European Journal of Operational Research 242 (2015) 910–919

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Decision Support

Behavioral technology credit scoring model with time-dependent covariates for stress test

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ARTICLE INFO

Article history:
Received 6 May 2014
Accepted 22 October 2014
Available online 13 November 2014

Keywords:
Technology credit scoring
Stress test
Time-varying covariate
Survival analysis

ABSTRACT

Technology based loan default is related not only to technology-oriented attributes (management, technology, profitability and marketability), and firm-specific characteristics but also to the economic situation after the loan. However, the default phenomenon for technology based loan has not reflected the change of economic situation. We propose a framework of utilizing a time varying Cox hazard proportional model in the context of technology based credit scoring. The proposed model is used for stress test with various scenarios of lending portfolio and economic situations. The results indicate that the firms with higher management score than average have the lower loan default rates than the firms with higher profitability or marketability score than average due to the effect of manager's knowledge and experience and fund supply ability when they are exposed under the same economic condition. In scenario test, we found the highest default rate under stable exchange rate with high consumer price index. Moreover, firms with a high level of marketability factors turn out to be significantly affected by economic conditions in terms of technology credit risk. We expect the result of this study can provide valuable feedback for the management of technology credit fund for SMEs.
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1. Introduction

Small and medium enterprises (SMEs) that have a new technology play vital roles in various industries, and their performance is an essential part of the national economy (Moon & Sohn, 2010). However, many SMEs experience financial difficulties. To survive in a fast-paced business environment, SMEs with a new technology need to raise funds for the commercialization of their technology (Jeon & Sohn, 2008; Ju & Sohn, 2014a). In order to support SMEs with high growth potential, various technology credit guarantee programs have been made available to those firms that attain high technology scores. However, high loan default rates have been reported with critical losses of technology credit fund. Inadequate and inaccurate evaluations were claimed to be associated with these serious problems (Moon & Sohn, 2010).

To improve technology-based credit evaluations, many efforts have been made to develop more advanced technology credit scoring models. Previous investigations that focused on the development of advanced credit scoring models are outlined below.

Using logistic regression, Sohn, Moon, and Kim (2005) suggested an improved technology credit scoring model based on the factors of individual evaluation attributes. Moon and Sohn (2010) extended it by not only considering technology-related attributes but also environmental conditions such as firm-specific characteristics and the economic environment at the time of the application. Also, Moon and Sohn (2011) proposed a survival model for loan default that considers the total perception scoring phenomenon. Ju and Sohn (2014b) proposed a survival model that can predict the probability of loan default by a start-up SME based on technology-oriented attributes, firm characteristics, and the economic environment at the time of lending. The expected loss for a given time was obtained based on the loan default probability, exposure at default, and the loss in the event of default.

These previous studies are associated with a technology credit scoring model that predicts loan default by SMEs at a given time, considering the evaluation attributes at the time of the application for funding. However, after the loan is made, attributes can change over time (Ammann & Suss, 2009; Bellotti & Crook, 2009). Therefore, time-varying covariates need to be accounted for when developing a behavioral technology credit scoring model. Moreover, potential interaction effects between a firm and the economy need to be reflected in the model. Some related papers that considered time-varying covariates are as follows. However, none of the time-varying covariate studies were done in the context of a technology credit scoring model. An examination of the interaction effects among time-varying economic indicators, firm characteristics, and technology attributes evaluated at the time of the application would have significant implications for improving technology credit funds.

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http://dx.doi.org/10.1016/j.ejor.2014.10.054
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In this paper, we suggest a behavioral technology credit scoring model that reflects the time-varying characteristics that are associated with the loan recipient firms for general manufacturing industry. In order to adopt time-varying variables, we employ the Cox proportional hazard model. The Cox proportional hazard (PH) model (Cox, 1972) is commonly utilized to predict loan default over time (Bellotti & Crook, 2009; Brown & Larson, 2007; Van den Poel & Lariviere, 2004).

Additionally, we apply the proposed model to stress tests in an effort to analyze the impact of economic changes on a technology credit fund. A stress test is a popular tool in the area of risk management to assess the potential impact of dynamic situations that might impact the financial sector (Bellini 2013; Coffinet, Pop, & Tiesset, 2012; Huang, Zhou, & Zhu 2009). We expect that the proposed model will provide guidelines for the effective management of a technology credit fund under a changing economic environment.

This paper is structured as follows. In Section 2, we review previous studies related to the Cox proportional hazard (PH) model with time-varying covariates. In Section 3, we propose a behavioral technology credit scoring model. In Section 4, we conduct a stress test based on historical scenarios. In Section 5, we discuss our study results and suggest further research.

2. Cox proportional hazard model with time-varying covariates

The Cox hazard regression model proposed by Cox (1972) has been widely used in survival analyses involving time-to-event data with censoring, and it has been extended to accommodate time-varying covariates (Mata & Portugal, 1994). In this paper, we apply the Cox proportional hazard model to represent changing economic conditions after a loan to technology-based firms. We define the event as a default by a SME on a technology credit loan. In this section, we briefly introduce the Cox proportional hazard model with time-varying covariates applied to our data.

