Transportation Research Part C 48 (2014) 360–378

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Measuring supply chain risk: Predicting motor carriers' ability to withstand disruptive environmental change using conjoint analysis

Craig Atwater [a], Ram Gopalan [b,*], Richard Lancioni [a], James Hunt [a]

[a] Department of Marketing & Supply Chain Management, Fox School of Business, Temple University, Philadelphia, PA 19122, United States
[b] Strategy, Information Systems & Operations Management, School of Business, Rutgers, The State University of New Jersey, Camden, NJ 08102, United States

ARTICLE INFO

Article history:
Received 28 February 2013
Received in revised form 2 August 2014
Accepted 17 September 2014

Keywords:
Scoring model
Supply chain risk
Motor carriers
Conjoint analysis

ABSTRACT

Supply chain risk measurement is an expanding research stream that considers the ability of networked firms to anticipate and respond to significant environmental risks, including major disruptions and unexpected events. However measuring and quantifying supply chain risk has proved an enormous challenge and this research contributes to this goal by developing a risk assessment scorecard, using conjoint analysis, for motor carrier firms. The resultant motor-carrier scorecard has been scaled from 300 to 900, to resemble the well-known FICO score for assessing consumer creditworthiness. Our scoring model enables motor carriers – and the firms that depend upon them in intermodal supply chains – to assess carriers' ability to withstand major disruptive events, which are broadly defined as events which might lead to a significant drop in carriers' income and profitability (e.g., such as that which occurred on September 11, 2001). Carriers with weaker risk scores (<600, on a 300–900 scale) are more likely to experience financial distress (and as a result possibly exit the industry itself); those with scores above 600 are less likely to depart. The model correctly identified 77 percent of motor carriers that ultimately exited the trucking industry following the significant environmental disruption caused by 9/11. Our computational experience indicates that the model accuracy, quantified in terms of Type I and Type II errors, compares favorably to prior results reported in the credit scoring literature.

1. Introduction

The primary goal of this research is to build a risk assessment model for motor carrier firms. The resultant risk scorecard can be used by motor carriers for self-assessment, or by supply chain partners of the motor carrier firm, or by lending institutions when assessing credit worthiness of the motor carrier. First, a snapshot of all motor carriers of the universe is taken and several attribute variables (of the motor carrier firms) are measured. These attribute variables are then used to build a risk scorecard for each motor carrier. The efficacy of this scorecard can then be measured in this manner. If a disruptive environmental event (e.g., September 11, 2001) is observed (after constructing the scorecard), we observe the motor carrier universe again (after the event) and identify stable motor carriers and separate them from those that failed as a result of the disruptive event. The validity of the risk scorecard can be quantified by its accuracy in this classification

* Corresponding author. Tel.: +1 856 225 6630.
E-mail address: ram.gopalan@rutgers.edu (R. Gopalan).

http://dx.doi.org/10.1016/j.trc.2014.09.009
0968-090X/

procedure (i.e., in predicting the exits). Of course, no scorecard is perfect, and both Type I errors (tagging a motor carrier as a non-exit when it is not) and Type II errors (tagging a motor carrier as an exit when in fact it is not) are to be expected. We have scaled our motor carrier risk score to resemble the well-known FICO score to predict consumer credit worthiness, in a range from 300 to 900.

While there has been a notable surge in research interest regarding supply chain risk management, most of this work has been conceptual in nature (Tang and Musa, 2011). We have identified more than 100 peer-reviewed articles, published over the past 5 years, that focused on the term "supply chain risk"; similarly Ellis and his coauthors uncovered 79 such studies in 2011. Clearly, a great deal of work has been done in this domain. But despite the increased attention to its sources, little research has been done to actually *quantify* risk. As numerous recent articles attest, empirical work is needed to develop metrics to both identify and scale the sources of disruption risk (Qi et al., 2011; Rao and Goldsby, 2009; Singhal and Singhal, 2012; Tang and Musa, 2011; Wagner et al., 2012).

