GResilient Index to Assess the Greenness and Resilience of the Automotive Supply Chain

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Discussion Papers on Business and Economics
No. 8/2011

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ISBN 978-87-91657-51-1

GRESILIENT INDEX TO ASSESS THE GREENNESS AND RESILIENCE OF THE AUTOMOTIVE SUPPLY CHAIN

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Structured Abstract

Purpose – The purpose of this paper is to suggest an Index entitled *GResilient* Index to assess the greenness and resilience of the automotive companies and corresponding supply chain.

Design/methodology/approach – An integrated assessment model is proposed based on Green and Resilient practices. These practices are weighted according to their importance to the automotive supply chain competitiveness. The Delphi technique is used to obtain the weights for the focused supply chain paradigms and corresponding practices. The model is then tested using a case study approach in the automotive supply chain.

Findings – The case study results confirmed the applicability of this Index in a real-world supply chain. The results show that the Resilient supply chain management paradigm is the one considered as the one that more contributes for the automotive supply chain competitiveness.

Research limitations/implications – The proposed Index was developed in the automotive sector context therefore it could not be adjusted to a different one. Future research could consider other aggregation methods for the Index construction.

Practical implications– Supply chain participants will be able to evaluate the performance of their companies or supply chain in terms of Green and Resilient paradigms. Also, the Index can be effectively employed for functional benchmarking among competing companies and supply chains.

Originality/value – This paper contributes to the literature by introducing a new Index for measuring the greenness and resilience of companies and supply chains. This Index can be used by managers to assess their *GResilient* level and seek for improvement.

Keywords: Green, Resilient, Supply chain management, Index, Automotive industry

Manuscript Type: Research Paper

Acknowledgments

This research is funded by Fundação para a Ciência e Tecnologia (project MIT-Pt/EDAM-IASC/0033/2008). The third author was supported by a PhD fellowship from Fundação para a Ciência e Tecnologia (SFRH/BD/43984/2008).

GRESILIENT INDEX TO ASSESS THE GREENNESS AND RESILIENCE OF THE AUTOMOTIVE SUPPLY CHAIN

1. Introduction

Supply Chain Management (SCM) is considered a strategic factor for increasing organizational effectiveness and for the better attainment of organizational goals such as enhanced competitiveness, better customer service and increased profitability (**Gunasekaran** and Tirtiroglu, 2001). A supply chain (SC) can be described as a network that links various agents, from the customer to the supplier, through manufacturing and services so that the flow of materials, money and information can be effectively managed to meet the business requirements (**Stevens**, 1989). In present-day business there is the assumption that SC's compete instead of companies being the success or failure of SCs mainly determined by the marketplace (**Christopher** and Towill, 2001). Among the various SCM paradigms the Green and the Resilient paradigm are considered critical to the SC competitiveness and success (**Carvalho** et al., 2011; **Carvalho** et al., 2010; **Azevedo** et al., 2010). In current business environment companies and SCs competitiveness depend not only on the lowest cost, high quality, reduced lead time and high service level, but also they should have the ability to avoid and overcome the innumerous disturbances that jeopardize their performance. In addition, companies and SC's are forced to adopted ecologically responsive practices to meet legislative requirements; this ecological responsiveness also can lead to sustained competitive advantage, improving their long-term profitability. Just recently the resilience and green topics have been object of studies in the SCM context. Carter and Rogers (2008) proposed that risk management, including contingency planning and supply disruptions, are critical issues that should be considered simultaneous with the environmental performance to achieve a sustainable SC. Rosič et al. (2009) also considered the simultaneous deployment of these two paradigms in the SC context.

Briefly, the Green paradigm is concerned with environmental risks and impacts reduction (Zhu et al., 2008), and the Resilient paradigm focuses on the SC ability to recover to a desired state after a disruption occurrence (**Christopher** and Peck, 2004).

The automotive SC provides a rich context to explore this issue. There are evidences that the tendencies of many automotive companies to seek out low-cost solutions may have led to leaner but more vulnerable SCs (**Azevedo et al. 2008**; **Svensson,** 2000). The automotive SC is also under pressure to become more sustainable and therefore more environmental friendly at the same time that are expected economic benefits from a more greening behaviour (**Koplin** at al., 2007; **Thun** and Muller, 2010).

Despite the relevancy of the topic, there is a lack of integrated assessment models that cover the simultaneously deployment of Green and Resilient paradigms in a SC context. To Mollenkopf et al. (2010) there is a lack of integrated metrics and measurement methods that cover Green strategies throughout the SC. Natarajarathinam et al. (2009) also stress the need for further research on developing scales for SC resilience is required.

Consequently, this paper main objective is to propose an Index named by *GResilient* Index to reflect the resilience and the greenness of companies and respective SC. The proposed Index is reached through the aggregation of a set SCM practices related to the Green and Resilient paradigms. Also, a Delphi method is used to develop a series of weighted SCM practices and paradigms importance through academics/experts in automotive research topics.

The paper is organized as follows. Following the introduction, a literature review on the two paradigms Green and Resilient are described from a SCM perspective being pointed out a set of management practices. Subsequently, an integrated assessment model is proposed to evaluate the company's and SC's level of greenness and resilience. Next, some insights on the proposed Index construction including the description of the Delphi method are presented.

After that, a case study approach is developed to illustrate the suggested *GResilient* Index application. Finally, some conclusions are drawn.

2. Green and Resilient supply chain management paradigms

Green SCM has emerged as an organizational philosophy by which to achieve corporate profit and market-share objectives by reducing environmental risks and impacts while improving the ecological efficiency of such organizations and their partners (**Rao** and Holt, 2005; **Zhu** et al., 2008). **Srivastava** (2007) defined Green SCM as "integrating environmental thinking into SCM, including product design, material sourcing and selection, manufacturing processes, delivery of the final product to the customer as well as end-of-life management of the product after its useful life." According to **Srivastava** (2007), Green SCM can reduce the ecological impact of industrial activity without sacrificing quality, cost, reliability, performance or energy utilization efficiency; meeting environmental regulations to not only minimize ecological damage but also to ensure overall economic profit.

