%)	p_value (≤0.05)	Check
1,1	N3	2	15	130 €	0.3232	88%	0.001	✓
	N2	3	24	150 €				
	N4	2	68	180 €				
	N1	2	40	200 €				
	N8	2	70	300 €				
	N11	4	70	400 €				
1,2	N5	10	50	1,500 €	0,.797	74%	0.041	✗
	N6	9	90	1,600 €				
	N10	10	120	2,000 €				
	N11	4	70	400 €				
1,3	N7	12	20	1,900 €	0.56	0%	0.411	✗
	N11	4	70	400 €				
1,4	N9	13	13	2,600 €	0.853	33%	0.224	✗
	N11	4	70	400 €				

Table 16. Addition of N11 – detail.

Figure 4. Graphical representation of the results of the cluster analysis for C1 with the addition of N11.



After the inclusion of N11 in the Cluster 1,1 it is necessary to check if the new α arrives at convergence, evaluating the differences between the new α (α_2) and the old α (α_1) value:

$$\Delta\propto^{1,1} = (\alpha_2^{1,1} - \alpha_1^{1,1})/\alpha_1^{1,1} = (0.32 - 1.39)/1.39. = -76\% \geq \pm 5\%$$

As the value of the difference is higher than 5 %, the new value $\alpha_2^{1,1}$ has not arrived at convergence yet and additional data would be needed for this particular cluster.

4.2.2. *Results obtained for all the cost items*

If we repeat the process applied for cost item C1 for the other cost items, it is possible to identify the best clusters in which N11 should be included (for each cost item). In particular, adding N11 to each cluster allows us to evaluate the new α value for each cluster, verifying the statistical values coming from the MLR. Evaluating the $\Delta\alpha$ for each cluster, is it possible to evaluate whether the α has arrived at convergence. The results of the analysis are reported in Table 17. It is possible to note that in some cases, the observation N11 fits in more than one cluster related to the cost item under evaluation (see, for example, C9 or C10). If the observation could be assigned to more than one cluster, it would be necessary to implement a more qualitative evaluation to identify which is the best cluster.

Of course, the higher the number of applications, the higher the robustness of the clusters, as well as the opportunity for testing a number of qualitative evaluations in non-trivial cases. Thus, Table 17 should rather be considered as a step to the actual identification of the targeted clusters, than the final table of these clusters.

C	Cost items	Cluster	Firms	Characteristics of the firms in the cluster	α value	α'value (with N11)	R^2 (≥80%)	p_value (≤0.05)	Check	Δα value
C1	Administrative staff	1,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium firm sizes	1,39	0,33	88%	0,001	✓	-76%
		1,2	N5, N6, N10, **N11**	Medium number of injuries; medium to high firm sizes	1,9	0,79	74%	0,041	✗	-
		1,3	N7, **N11**	High number of injuries; low firm sizes	0,13	0,56	0%	0,411	✗	-
		1,4	N9, **N11**	High number of injuries; low firm sizes	0,07	0,85	33%	0,224	✗	-
C2+3	Time lost by supervisors and managers	2,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries	1,88	197,2	89%	0,001	✓	10389%
		2,2	N5, N6, N7, **N11**	Medium to high number of injuries	330,8	325,8	93%	0,06	✗	-
		2,3	N9, **N11**	High number of injuries	384,6	370,8	97%	0,077	✗	-
		2,4	N10, **N11**	Medium number of injuries	600	548	89%	0,147	✗	-
C4	Insurance costs	4,1	N1, N2, N3, N4, N8, **N11**	Low to medium FI; low to medium SI; low to medium sector insurance cost	7,05	6,09	60%	0,025	✗	-
		4,2	N5, N6, **N11**	Medium FI medium SI; medium sector insurance cost	10,65	10,73	98%	0,004	✓	1%
		4,3	N7, N9, **N11**	High FI; high SI; high sector insurance cost	3,41	3,42	98%	0,007	✓	0%
		4,4	N10, **N11**	High FI high SI; high sector insurance cost	2,71	2,72	96%	0,082	✗	-
C5	Cost due to reduced productivity of the injured employee	5,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence; low to high salary	2,49	2,31	92%	0,0001	✓	-7%
		5,2	N5, N6, **N11**	Medium number of injuries; medium to high days of absence; low salary	2,26	2,26	99%	0,0001	✓	0%
		5,3	N7, N9, N10, **N11**	High number of injuries; medium to high days of absence; medium to high salary	2,16	2,17	98%	0,0001	✓	0%
C6	Cost of lost production	6,1	N2, N3, N5, N7, N9, **N11**	Low to high number of injuries; low to medium days of absence; low to medium firm size	237,1	125,2	82%	0,003	✓	-47%
		6,2	N1, N4, N6, N8, **N11**	Low to medium number of injuries; low to high days of absence; low to high firm sizes	680	681,8	98%	0,0001	✓	0%
		6.3	N10, **N11**	Medium number of injuries; high days of absence; high firm sizes	9,6	1153	98%	0,02	✓	11910%
C7	Cost of time lost by injured employee	7,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence; low to high training days	1,52	1,42	89%	0,01	✓	-7%
		7,2	N5, N6, N7, N9, **N11**	Medium to high number of injuries; medium to high days of absence; low to high training days	0,75	0,73	89%	0,03	✓	-3%
		7.3	N10, **N11**	Medium number of injuries; high days of absence; low to high training days	1,14	1,14	99%	0,003	✓	0%
C8	Overtime costs	8,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence; low to high salary	1,8	1,68	96%	0,0001	✓	-7%
		8,2	N5, N6, N9, **N11**	Medium to high number of injuries; medium to high days of absence; low to high salary	2,04	2,04	98%	0,0001	✓	0%
		8.3	N7, N10, **N11**	Medium number of injuries; medium to high days of absence; medium to high salary	1,98	1,97	99%	0,002	✓	-1%
C9	Training costs	9,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence; low to high training days	0,15	0,15	78%	0,05	✗	-
		9,2	N5, N6, N7, N9, **N11**	Medium to high number of injuries; medium to high days of absence; low to high training days	0,04	0,04	93%	0,001	✓	0%
		9.3	N10, **N11**	Medium number of injuries; high days of absence; low to high training days	0,05	0,05	99%	0,015	✓	0%
C10	Cost due to reduced productivity of the substitute	10,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence; low to high training days	1,2	1,21	92%	0,0001	✓	1%
		10,2	N5, N6, N7, **N11**	Medium to high number of injuries; medium to high days of absence; medium to high training days	0,5	0,5	92%	0,005	✓	0%
		10,3	N9, N10, **N11**	Medium to high number of injuries; medium to high days of absence; medium to high training days	0,62	0,61	89%	0,004	✓	-2%
	Court costs	11,1	N1, N2, N3, N4, N8, **N11**	Low to medium number of injuries; low to medium days of absence	13,02	1279	90%	0,001	✓	9723%

