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Dynamics in rail infrastructure provision: Maintenance and renewal costs in Sweden

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ABSTRACT

In this paper, we extend to the literature on marginal wear and tear cost estimation in railways, by applying a panel vector autoregressive model to rail infrastructure renewals and maintenance costs, using an extensive dataset from Sweden. This study is significant given the inherent difficulties in modelling the substantial renewals element of infrastructure costs, as well as the need to account for the dynamics in renewals and maintenance. The dynamic model allows us to estimate equilibrium cost elasticities with respect to train usage, which are significantly larger than their static counterparts. Overall, this work highlights that dynamics in rail infrastructure costs are important to consider when setting track access charges with respect to the wear and tear caused by traffic. This is particularly important given several countries, for example France, Sweden and Switzerland, are now setting access charges at marginal costs based on econometric studies.

1. Introduction

Infrastructure investments consume a large amount of resources. To reap the benefits of an investment, the infrastructure must be maintained and renewed due to the wear and tear caused by traffic and to some extent weather conditions - that is, maintenance and renewals will affect the performance and reliability of the infrastructure. For a given traffic level, the objective of the infrastructure manager (IM) is to minimize whole life maintenance and renewal costs (as well as train delay costs). In doing this, the IM needs to consider the with-in year substitution possibilities and intertemporal relations in maintenance and renewal activities. This is because maintenance and renewal activities are input substitutes in the production of infrastructure services, both between each other and in their phasing over time. This is the basis of Life Cycle Asset Management. In general, a cost minimizing plan would imply that maintenance costs for a given asset would increase over time, until it is beneficial to renew the asset instead of letting the maintenance (and train delay) cost level increase any further. Hence, a renewal is likely to be preceded by high maintenance costs and then followed by low maintenance costs.¹ This also implies that a temporary deviation from the plan

of maintenance and renewal activities, due to for example a change in traffic, will have an effect on the future pattern of these activities.

The dynamics in maintenance and renewals implies that an IM needs to strike a balance within and between these activities for a certain traffic level, and an increase in traffic may require an immediate as well as intertemporal adjustment of these costs. This implies that the cost impact from traffic needs to be studied in a dynamic context, which is the objective with this paper. Specifically, the purpose of this paper is to provide empirical evidence on the interdependence between maintenance and renewals, as well as their intertemporal effects. The estimates can be used to calculate the marginal cost for traffic, which has become an important part of the track access charges that were introduced after the vertical separation between train operations and infrastructure management in Europe as of the 1990s.²

In this study, we estimate a panel vector autoregressive (panel VAR) model. This is a dynamic model that considers several endogenous variables - renewals and maintenance in our case - in a multiple equation system. Our estimation approach is similar to that in Wheat (2015), with the contribution that we take the panel data structure into account. Hence, we are able to model unobserved individual heterogeneity, which

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¹ However, we note that there may be reason to lower the level of preventive maintenance during a certain period before a renewal is made. Yet, this may be countered with a need for more corrective maintenance prior to the renewal.

² The Swedish reform took place in 1988, preceding the wider European reform.

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in our case are unobserved effects specific for each contract area. Moreover, we have access to ton-km instead of train-km, where the former provides a better relation to wear and tear.

A central facet of the VAR model is to make structural analyses, in which the response of the endogenous variables is traced through time following a ‘shock’ to the equation system. We make use of an impulse response analysis (IRA) to trace how maintenance/renewal costs evolve over time following a disruptive shock. This shock could be caused by a factor outside of the considered explanatory variables and thus captured as perturbing the error in the model. An example in this case is changes in the budget constraint or severe weather incidents. Alternatively, a shock can come from a change in the exogenous explanatory variables within the model e.g. traffic. Both of these shock types require the IM to adjust maintenance and renewal activities in response. To identify these shocks and their impact, we utilize the temporal dependence between maintenance and renewals, where we expect the latter to react more slowly than the former.

The paper is organized as follows. In section 2, we present the empirical context in which our study is positioned. The methodology used is described in section 3. It also includes a subsection in which we expand on the mechanisms behind the dynamics in rail infrastructure provision, as well as a subsection on the equilibrium cost elasticity with respect to traffic; an elasticity that can be used in a calculation of the marginal cost for the wear and tear of the infrastructure. Section 4 comprises a description of the data. We specify our model in Section 5. The estimation results are presented in Section 6. Section 7 concludes.

