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A framework to evaluate policy options for supporting electric vehicles in urban freight transport

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ABSTRACT

Electric vehicles (EVs) are considered as a feasible alternative to traditional vehicles. Few studies have addressed the impacts of policies supporting EVs in urban freight transport. To cast light on this topic, we established a framework combining an optimization model with economic analysis to determine the optimal behavior of an individual delivery service provider company and social impacts (e.g., externalities and welfare) in response to policies designed to support EVs, such as purchase subsidy, limited access (zone fee) to congestion/low-emission zones with exemptions for EVs, and vehicle taxes with exemptions for EVs. Numerical experiments showed that the zone fee can increase the company's total logistics costs but improve the social welfare. It greatly reduced the external cost inside the congestion/low-emission zone with a high population, dense pollution, and heavy traffic. The vehicle taxes and subsidy were found to have the same influence on the company and society, although they have different effects with low tax/subsidy rates because their different effects on vehicle routing plans. Finally, we performed a sensitivity analysis. Local factors at the company and city levels (e.g., types of vehicle and transport network) are also important to designing efficient policies for urban logistics that support EVs.

1. Introduction

Urban freight transport that serves trading activity is fundamental to sustaining current lifestyles. The logistic costs of freight transport have a direct bearing on economic efficiency and social welfare. Heavy freight vehicles cause more severe environmental and health problems than passenger vehicles. Russo and Comi (2012) noted that urban freight vehicles account for about 6–18% of total urban transport but for about 19% of energy use and for about 21% of CO_2 emissions. Urban freight vehicles are also responsible for a large part of local transport-based pollution (IEA, 2013) such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM). Cities clearly need to reduce pollution-intensive freight traffic by managing logistic processes more efficiently and switching to low emission vehicles. Electric vehicles (EVs) are being considered to replace internal combustion engine vehicles (ICEVs) in order to mitigate the pollution caused by urban freight transport owing to the former's zero tailpipe emissions, although introducing EVs to the market will increase emissions at the site of the power plants. A long-term shift to an economy that is compatible with climate stabilization will require a vehicle fleet that is predominantly powered by electric drives in the 2040–2050 timeframe (Mock and Yang, 2014).

The main challenges for EVs in real-life urban freight transport are their high acquisition cost, long recharging time, low capacity,

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and limited driving range. These influence the vehicle purchase and routing decisions of logistics companies. Various national and local policies have been implemented to provide fiscal incentives for encouraging the purchase and use of EVs in freight transport (Taefi et al., 2016). Several examples of the measures[1] are given below.

- Purchase subsidy on EVs: Direct subsidy is given to reduce the purchase price of EVs.
- Limited access (zone fee) to congestion/low-emission zone: For the purpose of generality, we define the term *limited zone* as representing a *low-emission zone* or *congestion zone* with restricted entry for high-emission or heavy vehicles (e.g., a fee charge or other deterrent) in order to reduce emissions or congestion.
- Vehicle taxes with exemptions for EVs: There are two main types of vehicle taxes. The vehicle registration tax is paid for the first registration. The annual circulation tax is paid to use the vehicle on the road. With an appropriate discount rate, these two taxes can be designed to work in the same way. EVs can be exempted from at least one of the vehicle taxes.

In this study, we consider an individual logistics company that provides delivery services for its customers. In response to these policies, the logistics company would adapt its vehicle fleet composition and vehicle routing plan in order to minimize the total logistic costs. This can have an influence on the total external costs of congestion, local air pollution and CO_2 emission from transportation, and on the overall social welfare.

Despite growing research interest in urban freight transport, few studies have addressed the impacts of supporting policies for EVs on logistics and society. As we discuss in the literature review in Section 2, research is needed to explore the relationships between (1) policy measures, (2) individual company's actions in response to the measures, (3) the effect on operational (routing) costs, and (4) the resulting changes to environmental impacts and welfare. As a contribution to cover this gap, we establish a framework that combines an optimization model with economic analysis to evaluate the potential operational, financial, and environmental effects of using EVs in urban freight operations. The framework focuses on obtaining an individual company's expected response to policies and corresponding changes in externalities and welfare. Previous empirical economic studies on relevant policy evaluation have usually focused on upfront purchase cost and assumed fixed annual routing costs for vehicles. Differently, to assess the impacts of supporting policies for EVs, the optimization model provides an opportunity to study how the policies can affect a logistics company's decisions on both purchase and routing of EVs.

We develop different scenarios in which logistics companies are exposed to policy options that support EVs: The purchase subsidy for EVs, vehicle taxes with exemptions for EVs, and limited access (zone fee) to the limited zone with exemptions for EVs. We establish an optimization model to determine the optimal fleet for a logistics company that transports the given demands of a single product from multiple dispersed depots to a known set of customers located in or outside a congestion/low-emission zone using two types of vehicles: EVs and ICEVs. The two types of vehicles differ in driving range, capacity, acquisition cost, energy cost, and entrance fee to congestion/low-emission zones. The aim of the company's logistic problem is to decide the vehicle fleet composition and routing while minimizing the fixed usage costs, routing costs, and entrance fees of vehicles to the congestion/low-emission zone. We term the problem as the *zone-dependent vehicle routing problem with a mixed fleet*. Based on the results of solving the optimization model, changes in the externalities produced by EVs and ICEVs and in the total welfare are calculated, and the influence of supporting policies for EVs is calculated.

We tested the proposed general framework with numerical experiments. The data are generated for a transport network under different scenarios. Based on the results from our numerical experiments, the purchase subsidy, zone fee, and vehicle taxes were found to increase the share of EVs in the vehicle fleet composition of the logistics company, decrease the distances traveled by ICEVs, and reduce externalities (i.e., congestion, local air pollution and CO_2 emission) and improve social welfare. In the numerical experiments, the zone fee had a larger impact on improving social welfare. This is because the zone fee significantly reduces the external cost by preventing emissions and congestion inside a zone with higher marginal external costs from a high population, dense pollution, and heavy traffic. However, in some of the sensitivity analyses, the zone fee may increase external costs by forcing ICEVs to travel around the zone to reach customers on the other side of the zone, which may lead to more emissions from fuel combustion or congestion. Although the vehicle taxes and subsidy resulted in almost the same influence on the company and society, they performed differently at low tax/subsidy rates because their different effects on vehicle routing plans. Finally, local factors at the company and city levels, such as the vehicle type and transport network, were found to also be important for designing policies that efficiently support EVs for urban logistics.

The rest of this paper is organized as follows. Section 2 reviews the related literature. Section 3 proposes a framework for evaluating urban freight policies. Section 4 presents the numerical experiments. The conclusions are presented in Section 5.

2. Literature review

In this section, we review relevant research on both economic and logistics research for the use and evaluation of supporting policies for EVs in the context of urban freight transport.

Traditionally, evaluation of transport policies in urban freight transport involves social and economic issues (Lagorio et al., 2016).

[1] The measures are commonly used in European cities for promoting EVs. With a focus on vehicle specific measures, we choose purchase subsidy for EVs, free access to the limited zone (congestion/low-emission zone) for EVs and vehicle taxes with exemptions for EVs for evaluation purpose. In terms of providing free access for EVs and imposing limitations for ICEVs, the concept of "limited zone" can be further generalized as parking lots/bus lanes/low-noise zones/pedestrian zones/areas with toll.