Some of the SC Green practices found in literature are: i) environmental collaboration with suppliers (**Holt** and Ghobadian, 2009); ii) ISO 14001 certification (**Gonzalez** et al., 2008); iii) minimization of waste (**Rao** and Holt, 2005); iv) reverse logistics (**Gonzalez** et al., 2008); v) environmental monitoring upon suppliers (**Paulraj**, 2009); vi) to reduce energy consumption (**Zhu** et al., 2008); vii) to reuse/recycling materials and packaging (**Paulraj**, 2009); viii) environmental collaboration with the customer (**Hu** and Hsu, 2006); ix) reverse logistics (**Srivastava**, 2007).

Today's marketplace it is also characterized by higher levels of turbulence and volatility. As a result, SCs are vulnerable to disruption and, in consequence, the risk to business continuity has increased (**Azevedo et al., 2008**). Whereas in the past the principal objective in SC design was cost minimization or service optimization, the emphasis today has to be upon

resilience (**Tang, 2006).** Resilient SCs may not be the lowest-cost, but they are more capable of coping with the uncertain business environment. According to **Cummings e**t al (2005), resilience can be defined as the "ability of the system to maintain its identity in the face of internal change and external shocks and disturbances". Considering the SC context, Resilience is referred as the SC ability to cope with unexpected disturbances (**Azevedo et al., 2010**). The aim of resilience strategies has two manifolds (**Haimes 2006**): i) to recover to the desired states of the system that has been disturbed, within an acceptable time period and at an acceptable cost; and ii) to reduce the disturbance impact by changing the effectiveness level of a potential threat.

The ability to recover from a disturbance occurrence is related to development of responsiveness capabilities through flexibility and redundancy (**Rice and Caniato**, 2003). A representative sample of the main Resilient practices in the SC context found in the literature is: i) strategic stock (**Tang**, 2006); ii) lead time reduction (**Christopher and Peck**, 2004); iii) maintaining a dedicated transit fleet (**Rice** and Caniato, 2003); iv) flexible supply base/ flexible sourcing (**Tang**, 2006); v) sourcing strategies to allow switching of suppliers (**Rice** and Caniato, 2003); vi) creating total SC visibility (**Iakovou** et al., 2007); vii) flexible transportation (**Tang**, 2006); viii) developing visibility to a clear view of downstream inventories and demand conditions (**Christopher** and Peck, 2004).

3. Integrated Assessment Model for GResilien Index Construction

The main objective of this section is to propose an integrated assessment model to evaluate the companies and SCs level of greenness, and resilience. Since the SC is composed by a set of *n* companies, each one with different degrees of SCM practices implementation, the SC overall behaviour will be affected by the aggregation of individual companies' behaviours.

3.1. GResilien Index for individual company

In a first step it is necessary to compute the company behaviour according to the Green and Resilient paradigms. The hierarchical relationships evolved in this assessment can be found in Figure 1.

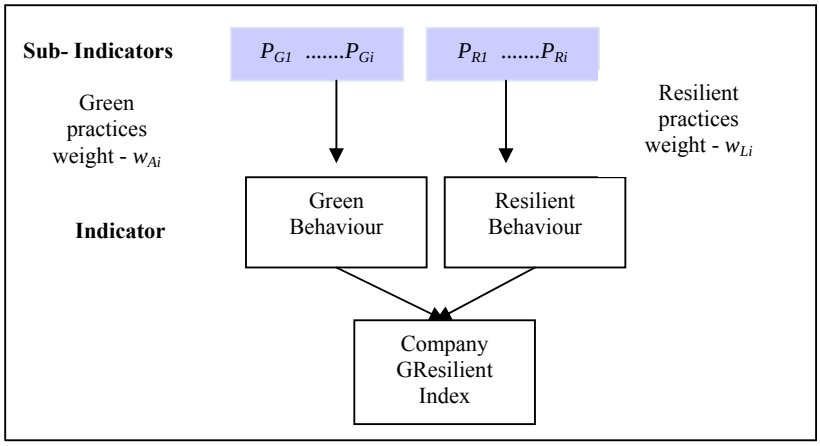

Figure 1: Hierarchical relationships evolved in the company behaviour assessment

Each indicator in Figure 1 intends to reflect the individual company behaviour in terms of its greenness and resilience. These indicators are a representative parameter of Green and, Resilient SCM practices implemented by each company. They are obtained by combining the information from the following sub-indicators: (i) Green SC practices (P_{G1}... P_{Gv}); and (ii) Resilient SC practices (P_{R1}... P_{Rt}). Each sub-indicator is assessed in a 5 points Likert scale were 1 means "practice not implemented" and 5 "practice totally implemented".

For each company the two indicators are proposed:

- *Green Behaviour* (B_G): it represents the set of SCM practices to achieve corporate profit and market-share objectives by reducing environmental risks and impacts while improving the company ecological efficiency.
- *Resilient Behaviour* (B_R): it represents a set of SCM practices reflecting the company ability to cope with unexpected disturbances.

