



# Productivity growth in urban freight transport: An index number approach



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## ABSTRACT

Improvement of operational efficiency is a common goal of most governmental freight transport policies. Productivity and efficiency analysis consequently provides a sound knowledge base. This paper illustrates how axiomatic production theory can be applied to model road freight transport, and proposes a logistics efficiency measure as the function representation. Based thereon, a logistics productivity index that decomposes into technical, cargo mix, vehicle capacity, and efficiency changes is established to determine the rate and drivers of growth. Emphasizing urban logistics, the paper discusses the limited access to reliable data at the micro level and illustrates how local or regional freight transport can be evaluated applying pseudo panel techniques to national freight surveys. Correspondingly, the theoretical productivity index is implemented on a pseudo panel covering the 24 largest cities in Norway between 2008 and 2012, when 12 of them entered a collaboration agreement to promote efficient transport. The results indicate a modest 0.6% average productivity growth. Efficiency change is the key driver of growth, countered by technical stagnation and regress. Negative productivity growth is expected if this trend continues. Moreover, the results do not reveal productivity gains from urban agglomeration or membership of the collaboration agreement, suggesting that prevailing transport and land use policies have so far been unable to foster productivity growth in urban freight transport.

## 1. Introduction

On the one hand, urban freight transport is a necessary condition for sustaining urban settlements and for maintaining the urban way of life. On the other, it produces a wide range of external costs such as noise, air pollution, accidents, and congestion. Because of high population densities in urban areas, these external costs are also typically very high.<sup>1</sup> With increasing urbanization and transportation, urban freight transport has therefore become an important issue on the political agenda worldwide; see e.g. [European Commission \(2011\)](#).

There are several ways to tackle the negative impacts of urban freight transport, including establishing eco-zones, delivery time restrictions, and vehicle weight restrictions.<sup>2</sup> One of the most promising measures to reduce the negative impacts is to minimize the number of trips required for freight movements ([Eidhammer and Jean-Hansen, 2008](#)), i.e., to foster productivity growth and efficiency improvements in urban logistics. This approach to improving the sustainability of urban freight transport, by decoupling the movement of goods from transport activities, is the focus of my paper. More precisely, it develops and decomposes a Logistics Productivity Index (LPI) to identify the rate and drivers of productivity growth, and illustrates empirical

implementation of the index in the context of urban freight transport. Thus, it establishes a management tool for freight transport policies in general, but pays special attention to urban freight transport. The availability of data for implementing the index at the city level is discussed.

[Caplice and Sheffi \(1994\)](#) distinguish between two types of logistics performance measures; productivity measures (i.e., the ratio of outputs to inputs; e.g., goods lifted per truck or trip) and utilization measures (i.e., the capacity used to the total capacity available). As noted by [McKinnon \(2015a\)](#), while ton kilometers per truck per annum have risen steeply in most countries as trucks have increased in size, weight, and power rating, this does not necessarily mean that trucks are on average running fuller than before. Consequently, he advocates the need for a separate set of utilization metrics in addition to productivity measures when assessing the operational efficiency of freight transport. A key objective of this paper is to illustrate that logistics performances need not be deduced from a set of indicators. Instead, an index that comprises productivity and utilization can be established and decomposed to identify their relative importance to intertemporal changes in logistics performances.

This paper illustrates how axiomatic production theory can be applied to model road freight transport, when the number of trips (or

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<sup>1</sup> See [Quack \(2008\)](#) for more on the pros and cons of urban freight transport.

<sup>2</sup> See [Browne et al. \(2008\)](#) for an overview and discussion of possible measures to deal with the negative impacts of freight transportation.

vehicle kilometers) and vehicle carrying capacities are modeled as inputs and the tons lifted of various cargo types as outputs. The modeling approach has several merits. First, as noted by McKinnon (2015a), measuring the degree of utilization is a challenging task; for dense commodities, the vehicle weight limit is critical, while for low-density products with high “stackability” the main constraint is the cubic capacity. The model proposed in this paper deals with the problem by modeling freight transport as a multi-output production process in which different cargo types have different input requirements. Second, the model framework allows measuring logistics productivity and efficiency given vehicle capacities, and to disentangle the impact of changing vehicle capacities on productivity. Third, the model framework is adopted from the productivity and efficiency analysis literature and is thus ideal for benchmarking road freight transport. The proposed approach identifies best practices from identified practices, as opposed to comparing current practices to theoretical – and perhaps unattainable – maxima (cf., the lading factor).<sup>3</sup> Fourth, production analysis is equipped to control for contextual variables that may influence logistics productivity, e.g., urban form (Allen et al., 2012).

Based on the model framework, I propose a LPI that allows assessing intertemporal changes in logistics productivity. This index is preferred to traditional productivity indices such as the Malmquist (1953) index because the LPI is easy accessible to stakeholders in transport by reporting intertemporal changes in goods lifted per trip (or per vehicle kilometer). The index decomposes into frontier shifts and efficiency improvements, where the frontier shift component can be further decomposed into input-output mix and technical changes and the efficiency component can be decomposed into pure and scale efficiency changes. The LPI thus allows pinpointing the sources of intertemporal changes in logistics productivity, and is consequentially highly useful for evaluating the outcomes of policies aimed to improve urban logistics performances. Frontier-based techniques to measure performances are particularly helpful to competition-based policies that distribute financial support among cities based on their previous efforts to and successes in promoting sustainable freight transportation.