The time-varying proportional hazard model estimates the relationship between the hazard rate (the likelihood of SME default), $\lambda(t)$ and a number of explanatory variables (three groups of input variables: the technology-oriented attributes, the firm-specific characteristics, and the economic indicators), $z(t)$ which are permitted to vary over time. The proportional hazard function is specified so that the explanatory variables shift an underlying baseline hazard function, $\lambda_0(t)$, up or down. The time-varying proportional hazard function is expressed as follows:

$$\lambda(t; z(t)) = \lambda_0(t)e^{\beta z(t)}. \tag{1}$$

In this equation, β is the set of coefficients to be estimated.

Cox (1972) describes how β can be estimated by maximizing the partial likelihood function of the probability of default observed in the sample. β is estimated from inferences on the conditional probability of defaulting in a given time period (Boyson, 2003).

It is assumed that there is a sample of n SMEs, k of which default on their loans during the observed period with default times of $t_1 < t_2 < \cdots < t_k$. The assumption of this model is that each default occurs in a different time period, with the defaults ordered from 1 to k chronologically. The remaining n–k SMEs are censored and have no loan default times during the sample period. However, these SMEs could default on their loan at some time after the sample period ends.

Let $z_i(t)$ be $z(t)$ for the SME with default time t_i and let $z_j(t)$ be $z(t)$ for each SME at risk at time t_i. Assign c_i equal to 1 if SME i defaults in observed period, otherwise zero. R_i is the set of SMEs at risk of loan default in period i. The partial likelihood function to be maximized is

$$L(\beta) = \prod_{i=1}^{n} \left(\frac{e^{\beta z_i(t_i)}}{\sum_{j \in R_i} e^{\beta z_j(t_i)}} \right)^{c_i}. \tag{2}$$

This allows the use of the maximum likelihood method to estimate β without needing to know the baseline hazard. However, in order to estimate survival probabilities, the baseline hazard is needed. This can be estimated based on the parameter estimates β given by the maximum likelihood estimation and using an estimate for the integrated baseline hazard given by Andersen (1992), as follows:

$$\lambda_0(t) = \sum_{t_i \le t} \frac{C_i}{\sum_{j \in R_i} e^{\beta z_j(t_j)}}. \tag{3}$$

With this information, the survival probability at time t can be given in terms of the hazard function:

$$S(t) = P(T \ge t) = \exp\left(- \int_0^t \lambda(u)\, du \right). \tag{4}$$

There are several studies related to time-varying proportional models. Using the Cox regression model with time-dependent covariates, Bellotti and Crook (2009) tested whether the probability of default of an individual is affected by macroeconomic conditions such as bank interest rates, the unemployment index, and earnings after the loan. Malik and Thomas (2010) proposed a hazard rate model to predict the probability of default by a consumer. They used Cox proportional hazard rate models, and their study results showed that the rates of default by consumers are significantly affected by macroeconomic variables such as interest rates, the GDP (Gross Domestic Product), and the CPI (Consumer Price Index). Their model can be used to predict consumer credit risk in loan portfolios. Thomas (2000) has also described the important impact that dynamic economic conditions can have on credit risk. In that study, four general macroeconomic variables were analyzed. Three macroeconomic variables that were shown to be significant on the default behavior of consumers were the CPI (specifically the rate of inflation), interest rates, and GDP growth. In this paper, we use the Cox PH model with time-varying economic covariates to predict defaults by SMEs on technology credit loans. Malik and Thomas (2010) suggested that consumer-specific ratings (behavioral scores) incorporate macroeconomic variables to construct a consumer default probability model. Their model showed that consumer default is significantly associated with macroeconomic factors. Carling, Jacobson, Linde, and Roszbach (2007) used the Cox proportional hazard model to explain the survival time to default for borrowers of a major Swedish bank. The authors estimated the expected survival time of firms using macroeconomic explanatory variables.

3. Empirical study

3.1. Data and variables description

In order to develop a behavioral technology credit scoring model with time-varying covariates, we apply the Cox proportional hazard (PH) model to our empirical data set based on three groups of input variables: technology-oriented attributes, firm-specific characteristics, and economic indicators. The technology-oriented attributes employed in the evaluations of these firms were divided into four sub-groups: management, technology, marketability, and profitability, which contain a total of 16 individual attributes, as displayed in Table 1 (Moon & Sohn 2010; Sohn et al., 2005) and Appendix A. These attributes are observed at the time of the application for the loan.

The data set consists of 4566 cases that obtained a credit guarantee by a technology scoring system implemented in Korea between 1999 and 2004. Obtained cases were evaluated by an expert committee sent by Technology Credit Guarantee Fund that screens SMEs. A total of 1327 firms experienced loan default during this period, and the remaining firms were censored cases. Censored cases represented not only SMEs successfully repaid their loan but also they are under technology credit guarantee. According to the scorecard in Table 1, an applicant firm was assessed in terms of the 16 attributes, all of which had a pre-assigned relative weight of 5 or 10. Those evaluated on a ten-point Likert scale are regarded to be worth two times more than those

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