This study begins to close the gap by proposing a risk scale for one significant element of inter-modal supply chains: motor carriers. Our research contributions can be classified under three headers:

1. Empirical contribution to the trucking industry: the motor carrier risk (MCR) metric developed in this work is a diagnostic tool that can enable industry members to examine their strengths and/or weaknesses in a disrupted environment. The resultant score can be viewed as an analog to the popular and well-known consumer FICO score; the MCR score reflects a motor carrier's soundness and resilience in the same way that a FICO score reflects a retail consumer's credit worthiness. This tool will also allow other supply chain members (such as firms outsourcing the logistics function to a third-party firm) to examine and assess critical providers, in order to develop appropriate contingency plans in the event of unexpected exits. As an outcome of this research, we are also able to identify six specific predictive variables that are crucial to a motor carrier's long term prospects; the six variables are Natural Log of Size (=measured in Revenue), Operating Income, Market Share, Change in Operating Revenue vs. Change in Transportation Services Index (TSI), Return on Sales and Annual Growth Rate. As an additional output, our conjoint model is also able to quantify the relative importance of these variables.
   The TSI represents an aggregate economic measure for the movement of freight. The metric is published by the Bureau of Transportation Statistics (TSI Methodology (2014)). The Transportation Services Index (TSI) is a measure of the month-to-month changes in the output of services provided by the for-hire transportation industries. The movement of the index over time can be compared with other economic measures to understand the relationship of changes in transportation output to changes in Gross Domestic Product (GDP). The freight transportation index in particular consists of measures of for-hire trucking, railroad freight services (including rail based intermodal shipments such as containers on flat cars), inland waterways transportation, pipeline transportation (including principally petroleum and petroleum products and natural gas), and finally air freight. The index does not include international or coastal waterborne movements, private trucking, courier services, or the US Postal Service (TSI Methodology (2014)). The independent variable "Change in Operating Revenue vs. Change in TSI" therefore measures the fortunes of an individual motor carrier firm relative to the overall economic growth of transportation services.
2. Theoretical contribution to the credit scoring literature: diagnostic scores serve to classify firms – or consumers – into either 'good' and 'bad' categories, and numerous scoring mechanisms, with varied levels of effectiveness have emerged over the years. Further, this study utilizes – for what is believed to be the first time in this way – a frequently-used marketing-research methodology that has rarely been used elsewhere. Conjoint analysis belongs to a class of multivariate research techniques that use participants' choices (e.g., rankings for a set of product configurations) to estimate the underlying attribute relationships, enabling researchers to study preferences (Green and Srinivasan, 1978). The researcher provides participants with an array of product configurations with attributes (factors) at pre-set, categorical levels and, given a set of evaluations (or rankings of the product configurations) by one or more respondent(s), conjoint analysis decomposes the inherent attribute utilities such that the inherent attribute tradeoffs – that resulted in the participants' evaluations – are fully understood. Thus, conjoint analysis enables researchers to understand the underlying value or significance of these factors (Lohrke et al., 2010). But conjoint analysis has *never* been used to decompose a score that was *not* derived from participants' choices in a product design experiment; i.e., it has not been used to ascertain trade-offs among component factors if the rankings (e.g., motor carrier performance rankings) were objectively and naturally determined by a disruptive event such as 9/11. Section 2 provides further details on the precise adaptation of the conjoint analysis methodology for developing the motor carrier scorecard.
3. Finally, this work uses data published by the Federal Motor Carrier Safety Administration (FMCSA) and illustrates the benefits of applying statistical methodology and data mining techniques to existing, large transportation data sets.

The rest of the paper is organized as below. Section 2 provides a literature review. Section 3 describes how conjoint analysis can be adapted to develop attribute utilities and build a scoring model. Section 4 describes the statistical methodology used for analyzing the data in-depth. Section 5 describes our research results and Section 6 provides conclusions and directions for future research.