Several previous studies apply index number theory to analyse road freight transport. Some examples include Kveiborg and Fosgerau (2007) who use a Divisia index to decompose the relative contributions of economic activities, the composition of commodities, the weight to value ratios, the handling of commodities, and the average load and trip length to the development of road freight traffic and transport in Denmark, Sorrell et al. (2009) who decompose the contributions of eleven key factors including GDP to intertemporal changes in road freight energy use based on the log-mean Divisia index approach, and Alises et al. (2014) who conduct a decomposition analysis to identify the drivers of the evolution of the road freight transport intensities of the United Kingdom and Spain. The approach introduced in this paper differs from these studies by being in the Malmquist (1953) index tradition,<sup>4</sup> using frontier analysis to disentangle technical and efficiency changes. While I am unaware of previous attempts to evaluate the operational efficiency of road freight transport using frontier-methods, they have been employed to assess the productivity and efficiency of transport companies. Cruijssen et al. (2010) use Data Envelopment Analysis (DEA) to assess the economic efficiency of 82 Belgium road transportation companies. Heng et al. (2012) account for air pollution

emissions when assessing the efficiency and productivity growth of trucking in U.S. states between 2002 and 2005. Zhang et al. (2015) propose a Malmquist CO<sub>2</sub> emission performance index that is used for assessing the dynamic performance of the Chinese regional transportation industry.

While the reviewed literature on index theory focuses on the development of freight transport at the national or sector level, this paper emphasizes urban freight transport. Betanzo-Quezada and Romero (2010) present an urban freight transport index, focusing on the attention of authorities in dealing with freight transport issues within cities. Their index ranks cities against a theoretical benchmark while the index presented in this paper identifies best practices from observed practices. I illustrate the usefulness of the LPI by analyzing the intertemporal development in the logistics performances of the 24 largest cities in Norway in a period when 13 of them entered a collaboration agreement with the central government to reduce greenhouse gas emissions and to make the cities a better place in which to live. The agreement, also known as the Cities of the Future agreement, became binding in 2008 and expired in 2014. Land use and transport are naturally among the most important areas of the collaboration agreement.

A major obstacle to monitoring logistics performances at the micro level is the limited accessibility to reliable data. This paper analyzes how local or regional freight transport can be evaluated using pseudo panel techniques based on the raw-data from national freight surveys. To that end, it utilizes DEA to empirically implement the LPI on a pseudo panel covering urban road freight transport in the 24 largest cities in Norway between 2008 and 2012.

This paper is structured as follows. The next section describes the theoretical foundations of the productivity index. Section 3 presents the dataset and the results, while Section 4 concludes.

## 2. Methods

Consider freight transport as a production process in which inputs (i.e., the number of trips and vehicle capacities) are used to produce outputs (i.e. the quantity or weight of the cargo throughput). Denote inputs by  $\mathbf{x} \in \mathfrak{R}_+^2$  and outputs by  $\mathbf{y} \in \mathfrak{R}_+^M$ . Assume that the production process is observed in  $s=1, \dots, S$  time periods. The technological possibilities for freight transport in period  $s$  may then formally be summarized by a technology set. In this paper I consider two contemporaneous reference technologies; the variable returns to scale (VRS) technology

$$T_{VRS}^s = \{(\mathbf{x}^s, \mathbf{y}^s): \mathbf{x}^s \text{ can produce } \mathbf{y}^s\}, \quad s = 1, \dots, S \quad (1)$$

and the constant returns to scale (CRS) technology

$$\begin{aligned} T_{CRS}^s &= \{(\mathbf{x}^s, \mathbf{y}^s): \mathbf{x}^s \text{ can produce } \mathbf{y}^s\}, \\ T_{CRS}^s &= \delta T_{CRS}^s \text{ for all } \delta > 0, \quad s = 1, \dots, S \end{aligned} \quad (2)$$

Following the usual convention, I assume that the technology sets satisfy the standard neo-classical axioms. That is,  $T$  is a compact and convex set satisfying the no free lunch and inactivity axioms, and free disposability of inputs and outputs. See Färe and Primont (1995) for more details on these axioms.

While the set theoretical representation of the technology is useful from an analytical perspective, it is insufficient for empirical analysis. Instead, function representations of the technology that can be estimated from data must be considered. In the case with only one output, the production function is a useful function representation that defines the maximal producible output for any given input vector. Distance functions are generally preferred function representations in cases with multiple inputs and outputs. These functions measure how far a given decision making unit is from the best-practice frontier by means of contracting inputs and/or expanding outputs, and are thereby useful measures of (in)efficiency. See Färe and Primont (1995) for more details on distance functions.

<sup>3</sup> As noted by McKinnon (2015b), under-utilization of vehicle capacity may not be an indicator of inefficiency, but rather an indicator that logistics companies make rational trade-offs among transport efficiency and other objectives.

<sup>4</sup> Grifell-Tatjé and Lovell (1996) argue that the main advantages of the Malmquist index over the Törnqvist and Fischer productivity indices are i) its weaker behavioural assumptions, ii) that its computation does not require price data, and iii) that it allows decomposing productivity changes into technical and efficiency changes.

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