C11+12+13	11,2	N5, N6, N9, **N11**	Medium to high number of injuries; medium to high days of absence	1089,9	1089	99%	0,0001	✓	0%
	11,3	N7, N10, **N11**	Medium number of injuries; medium to high days of absence	1024	914	87%	0,06	✗	-

Table 17. Update and convergence of α for each cluster.

5. Discussion and Conclusions

The evaluation of non-safety costs is deemed as particularly relevant for a firm in order to properly understand the economic burden deriving from a work-related accident (Bonafede et al., 2016) and to allow proper budgeting for safety investments (Rikhardsson and Impgaard, 2004). The present study has presented a methodology to evaluate these costs ex-ante, i.e. before an accident occurs, based on the collection of data easily accessible from firms. In developing the methodology, a particular focus was given to SMEs, considering the limited resources and the difficulties in applying a structured methodology for the evaluation of costs. The application of the developed methodology led to the identification of different clusters for each cost item considered, based on the shape of each cost function. The shape of the functions depends on the value of the estimators of different costs. The definition of these clusters is particularly relevant because it allows firms to have an ex-ante evaluation of non-safety costs, based on the collection of data and the estimators, easily accessible by firms. Of course, the use of such tool might be tremendously beneficial for companies, but also for policy makers, when it comes to the identification of supporting actions for companies' OSH.

The development of the above-mentioned methodology helps overcome issues related to the availability of consistent and reliable historical data to quantify non-safety costs (Jallon et al., 2011; Micheli et al., 2015), identifying estimators for evaluating the extent to which variables related to the specific accident and the parameters related to the characteristics of the single firm influence the cost items (Akcay et al., 2018; Battaglia et al., 2014; Feng et al., 2015; Rikhardsson and Impgaard, 2004; Rohani et al., 2015b; Sun et al., 2006). Moreover, the development of the shape of the cost functions, based on the evaluation of estimators, allows us to evaluate non-safety costs focusing on the specific characteristics of the single firm (Micheli and Cagno, 2010).

The main limitation of the present study lies in the sample investigated. Indeed, for some of the clusters, the MLR could have not been applied; moreover, further observations are necessary to arrive at the convergence of α. The possibility of having more observations would also allow the users of such proposal to consider other contextual factors, such as geographical areas, and explore the influence of manufacturing sectors in cost definition more deeply. Additionally, some uncertainty intrinsically affects the estimation because the predicted costs are assessed by asking each firm to guess a possible future scenario for the next 10 years.

Future streams of research would be addressed at making the management more aware of OHS, by putting more investments on prevention programs (Rohani et al., 2015a). It would be possible, indeed, to foster the adoption of these programs by making it clear that, in addition to non-safety costs, there are also benefits other than safety deriving from the adoption of safety-related interventions, such as productivity (Cagno et al., 2018), and also considering the relevance of safety within the sustainability framework (Rikhardsson, 2006). An additional boost to the adoption of safety programs, indeed, could come from a complete analysis of the adoption process within a broader sustainability perspective (Trianni et al., 2017). On one hand, besides understanding the barriers and drivers for the adoption of such programs (Cagno et al., 2016; Masi and Cagno, 2015), it would be necessary to understand the mechanisms between barriers and drivers considering an industrial sustainability viewpoint (Neri et al., 2018). On the other hand, understanding the different interrelations with all the sustainability areas could help firms better consider effective performance indicators for safety (Cagno et al., 2019), that up to now seem to be left behind compared to other industrial sustainability areas (Trianni et al., 2019).

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