It is supposed that for each company the indicators can be computed aggregating the correspondent individual sub-indicators according to their importance. For each company *j* a generic formula in Equation 1 can be used to compute each indicator B_x according to the paradigm *x*, being *x* = G (for Green) or R (for Resilient). Equation 1 shows that the company behaviour according to a particular paradigm is function of each practice implementation level and corresponding weight.

$$\left(B_x\right)_j = f\left[w_{x1} \times \left(P_{x1}\right)_j, \ldots, w_{xy-1} \times \left(P_{xy-1}\right)_j, w_{xy} \times \left(P_{xy}\right)\right] \quad \text{(eq.1)}$$

Where:

- $(B_x)_j$ represents the company *j* behaviour according to the paradigm *x* (*x* = G or R).
- $(P_{xi})_j$ represents for company *j* the implementation level of practice *i* of paradigm *x*. A total of *y* practices are considered for each paradigm. Each practice implementation level is assessed in a 5 points Likert scale were 1 means "practice not implemented" and 5 "practice totally implemented".
- w_{xi} is the weight of practice *i* of paradigm *x*. This weigh is common for all companies belonging to the same SC. The weights values reflect the importance of each practice in the SC. It assumes values between 0 (not important) to 1 (extremely important).

Equation 1 shows that the company behaviour according to a particular paradigm is given by a function of each practice implementation level and corresponding weight. For each company the behaviour B_x according to each paradigm goes from 1 (none paradigm practice implemented) to 5 (all the seven paradigms practices are implemented).

The *GResilient* Index for a particular company ($GResilient_j$) is a composite indicator which is function of the company indicators of each paradigm and corresponding weights (Equation 2):

$$\text{GResilient}_j = f\left[w_R \times \left(B_R\right)_j, w_G \times \left(B_G\right)_j\right] \quad \text{(eq. 2)}$$

Where:

- $(B_x)_j$ represents the company *j* behaviour according to the paradigm *x* (*x* = G or R).
- w_G, w_R, represent, respectively, the weight of Green and Resilient paradigms. The weights values reflect the importance of each paradigm for the SC competitiveness. It assumes values between 0 (not important) to 1 (extremely important).

The company *GResilient* Index goes from 1 (none paradigms are deployed in the company) to 5 (all the paradigms are completely deployed in the company).

3.2 GResilient Index for supply chain

To assess the SC *GResilient* Index ($GResilient_{sc}$) the hierarchical relations of Figure 2 are considered.

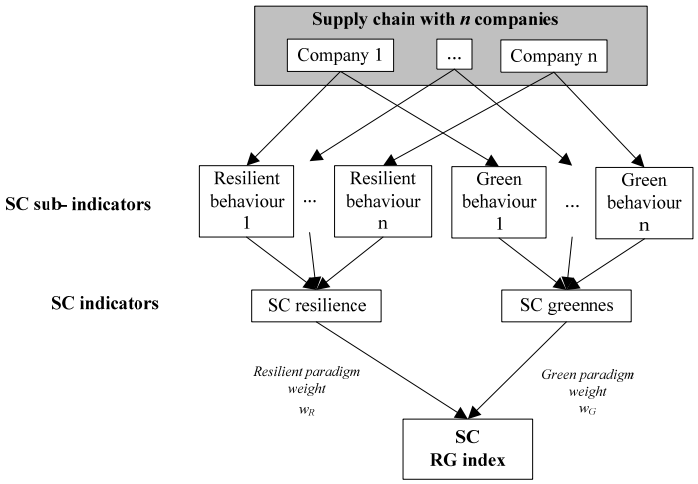

Figure 2: Hierarchical relations involved in the supply chain *Gresilient* Index

Considering that a SC is constituted by *n* companies, to assess the SC *GResilient* Index the individual companies' Green and Resilient behaviours will be used as sub-indicators. They can be aggregated using Equation 3 to obtain each SC indicator according to each paradigm (SCI_x):

$$SCI_x = \frac{\sum_{j=1}^{n} (B_x)_j}{n} \quad \text{(eq. 3)}$$

Where

- n is the number of companies considered in a particular SC.
- $(B_x)_j$, is the company j behaviour according to the paradigm x (x = G or R).

The *GResilient* Index for a particular SC (*GResilient* $_{SC}$) is a composite indicator which is function of the SC indicators of each paradigm and corresponding weights (Equation 4):

$$\text{GResilient}_{SC} = f\left(w_R \times SCI_R , w_G \times SCI_G\right) \quad \text{(eq. 4)}$$

Where

- SCI_G, SCI_R , represents, respectively, the SC behaviour according to Green and Resilient paradigms.
- w_G, w_R, represents, respectively, the weight of Green and Resilient paradigms. The weights values reflect the importance of each paradigm for the SC competitiveness. It assumes values between 0 (not important) to 1 (extremely important).

The *GResilient* Index goes from 1 (none paradigms put into practice in the SC companies) to 5 (all the paradigms are completely deployed in the SC companies).

3.3 Composite Index aggregation

Aggregation is always a potential area of methodological controversy in the field of composite Index construction (**Nardo** et al. 2005; **Zhou** et al. 2006). There are various linear methods for aggregation; the most common are additive, multiplicative and additive weighting (**Fetscherin**, 2010; **Nardo et al. 2005**; **Zhou** et al. 2006; **Curwin** and Slater, 2008). However, to admit a linear method it is necessary the absence of synergy or conflict effects among the indicators (**Nardo** et al. 2005). This is, variables should be independent (**Farmer**,

1987; **Curwin and Slater**, 2008). Moreover, linear additive aggregation only can be applied when all indicators have the same measurement unit, and this type of aggregation implies that poor performance in some indicators can be compensated by sufficiently high values of other indicators (**Nardo** et al. 2005). The multiplicative aggregation is appropriate when strictly positive indicators are expressed in different ratio-scales, and it entails partial (non constant) compensability, i.e. compensability is lower when the composite indicator contains indicators with low values (**Nardo** et al. 2005).

The choice of the most adequate aggregation method depends on the purpose of the composite indicator, as well as the nature of the subject being measured (**Fetscherin**, 2010). The right selection of the components of composite Indexes and their weights it is also critical for the aggregation process. Despite these concerns, **Singh** et al. (2009) suggest that composite indices should remain relatively simple in terms of their construction and interpretation. The simple additive weighting method has been widely used in practice due to its transparency and ease of understanding for non-experts (**Zhou** et al. 2006).

