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Marginal railway track renewal costs: A survival data approach

Mats Andersson, Gunilla Björklund *, Mattias Haraldsson

Swedish National Road and Transport Research Institute (VTI), and Centre for Transport Studies, Box 55685, SE-102 15 Stockholm, Sweden

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ABSTRACT

In this paper, renewal costs for railway tracks are investigated using survival analysis. The purpose is to derive the effect from increased traffic volumes on rail renewal cycle lengths and to calculate associated marginal costs. A flow sample of censored data containing almost 1300 observations on the Swedish main railway network is used. We specify Weibull regression models, and estimate deterioration elasticities for total tonnage as well as for passenger and freight tonnages separately. Marginal costs are calculated as a change in present values of renewal costs from premature renewal following increased traffic volumes. The marginal cost for total tonnage is estimated to approximately SEK 0.002 per gross ton kilometre.

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1. Introduction

Rail infrastructure managers face the problem of track wear and tear in their daily business. This is caused by operating train services as well as non-traffic factors such as location and climate. The wear and tear process can be managed by undertaking maintenance activities, but eventually a more substantial renewal activity is necessary. The wear and tear question should therefore be seen as a joint maintenance and renewal problem. Pricing infrastructure wear and tear is of great importance from an efficiency standpoint. It is also important because of the move towards separation of rail infrastructure from train operations, driven by the European legislation, which also requires countries to set rail infrastructure charges based on the direct cost of running different services, including the wear and tear cost (Andersson et al., 2012). The legislation has been implemented in a variety of ways, with a number of countries going for complete separation (e.g. Sweden), whereas others retaining infrastructure and operations as separate subsidiaries within the same group (Nash, 2010). Over the last decade, research on the subject has gradually increased for all modes of transport, both in Sweden and internationally (Andersson, 2008, 2011; Andersson et al., 2012; Bruzelius, 2004; Nash, 2003; Nash and Matthews, 2005; Nash and Sansom, 2001; Thomas et al., 2003; Wheat and Smith, 2008; Wheat et al., 2009). Sweden has a long tradition of marginal cost pricing in the transport sector, but to date, railway infrastructure wear and tear fees have excluded costs for rail renewal. This issue has drawn some attention regarding the lack of empirical evidence on the size of a pricing relevant rail renewal cost component (Nash, 2005). In the European project CATRIN (Cost Allocation of Transport Infrastructure Cost), it was found that many studies have investigated maintenance costs but only a few studies have looked at renewal costs, and those who have done that show a lot of variations in the results (Wheat et al., 2009). The conclusion from CATRIN is that there is a need to better model renewal costs and that further use of survival analysis should be considered.

* Corresponding author. Tel.: +46 (0)8 55 53 65 04.
E-mail address: gunilla.bjorklund@vti.se (G. Björklund).

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The fee for railway infrastructure wear and tear in Sweden is based on econometric analyses of infrastructure operation and maintenance costs by Johansson and Nilsson (2004) and Andersson (2006). Johansson and Nilsson (2004) use cost data from the mid 1990's, but detailed information on renewals was not available at the time of their analysis. Andersson (2006, 2008) extends their analysis with data from 1999 to 2002 by analysing an aggregate of maintenance and renewal costs using initially pooled ordinary least squares (POLS) and later fixed effects (FE) models. He finds a higher cost elasticity with respect to output than Johansson and Nilsson (2004) and increased marginal costs in the POLS approach, but a lower cost elasticity in the FE approach. The POLS approach was rejected and furthermore, the cost function approach to identify the marginal cost of the aggregate of maintenance and renewal is questioned. As rail renewals have long life cycles (are rare events), the lack of comprehensive time-series data questions the adequacy of applying traditional regression analysis to the renewal problem. An alternative econometric approach to model rail renewal costs is therefore presented in Andersson et al. (2012). They use models for censored and truncated data to model the renewal cost problem. The results are promising in terms of elasticity and marginal cost estimates. The recommended model is a two-part model that deals with the renewal problem in two stages. Stage one models the decision to renew or not using a probit model and stage two deals with the size of the renewal using a truncated regression model. The corner solution model used in Andersson et al. (2012) is preferred if there is good information available on both infrastructure and costs. In contrast to previous applications of econometric models, we suggest a different approach using an analytical expression for the marginal cost of rail renewal, and survival analysis of track segments as input to the marginal cost calculation. This method gives an opportunity to estimate an average marginal cost of renewal when detailed cost data is not available.

In the present paper, almost 1300 railway track segment observations are used to analyse rail life in relation to freight and passenger traffic in Sweden. Weibull survival functions are estimated using rail life as dependent variable while traffic and other infrastructure variables are used as covariates.

The main findings are that the estimated models give a good fit of the data. We find strong positive duration dependence, with a more than proportional increase in renewal probability over time with respect to accumulated traffic. This supports the choice of the Weibull model for this data. The weighted average marginal cost for total tonnage are estimated to approximately SEK 0.002 per gross ton kilometre.[1]

The outline of the paper is as follows. In Section 2, we describe the modelling approach followed by a data review in Section 3. The model results are presented in Section 4. Marginal costs are calculated in Section 5 while a discussion and conclusions are given in Section 6.

2. The modelling approach

2.1. Modelling rail life

Survival data are used in a number of research disciplines. In medicine, it can be the case of time elapsed between a treatment and a specific health state. In labour economics, it can be the time spell of a person being unemployed or in engineering, the time until a component fails to perform its intended function.

In this paper, the expected life of railway track segments is analysed using parametric survival models. The general theory and concepts of survival analysis and model estimation is well developed, e.g. Kiefer (1988), Lancaster (1990) or Klein and Moeschberger (2003). We follow the terminology of Klein and Moeschberger (2003) in the presentation of the underlying theory of the survival analysis.

Let X be a nonnegative random variable, representing the time in years between two railway track segment renewals i.e. rail life. There are a few different ways of characterising the distribution of X and if we know any of these, the others can be identified. First, the distribution of X can be represented by a survival function. The survival function S states the probability P of an individual track segment surviving beyond time x.

$$S(x) = P(X > x) \tag{1}$$

The survival function is the complement to the cumulative distribution function F, $S(x) = 1 - F(x)$, where $F(x) = P(X \leqslant x)$. The probability density function f gives the unconditional probability of a track segment being renewed in time x, $f(x) = -\frac{dS(x)}{dx}$.

Second, the probability that a track segment of age x will be renewed instantaneously after x ($x + \Delta x$) is represented by the hazard rate h. The hazard function for a continuous variable is defined by

$$h(x) = \lim_{\Delta x \to 0} \frac{P[x \leqslant X < x + \Delta x | X \geqslant x]}{\Delta x} = \frac{f(x)}{S(x)} = \frac{-d \ln[S(x)]}{dx}. \tag{2}$$

The cumulative (or integrated) hazard function H is defined as

$$H(x) = \int_0^x h(u)du = -\ln[S(x)]. \tag{3}$$

[1] The exchange rate from Swedish Kronor (SEK) to Euro (EUR) is SEK 9.24/EUR and from Swedish Kronor to US Dollar (USD) is SEK 8.28/USD (May 22, 2015).

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