2. Empirical context

Econometric analysis of railway maintenance and renewals costs is accepted by the European Commission as an appropriate methodology to set track access charges across EU member states (European Commission, 2015), and several countries, including Sweden, France and Switzerland have used econometric methods to inform the level of access charges within their countries. This motivates the empirical literature on marginal cost of railway infrastructure (see Link et al., 2008; Wheat et al., 2009), which has a wealth of research on the maintenance cost element (Munduch et al., 2002; Johansson and Nilsson, 2004; Wheat and Smith, 2008; Gaudry and Quinet, 2009). However, the econometric evidence on the marginal cost associated with renewals cost element is much less robust. Studies often add renewal costs to maintenance in the estimations (Andersson, 2006; Tervonen and Pekkarinen, 2007; Marti et al., 2009; Wheat and Smith, 2009), yet there are a couple of examples focusing on renewals only, although these use very disaggregate data by asset (Andersson et al., 2012; Andersson et al., 2016). The lack of evidence on renewals cost partly reflects the lumpy nature of renewals investments, which in turn implies a long time series is required to capture the evolution of renewals expenditure to changes in traffic (Link et al., 2008; Wheat et al., 2009).

Renewals expenditure accounts for roughly one third of the sum of maintenance and renewals expenditure in Sweden (Trafikverket, 2016) and so the significance of this cost category and its relationship with maintenance should not be understated.³ In general, the importance of performing renewals and maintenance activities at the right time has generated a rather extensive literature on the optimization of these activities: Gaudry et al. (2016) and Andrade and Teixeira (2011) are railway examples, while Sathaye and Madanat (2011), De la Garza et al. (2011) and Gu et al. (2012) analyse the optimization of pavement maintenance and resurfacing activities (see Sharma and Yadava (2011) for a literature review on this area). Related to this literature is Small et al. (1989), who presents an equilibrium pricing and investment model,

³ The share can be larger (or smaller) in other countries. See for example Grimes and Barkan (2006) for renewals as a proportion of total maintenance costs in the US during 1978–2002.

in which optimal road durability for a certain traffic volume is calculated together with the corresponding marginal costs.

Still, there is a lack of empirical evidence on the dynamics between and within maintenance and renewal activities (i.e. the interdependence and intertemporal effects as described in the introduction and more in depth in section 3.1), especially in the literature on rail infrastructure costs. A notable exception is the study by Wheat (2015), in which a VAR model is estimated for both maintenance and renewal costs in ten zones in Britain over a 15-year period. The study finds evidence on intertemporal effects, yet not for a relationship between renewals and maintenance costs. An intertemporal effect is also found by Odolinski and Nilsson (2017) who estimate a dynamic model (system GMM) for maintenance costs only. Similar to Wheat (2015), they find that an increase in maintenance costs in one year - due to for example a traffic increase - predicts an increase in maintenance costs in the next year. Other examples on research where the dynamics between maintenance and renewals are taken into account, is Andersson (2008) and Odolinski and Smith (2016) who both use a dummy variable approach. However, it involves an arbitrary definition of major renewals and only allows for a stepwise effect of renewals on maintenance costs.

Thus, econometric evidence on the dynamics in rail infrastructure provision is scarce, despite its relevance for track access charges. Ultimately, marginal cost estimates that take dynamic effects of renewals and maintenance into account will be closer to the actual cost of running one extra unit of traffic on the railway, compared to the cost estimates based on static models for maintenance (see for example Wheat et al., 2009) and renewals (see for example Andersson et al., 2012; Andersson et al., 2016).

3. Methodology

Sims (1980) proposed the VAR model as an alternative to the simultaneous equation macroeconomic models prevalent at the time, which he criticized for its problems with arbitrary identification. The (so called) exogenous variables in the models - used for example to identify an effect on either the demand or supply - were often not strictly exogenous due to expectations in the economy that can change the behaviour of the consumer (the demand) in addition to the variable's direct effect on the supplier and vice versa. Hence, there is a problem of simultaneity in the outcomes, which is the same type of problem we have with maintenance and renewals. The VAR framework dispenses with such arbitrary identification through the use of lagged explanatory variables which are by definition weakly exogenous even if the values in the current time period are endogenous.

The objective in using a VAR model is to capture the effects of exogenous shocks via identification strategies which, if properly specified, can make the model useful for forecasting and policy analysis. One strategy is to make use of the temporal dependence between the variables - that is, how fast they react to a shock. Considering the endogeneity of the maintenance and renewals, where we also expect the latter to react more slowly to a shock than the former, estimating a VAR model can be a fruitful approach for analyzing the dynamics in infrastructure provision, as explained further in section 3.1.

We consider a panel VAR(p) model, where p denotes the lag length used in the model.⁴ We have two endogenous variables: renewal costs (R_{it}) and maintenance costs (M_{it}), where $i = 1, 2, \dots, N$ contract areas and $t = 1, 2, \dots, T$ years. $\alpha_{1,i}$ and $\alpha_{2,i}$ are the unobserved individual-specific effects for the renewal and maintenance equations respectively, while $u_{1,it}$ and $u_{2,it}$ are their respective residuals, where $(u_{1,it}, u_{2,it}) = \mathbf{u}_{it} \sim iid(0, \Sigma)$. Σ is the covariance matrix of the errors. We also include a vector of exogenous variables \mathbf{X}_{it} with parameters β_1 and β_2 for the maintenance and renewal equations respectively. Importantly

⁴ Here we present the VAR(1) model for expositional simplicity. We consider further lags in the model estimation.

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