Considering all the previous arguments, the additive weighting method was selected as aggregation method. Since this is a linear model, it is applicable only if there is independency between variables. Therefore it is necessary to verify if this model is applicable in real case situations were this assumption may not be verified. According to **Farmer** (1987) even if the assumption of independence between variables does not hold, the simple additive weighting method would also yield extremely close approximation to the ideal value function. **Nardo** et al. (2005) stress that in these situations the model could be applied but the resulting composite indicator can be biased, i.e. it will not entirely reflect the information of its sub-indicators.

3.4 Managerial Implications of *GResilient* Index

The proposed model to assess the SC behaviour in terms of the implementation level of Green and Resilient practices it is an important contribution to managers. It serves as a tool to

managers do a check list of a set of practices implementation level considered as most important to individual companies and also SC to be more competitive. By this way, they can adjust the organizations' behaviour according to the reached *GResilient* Index score in order to: (i) to reduce environmental risks and impacts while improving company ecological efficiency; and (ii) to improve its ability to cope with unexpected disturbances.

Also, it allows implementing a functional benchmarking approach since the assessment of the *GResilient* Index in companies belonging to the same automotive SC makes possible a comparison among their practices, having as reference the best in class (**Camp**, 1995; **Fong** et al., 1998; **Zairi**, 1992). This contributes to the individual company and SC improvement meeting or surpassing industry best practices obliging them to be more rigorous in establishing priorities, targets and goals in terms of the greenness and resilience of the company and SC.

4. Composite *GResilient* Index construction

The proposed model to assess the SC behaviour in terms of *GResilient* can be used by SC managers considering the following: i) the set of Green and Resilient practices should be appropriated to the type of SC; ii) the weight of the practices and paradigms should be accessed by a set of experts. The Delphi method is suggested as a tool to support the weights determinations; and iii) the variables independency should be asses to a correctly interpretation of the composite additive weighting Index.

Considering the theoretical model proposed in the previous section, a model for the automotive SC is derived

4. 1 Company sub-indicators

In a first step it is necessary to identify the set of relevant Green and Resilient practices for the companies belonging to the automotive SC. Using the literature review a set of practices was selected to assess the company indicators (Table 1).

Table 1. Indicators and sub-indicators for company behaviour assessment

Indicators	Sub- indicators
B_G = Green behaviour	P_{G1}= Environmental collaboration with suppliers
	P_{G2}= Environmental monitoring upon suppliers
	P_{G3}= ISO 14001 certification
	P_{G4}= To reduce energy consumption
	P_{G5}= To reuse/recycling materials and packaging
	P_{G6}= Environmental collaboration with the customer
	P_{G7}= Reverse logistics
B_R = Resilient behaviour	P_{R1}= Sourcing strategies to allow switching of suppliers
	P_{R2}= Flexible supply base/ flexible sourcing
	P_{R3}= Strategic stock
	P_{R4}= Lead time reduction
	P_{R5}= Creating total supply chain visibility
	P_{R6}= Flexible transportation
	P_{R7}= Developing visibility to a clear view of downstream inventories and demand conditions

Each practice of Table 1 is obtained in a 5 point Likert scale, which makes possible the individual company behaviour assessment in terms of the SCM paradigms focused in this study.

4.2. Weighting Determination

A series of weighted SCM paradigms and corresponding practices was developed based on the Delphi approach. Each SCM paradigm and corresponding practices rating was measured using a score between 1 and 5, with 1 representing "nothing important" and 5 representing "extremely important".

The weighting for each set of variables, this is, Green and Resilient paradigms importance and also the two sets of SCM practices importance, was computed by using Equation 5 (**Yeung** et al., 2007):

$$w_z = \frac{M_z}{\sum_{g=1}^{n} M_g} \qquad \text{(eq. 5)}$$

Where:

- w_z represents the weighting of a particular variable z (it can be paradigm importance or a practice importance)
- M_z represents the mean rating of a particular variable z
- $\sum_{g=1}^{n} M_g$ represents the summation of mean rating of each set of variables

4.3 Delphi study

The Delphi technique is a highly formalized method of communication that is designed to extract the maximum amount of unbiased information from a panel of experts (**Chan** et al., 2001). It offers important advantages in situations where it is crucial to define areas of uncertainty or disagreement, as it is the case. It also makes possible to assess uncertainty in a quantitative manner. Therefore, it is appropriate to adopt the Delphi technique to obtain a series of weighted SCM paradigms and corresponding practices to assess the level of greenness and resilience of the automotive SC.

According to **Linstone** and Turoff (1975) the key steps in preparing a Delphi study are: (i) the definition of experts and their selection; (ii) the number of rounds; and (iii) the questionnaire structure in each study round. Generally, the number of rounds ranges from two to seven and the number of participants varies between 3 and 15 (**Rowe** and Wright, 1999).

The success of the Delphi method depends mainly on the careful selection of the panel members (**Chan** et al., 2001). As the information solicited requires in-depth knowledge and sound experience about, for one hand the automotive industry and for the other the Green and Resilient SCM paradigms, a purposive approach was adopted to select this group of experts (**Chan** et al., 2001). The following two criteria were formulated in order to identify eligible participants for this part of the study: i) having current/recent involvement in automotive industry research topics; ii) having a sound knowledge and understanding of Green and

Resilient SCM paradigms. In order to obtain the most valuable opinions, only academics/experts who met the two selection criteria were considered. A total of 21 academics/experts were invited to participate in this study, but only 11 agreed on collaborate with us.

