1st European Symposium on Quantitative Methods in Transportation Systems, 4-8th September 2012, Lausanne, Switzerland

Identifying the Main Drivers of Technical Efficiency of Urban Metro Systems using Stochastic Frontier Techniques

Shane Canavan, Daniel J. Graham, Patricia C. Melo, Richard J. Anderson
Centre for Transport Studies
Railway and Transport Strategy Centre
Department of Civil and Environmental Engineering
Imperial College London
London SW7 2AZ

ABSTRACT

This paper investigates the key determinants of output efficiency of metro systems by investigating a panel data set of 27 metro systems across 20 countries, from a period of 1994 to present. The study complements conventional benchmarking findings by undertaking an econometric benchmarking approach based on stochastic frontier analysis. New results are provided to the field, as it is believed an approach of this kind has so far not been applied specifically to metro systems.

As the world's population has verged towards the 7 billion mark, an unprecedented population shift has been witnessed from rural to urban areas. According to the United Nations Population Fund it is expected that the world's urban population will increase to approximately 5 billion by 2030, composing of 60% of all global inhabitants. As a whole, the causes and ramification of this shift are exceedingly complex, and the actions required for dealing with the strain imposed are extensive. Amongst the more successful solutions, has been high capacity and high frequency services provided by metro systems. However, the use of metro systems does also raise some contentious issues. Metro systems generally cost public money. Funds are often received from either government, or local authorities for compensation payments for reducing fares for certain socio-economic groups, contractual fees, as well as for a variety of subsidies such as operating and energy services. It is clear that discrepancy in the ability of metro operators to provide an efficient service in terms of their use of physical and labour assets and resources warrants closer investigation.

Intuitively, urban rail systems can be examined based on three characteristics, namely the urban areas they serve, the physical system, as well as the operating characteristics. Sutcliffe (2002) and Mackett and Sutcliffe (2003) provide a good overview of the factors behind the success of urban rail systems. Based on previous studies, they blend numerous criteria into five sets of objectives for analysis. These are presumed to represent the main objectives and justification of the systems. These can be listed as achieving high patronage, operating a cost-effective system, increasing public transport usage, reducing traffic congestion and environmental problems, and improving land-use and urban growth patterns. From these, some main factors can be identified that influence success. Although these studies are largely subjective, they provide a solid building block of factors to consider for more rigorous and empirical studies, which to date have been rather scarce for metros specifically.

There exists a diverse array of methodological procedures to choose from, where the use of each depends on the purpose of productivity measurement, as well as also being based on data availability. Coelli et al (2005) provides a comprehensive review of production economics giving an overview of both methodological and measurement approaches. Non-parametric approaches to productivity measurement have been widely used, mainly as they can be directly constructed from data without the need for statistical estimation of production or cost functions. Examples of non-parametric methods include partial productivity measures (PFP), total factor productivity (TFP), free disposal hull (FDH), and data envelopment analysis (DEA).

Parametric approaches allow for dealing with error in the data and for statistical hypothesis testing. Stochastic frontier analysis (SFA) is considered to be one of the more prominent approaches, and allows us to distinguish between the effects from data noise and error from those of inefficiency. This technique is also more suitable to deal with small samples than non-parametric approaches. The stochastic frontier production function model was proposed by Aigner et al (1977) and Meeusen and Broeck (1977) independently. Later, this was extended by Schmidt and Knox (1979) to incorporate allocative inefficiency. Comprehensive overviews of the econometric developments of SFA are summarised in Kumbhakar and Lovell (2000) and Coelli et al (2005). Gong and Sickles (1992) provide a fairly comprehensive review of the comparative performance between DEA and SFA using a Monte Carlo technique. On many occasions it was found that a stochastic frontier approach represented individual efficiency and productivity levels better than DEA.

Consequently, SFA has been adopted for this research, specifically models specified according to Battese (1995), which permit the estimation of both technical change and time-varying technical inefficiency for the different metro systems. Starting with a standard production function, SFA estimates the maximum production frontier for the sample of metro systems by carrying out maximum likelihood estimates for the parameters. Two models are estimated, a supply side model which considers capacity operating kilometres as the output variable, and a demand side model which considers passenger journeys as the output variable.

The data used originates from two consortiums, namely the Community of Metros (CoMET) and the Nova Group (Nova), managed by the Railway and Transport Strategy Centre (RTSC) based at Imperial College

London. Conventional inputs include labour, capital and energy. However, in addition to these, variables that affect efficiency considered include network characteristics, operating environment, as well as organisational and regulatory factors.

The results reveal a number of significant drivers of technical efficiency. Estimates for metro service reliability are found to be positively linked to technical efficiency. This indicates that improving metro reliability increases output efficiency, as the hours of lost service and the amount of wasted input factors are both reduced. This highlights the need for incident prevention, as well as incident recovery. Network density and urban population are also both found to be significant, which is consistent with previous literature that has considered economies of urban density. As expected, results for subsidy requirement confirm previous indications that reliance of subsidies reduces output efficiency as this leads to inefficiency in allocation and use of input factors, as well as reducing the ability to sustain long term investment in assets. Finally, the age of a metro system is considered to be significant as older systems may require more complex operations, maintenance, and management of assets. However, it is unclear how useful or practical a change in strategy might improve output efficiency in this case.

JEL Classification: C33, C51, D24

Key words: Stochastic frontier analysis, Technical efficiency, Metro system, Panel data.

References:

AIGNER, D., LOVELL, C. A. K. & SCHMIDT, P. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics,* 6**,** 21-37.

BATTESE, G. E. & COELLI, T. J. 1995. A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics,* 20**,** 325-332.

COELLI, T., PRASADA RAO, D. S., O'DONNELL, C. J. & BATTESE, G. E. 2005. An introduction to efficiency and productivity analysis. *2nd Ed. Springer*.

GONG, B.-H. & SICKLES, R. C. 1992. Finite sample evidence on the performance of stochastic frontiers and data envelopment analysis using panel data. *Journal of Econometrics,* 51**,** 259-284.

KUMBHAKAR, S. C. & LOVELL, C. A. K. 2000. *Stochastic Frontier Analysis,* Cambridge University Press.

MACKETT, R. & BABALIK SUTCLIFFE, E. 2003. New urban rail systems: a policy-based technique to make them more successful. *Journal of Transport Geography,* 11**,** 151-164.

MEEUSEN, W. & BROECK, J. V. D. 1977. Efficiency Estimation from Cobb-Douglas Production Functions with Composed Error. *International Economic Review,* 18**,** 435-444.

SCHMIDT, P. & KNOX, L. C. A. 1979. Estimating technical and allocative inefficiency relative to stochastic production and cost frontiers. *Journal of Econometrics,* 9**,** 343-366.

SUTCLIFFE, B. E. 2002. Urban rail systems: analysis of the factors behind success. *Transport Reviews,* 22**,** 415.