Virtual (by email) interviews were launched with academics/experts in automotive research topics to verify the validity of the considered SCM practices and also to rank the two management paradigms according to their importance to the competitiveness of the automotive SC. Therefore a set of variables were assessed: i) the importance of Green and Resilient paradigms for the competitiveness of the automotive SC; ii) the importance of Green practices to a SC to be considered Green; iii) the importance of resilience practices to a SC to be considered Resilient.

The Delphi method used in this research comprised two rounds. In the first round the respondents were asked to give their perception about the importance of the SCM paradigms to the automotive SC to be considered competitive, and also to register the importance of each suggested practice to the greenness and resilience of the automotive SC. In the second round respondents were provided with the consolidated results from Round 1 and were invited to reconsider their options to see if they would like to adjust their original choice.

4.3.1 Two Rounds of Delphi Questionnaires

The first round of Delphi questionnaire (see Appendix A) was sent to the group of panel members by e-mail in February 2011. The panel members constituted by academics/experts were informed that would be two rounds of questionnaires. In this first round the 21 academics/experts were asked to give their perception about the importance of Green and Resilient paradigms and also the corresponding practices to the competitiveness of the automotive industry. From these 21 academics/experts 11 responses were collected. Similar to the first round, the second round questionnaire (see Appendix B) was forwarded to the group

of panel members (11 academics/experts) by e-mail in the first week of March. In this round the results of first round were consolidated and presented to the experts. Then they were requested to reconsider whether they would like to change any of their original choices in the light of the consolidated results from the first round. All the eleven questionnaires were completed at the end February 2011.

Using Equation 5 it was computed the weighting for the two SCM paradigms (Table 2) and also Green and Resilient practices (Table 3). Table 2 shows the relative importance of each SCM paradigm and corresponding practices by the 11 academics/experts. The order of importance of the SCM paradigms obtained from the academics/experts perception, after the two rounds, is the following one: the most important is Resilient. As can be seen from the Kendall's coefficient of concordance the consistency of the experts/academic rankings was improved after the Round 2.

Table 2 - Results of Round 1 and Round 2 of Delphi questionnaire for the paradigms importance.

Statistics / **Variables**		**First round**			**Second Round**		
		Mean rating	*Rank*	*Weighting*	*Mean rating*	*Rank*	*Weighting*
	Green	3.36	2	0.43	3.1	2	0.41
	Resilient	4.45	1	0.57	4.5	1	0.59
	Number (n)	11			11		
	Kendall's Coefficient of concordance (W)	0.405			0.669		
	Level of significance	0.035			0.007		
Note: For "Mean rating"= 1 nothing important and 5 = extremely important							

Among the seven practices associated to each SCM paradigm their rank of importance to a SC to be considered Green and Resilient is presented in Table 3.

Table 3 - Results of Round 1 and Round 2 of Delphi questionnaire for the practices importance.

Variables	Statistics	Round 1			Round 2		
		Mean rating	*Rank*	*Weighting*	*Mean rating*	*Rank*	*Weighting*
Green Practices	Environmental collaboration with suppliers	4.27	4	0.14	4.2	3	0.15
	Environmental monitoring upon suppliers	3.45	7	0.12	2.9	7	0.10
	ISO 14001 certification	4.00	5	0.14	3.9	5	0.14
	To reduce energy consumption	4.73	2	0.16	4.9	1	0.17
	To reuse/recycling materials and packaging	4.82	1	0.16	4.8	2	0.17
	Environmental collaboration with the customer	3.91	6	0.13	3.7	6	0.13
	Reverse logistics	4.36	3	0.15	4.1	4	0.14
	Number (n) *Kendall's Coefficient of concordance (W)* *Level of significance*	11 0.446 0.000			11 0.663 0.000		
Resilient Practices	Sourcing strategies to allow switching of suppliers	4.36	1	0.17	4.5	2	0.15
	Flexible supply base/ flexible sourcing	4.27	2	0.16	4.6	1	0.16
	Strategic stock	3.82	4	0.15	4.1	5	0.14
	Lead time reduction	3.27	6	0.12	4.1	5	0.14
	Creating total supply chain visibility	3.55	5	0.13	4.3	3	0.15
	Flexible transportation	4.20	3	0.16	4.2	4	0.14
	Developing visibility to a clear view of downstream inventories and demand conditions	2.91	7	0.11	3.3	6	0.12
	Number (n) *Kendall's Coefficient of concordance (W)* *Level of significance*	11 0.151 0.126			11 0.309 0.0024		
Note: For "Mean rating"= 1 nothing important and 5 = extremely important							

After the Round 2 Delphi questionnaire, as regards the Green practices, the ones considered the most important to the greenness of the automotive SC are: to reduce energy consumption and to reuse/recycling materials and packaging. The Green practice considered less important is environmental monitoring upon suppliers.

Considering the Resilient practices, the experts/academics highlighted the flexible supply base/ flexible sourcing followed by the sourcing strategies to allow switching of suppliers, and also creating total SC visibility. The Resilient practice considered less important is developing visibility to a clear view of downstream inventories and demand conditions.

4.3.2 Analysis of Consistency after the Two Rounds

In order to obtain a measure of consistency of the 11 experts/academics responses, a statistical test was applied. The Kendall's Coefficient of concordance (W) is used to study the degree of association among rankings of several objects by several judges (**Israel**, 2009). This coefficient varies between "0" indicating no agreement between judges and "+1" indicating complete agreement among the judges on the ranking of various attributes. Using MegaStat application for Excel, the Kendall's Coefficient of concordance was computed for each set of experts/academics responses related to the SCM paradigms and Green and Resilient practices importance.

Table 2 and Table 3 show that Kendall's Coefficient of concordance for SCM paradigms and practices rankings were improved after the two rounds. Therefore, it can be concluded that after the second round of Delphi questionnaire there is a significant amount of agreement among respondents with the group of experts/academics.

4.4. *GResilient* Composite Index construction

The proposed composite *GResilient* Index is composed by the weights determined through the two rounds of the Delphi questionnaire. As referred in section 3.3 the additive weighting method was selected as aggregation method for composite *GResilient* Index. In order to test the assumption of a linear model was determined a correlation matrix for each set of variables. The correlation coefficient values range from "-1" to "+1". The value "-1" indicates a perfect negative relationship, a value "+1" indicates a perfect positive relationship and "0" indicates no relationship at all (**Israel**, 2009). The correlation coefficient for the Green and Resilient paradigms is (-.392) which means that these two SCM paradigms can be considered as independent variables in the Index construction.

Table 4 reveals that almost all variables are not highly correlated to each other at 5% significance level; more, the majority of them are even insignificantly correlated with each

other. Therefore, it is valid to consider a linear additive weighting model in deriving the *GResilient* Index.

Table 4. Correlation matrix among the SCM weighted practices

Correlation matrix		P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	P_{G7}
Green practice	P_{G1}	1.000						
	P_{G2}	.292	1.000					
	P_{G3}	.350	.426	1.000				
	P_{G4}	.080	-.056	.363	1.000			
	P_{G5}	.449	-.083	.243	.671*	1.000		
	P_{G6}	.375	.354	.230	-.100	-.149	1.000	
	P_{G7}	.449	.031	.689*	.671*	.542	.466	1.000
Correlation matrix		P_{R1}	P_{R2}	P_{R3}	P_{R4}	P_{R5}	P_{R6}	P_{R7}
Resilient practice	P_{R1}	1.000						
	P_{R2}	.812**	1.000					
	P_{R3}	.620*	.564	1.000				
	P_{R4}	-.255	-.152	.132	1.000			
	P_{R5}	.368	.028	.507	.507	1.000		
	P_{R6}	.793**	.720*	.772**	.131	.506	1.000	
	P_{R7}	-.082	-.279	-.423	-.051	.283	-.318	1.000
Correlation matrix		P_{G1}	P_{G2}	P_{G3}	P_{G4}	P_{G5}	P_{G6}	P_{G7}
	Notes:** Correlation is significant at the 0.01 level (2-tailed) * Correlation significant at the 0.05 level (2-tailed)							

After the weights computed and the linear model assumption verified it is now possible to suggest a *GResilient* Index to assess the level of greenness and resilience for the automotive SC through one composite indicator (Equation 6).

$$\text{GResilient}_{SC} = 0.59 \times \frac{\sum_{j=1}^{n} \left(0.15 \times P_{R1j} + 0.16 \times P_{R2j} + 0.14 \times P_{R3j} + 0.14 \times P_{R4j} + 0.15 \times P_{R5j} + 0.14 \times P_{R6j} + 0.12 \times P_{R7j}\right)}{n} + 0.41 \times \frac{\sum_{j=1}^{n} \left(0.15 \times P_{G1j} + 0.10 \times P_{G2j} + 0.14 \times P_{G3j} + 0.17 \times P_{G4j} + 0.17 \times P_{G5j} + 0.13 \times P_{G6j} + 0.14 \times P_{G7j}\right)}{n} \quad \text{(eq.6)}$$

Where:

- n is the number of companies considered in a particular SC

- $(P_{xi})_j$ represents for company *j* the level of implementation of practice *i* of paradigm *x*. A total of 7 practices (i = 1, …,7) are considered to each paradigm. The implementation level for each practice is assessed in a 5 points Likert scale were 1 means "practice not implemented" and 5 "practice totally implemented

GResilient Index is a composite indicator constituted by a set of sub-indicators reflecting the SC behaviour in terms of Green and Resilient paradigms. This composite indicator is computed to a specific SC, considering the level of implementation of the focused practices in the companies belong to the SC. The *GResilient* Index goes from 1 (none paradigms put into practice the SC companies) to 5 (all the paradigms are completely deployed in the SC companies).

5. *GResilient* Index application. A Case study in Automotive SC

5.1 Methodology

Since the main objective of this research is to propose a *GResilient* Index for the SC, a case study approach was chosen to illustrate the Index application. This approach is adequate when the boundaries of a phenomenon are not only still unclear, but there is also no control over behavioural events (**Rowley**, 2002).

Since SC behaviour may differ from country to country (**Rosenzweig** and Singh, 1991) it is more effective to focus on one SC in one country before moving on to cross-SCs and cross-country studies. A single SC research design concerned with the Portuguese automotive SC was chosen. Being so, a sample consisted of four companies within the Portuguese automotive SC was selected. The case study comprises one automaker and three first-tier suppliers. The Portuguese auto components industry sold 80% of the production to foreign markets, having a strategic role in the economy representing 2.2% of the country's Gross Domestic Product (**AFIA,** 2008). The case study selection was also made on "planned opportunism" (**Pettigrew**, 1990). The researched automaker is a partner in an international

research project that aims to explore the influence of Lean, Agile, Resilient and Green paradigms on SC performance.

To limit expert bias in the study results, data concerned to personal judgment of the participants were obtained through structured interviews. Two visits were made to the company's facilities. In the first one the research project was presented and it was collected general information about the company, its product and processes. In the second visit, one interview was made to each company manager according to the interview protocol in Appendix C. However, despite the company anonymity was assured, the respondents may make effort to protect the image and reputation of their companies. Also, other sources of evidence such as industry databases, newspaper clippings and company web sites were used to corroborate and augment evidence.

A case study approach is developed in this section, looking at four companies from the Portuguese automotive SC. The objective is to illustrate the application of the proposed *GResilient* Index in the previous section.

5.2. Case Study Profile

Table 5 summarises the four case study profiles according to the product lines, position in the SC and company size. As can be seen, three companies analysed are first-tier suppliers, meaning they supply automakers.

Table 5. Case studies profile

	Product Lines	**Position in the supply chain**	**Company size (employees)**	**Interviewed**
Company 1	Vehicles	Automaker	More than 1000	SC supervisor
Company 2	Plastic parts	first-tier supplier	200 - 500	Product engineer
Company 3	Front rear	first-tier supplier	50-100	Logistics Manager
Company 4	Exhaust systems	first-tier supplier	50-100	Lean Manager

The selected companies have some common characteristics. In the automotive SC context, the balance of power among SC members is uneven. The automaker has huge power, controlling

the entire production cycle from the product design to product manufacturing and parts sourcing, and in some cases the suppliers' processes. Typically, in this SC there are a limited number of suppliers for components and parts, and the control of the automaker can extend to the second-tier suppliers (the first-tier suppliers can only purchase components and materials from some approved suppliers).

The automaker produces four different models of vehicles, managing its operations according to a lean philosophy, in a virtual zero stocks environment. It produces customized vehicles according to the customer orders; each consumer decide the vehicles customization, choosing the body colour, interior trim, instrument panel, engine characteristics, among others specifications. The companies studied use a JIT production philosophy, producing components according to the automakers daily requirements, although some sub-assemblies are produced in batches according to a make-to-order policy. The transport of final products to the automaker is performed using specific reusable containers or racks adapted to each product type. These reusable containers or racks will directly supply the assembly line and act as a kanban, that is, their return to the suppliers will act as a signal that more components are needed.

The selected companies mainly perform assembly operations, but one has plastic injection processes. Thus they have "clean production processes", with no raw materials being transformed into complex materials by elaborate chemical or mechanical processes.

5.3 *GResilient* Index calculation

In a first stage the data related to the implementation of a set of Green and Resilient practices were collected in each company.

The Green concerns are embedding in the companies' operations. All the studied companies are certified by ISO14001. The automaker request that the first-suppliers located in the same industrial park should have ISO 14001 certification.

All the companies implemented energy consumption reduction and reuse/recycling programs. For example, Company 3 had changed their plant roof to include transparent roof material so the natural light can be used. Company 4 had changed a particular production process to reduce the water and energy consumption at the same time that reduced the process time. All companies employ reverse logistics management mainly by using returnable/reusable packages and racks, and return of defective items. However, the first-tier suppliers referred a low environmental collaboration with their suppliers because it is the automaker that select and choose the second-tier suppliers.

The studied companies' present high levels of Resilient practices implementation. All of them have a strategic stock of critical components to overcome material shortages. There is also a concern to develop a flexible base of suppliers, despite the fact of the number of available suppliers for certain components being limited. All of the companies adopted flexible transportation modes and routes. For example to overcome a road block because a transportation strike, Company 4 adopted a transportation solution that comprises the maritime transportation of a full truck load from Italy to a Portugal, and them the truck follow by road to their installations. Contrary to the manager's expectations, this solution had revealed to be quicker than the usual road transportation.

From the above analysis it is possible to state that there are some practices totally implemented by the researched companies. These practices are: strategic stock and ISO 14001 certification. By the other side, the SCM practices with lower levels of implementation are: environmental collaboration with suppliers, environmental collaboration with the customer and environmental monitoring upon suppliers. Based on the summarized information the company's behaviour according to the Green and Resilient paradigms were computed (Table 6).

Table 6. Individual company's behaviour

Paradigm *x*	**$(B_x)_i$**				**$\sum (B_x)_i/4$**	**w_x**	**SC Behaviour**	**SC *GResilient* Index**
	Company 1	**Company 2**	**Company 3**	**Company 4**				
Green	4.11	3.61	3.61	3.61	3.73	0.41	1.53	4.06
Resilient	4.41	4.45	4.12	4.14	4.28	0.59	2.52	
Company *GResilient* Index	4.29	4.10	3.91	3.92				

According to the Table 6, among the studied companies the SCM paradigm with higher levels of implementation is the Resilient. Beyond this analysis, and looking to the SC behaviour column it is possible to see that the researched automotive SC has better Resilient behaviour than Green behaviour. This difference between the paradigms implementation level and SC behaviour is justified by the importance of the paradigms, the Resilience is fundamental to keep operations running even when SC disruptions happen. Computing the Green and the Resilient behaviour the four companies into the *GResilient* Index it was reached a value of 4.06. Since the *GResilient* Index is between 1 and 5, this means that this researched SC presents a positive and upper mean Index. Also, analysing the columns of the Table 6, it is possible to identify the companies with higher influence level on the SC *GResilient* Index. In this context, the Company 1 seems to be the main responsible for the *GResilient* Index score followed by Company 2. This seems reasonable since the Company 1 is an automaker which has an important influence on the behaviour of all the SC.

6. Conclusions

This paper follows an innovative approach suggesting an integrated composite Index, entitled *GResilient* Index, to translate the automotive SC behaviour in terms of greenness and resilience. The proposed integrated assessment model supports the development of two *GResilient* Indexes: one to assess the individual company behaviour in terms of the Green and

Resilient SCM paradigms, and the other one to determine the same behaviour, but for the entire SC.

This research approach was developed in touch with the automotive SC reality. The *GResilient* Index was constructed with the collaboration of experts/academics and also on the automotive reality. Besides this, the implementation of the proposed *GResilient* Index is illustrated by a case study approach using the information gathered in four automotive companies. The main objective of doing a case study is to illustrate the *GResilient* Index application in the focused SC in order to guide managers into its implementation.

The proposed composite Index is a way to fulfil the research gap on an integrated approach about the greenness and the resilience of the SC, in general and in the automotive SC in particular.

The content of this paper is particularly important to managers do a check list of a set of practices implementation level considered as most important to individual companies and SC competitiveness. By this way, they can adjust the organizational behaviour according to the reached *GResilient* Index score in order to reduce environmental risks and impacts while improving company ecological efficiency and also to improve its ability to cope with unexpected disturbances. More, it makes possible to implement functional benchmarking approaches in the automotive SC and to do a ranking among the companies, according to the *GResilient* Index reached. This serves as a motivation to companies try to reach better position among their partners and to be more rigorous in establishing priorities, targets and goals, in terms of greenness and resilience.

Despite the important contributions of this paper, limitations of the study should be noted. First, the proposed Index is focused on the automotive industry. So, the practices suggested in the integrated assessment model translate particularly the reality of this sector making it not adjusted to a different sector. Second, the Delphi method used to support the weighting determination was developed through only two rounds. Besides it respects the number of

rounds referred by Rowe and Wright (1999), which is between two and seven, if more rounds were developed the validity of the answers collected from the questionnaires will be improved. Building on from this study, future research should therefore be directed at exploring the application of the suggested *GResilient* Index in an extended automotive SC. Also, based on the theoretical approach performed in this study, a deeper analysis of the kind of relationships among the Green and Resilient paradigms and corresponding practices should be explored to different kind of mathematical models could be suggested.

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APPENDIX A

Structured Interview Protocol - First Round

This framework is intended to support a research regarding the assessment of an GResilient Index proposal to the Automotive Industry. To do this, it is important to get information about experts perception on the importance of Green and Resilient paradigms to the competitiveness of the automotive industry. Try to answer to the questions, please.

Academic/experts identification

Faculty Department :
Area(s) of expertise:
Do you have any research on the automotive industry?
If Yes in what kind of field(s)?
____ Strategy ____ Operations Management ____ Logistics
____ Supply chain Management _____ Equipment/maintenance _____ Ergonomics
others: _____

1 - For the following supply chain management paradigms, please describe your perception about their importance to the competitiveness of the automotive industry.

	1 nothing important	**2**	**3**	**4**	**5 extremely important**
Green					
Resilient					

2 - - For the following Green practices, please describe your perception about their importance to the **greenness** of the automotive supply chain

	1 nothing important	**2**	**3**	**4**	**5 extremely important**
Environmental collaboration with suppliers					
Environmental monitoring upon suppliers					
ISO 14001 certification					
To reduce energy consumption					
To reuse/recycling materials and packaging					
Environmental collaboration with the customer					
Reverse logistics					

3 - For the following Resilient practices, please describe your perception about their importance to the **resilience** of the automotive supply chain

	1 nothing important	**2**	**3**	**4**	**5 extremely important**
Sourcing strategies to allow switching of suppliers					
Flexible supply base/ flexible sourcing					
Strategic stock					
Lead time reduction					
Creating total supply chain visibility					
Flexible transportation					
Developing visibility to a clear view of downstream inventories and demand conditions					

Thanks for the collaboration.

APPENDIX B

Structured Interview Protocol - Second Round

This framework is intended to support a research regarding the assessment of an *GResilient* Index proposal to the Automotive Industry. To do this, it is important to get information about experts perception on the importance of Green and Resilient paradigms to the competitiveness of the automotive industry. **This is a second round questionnaire which incorporates the average answers obtained from the first round.** knowing this information, try to answer to the questions, please.

Academic/experts identification

Faculty Department :

Area(s) of expertise:

Do you have any research on the automotive industry?

If Yes in what kind of field(s)?

____ Strategy ____ Operations Management ____ Logistics

____ Supply chain Management _____ Equipment/maintenance _____ Ergonomics

others: _____

1 - For the following supply chain management paradigms, please describe your perception about their importance to the competitiveness of the automotive industry.

	1 nothing important	**2**	**3**	**4**	**5 extremely important**	**1st round Average**
Green						3,36
Resilient						4,45

2 - For the following Green practices, please describe your perception about their importance to the **greenness** of the automotive supply chain

	1 nothing important	**2**	**3**	**4**	**5 extremely important**	**1st round Average**
Environmental collaboration with suppliers						4,27
Environmental monitoring upon suppliers						3,45
ISO 14001 certification						4,00
To reduce energy consumption						4,73
To reuse/recycling materials and packaging						4,82
Environmental collaboration with the customer						3,91
Reverse logistics						4,36

3 - For the following Resilient practices, please describe your perception about their importance to the **resilience** of the automotive supply chain

	1 nothing important	**2**	**3**	**4**	**5 extremely important**	**1st round Average**
Sourcing strategies to allow switching of suppliers						4,36
Flexible supply base/ flexible sourcing						4,27
Strategic stock						3,82
Lead time reduction						3,27
Creating total supply chain visibility						3,55
Flexible transportation						4,20
Developing visibility to a clear view of						2,91

downstream inventories and demand conditions						

Thanks for the collaboration.

APPENDIX C

Structured Interview Protocol

This framework is intended to support a research regarding the determination of a *GResilient* Index to the automotive SC.

A - Firm characterization

Please indicate the following data that characterize your company:

- Sector
- Number of employees
- Primary product(s)
- Primary customer activity(ies)
- Your job title
- Your job responsibilities
- Your firm's position in the supply chain

B – Green practices

For the following practices, please information on their implementation level in your company (considering the following scale: 1 not implemented, 2, 3, 4, 5 totally implemented)

- Environmental collaboration with suppliers
- Environmental monitoring upon suppliers
- ISO 14001 certification
- To reduce energy consumption
- To reuse/recycling materials and packaging
- Environmental collaboration with the customer
- Reverse logistics

C - Resilient practices

For the following practices, please information on their implementation level in your company (considering the following scale: 1 not implemented, 2, 3, 4, 5 totally implemented)

- Sourcing strategies to allow switching of suppliers
- Flexible supply base/ flexible sourcing
- Strategic stock
- Lead time reduction
- Creating total supply chain visibility
- Flexible transportation
- Developing visibility to a clear view of downstream inventories and demand conditions

Thanks for the collaboration.