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Emission reduction via supply chain coordination

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ABSTRACT

This paper examines the environmental impact of potential coordination on supply chains. A decentralized two-node supply chain is studied, in which one node is a buyer ordering from a second node, who is a supplier operating under the lot-for-lot policy. The supplier is allowed to use a quantity discount to manipulate the buyer's decision reducing both his individual cost and system's operational costs. This results in decreasing the frequency of deliveries. We demonstrate that environmentally friendly policies could be also cost saving. The crucial factor about the environmental benefits is the total distance travelled rather than the vehicle loads. We establish the magnitude of the environmental benefits using numerical examples under specific operational parameters. Complete and incomplete information cases are investigated, where the buyer and the supplier make their decisions to optimize their own business operations.

1. Introduction

Environmental considerations in supply chain management have become more and more important for many firms as they are imposed mainly by new legislation as well as the need to improve further their environmental profile for their clientele. Especially, during the last two decades both practitioners and academics have paid attention to the improvement of the environmental impact on supply chains, introducing the 'Green Supply Chain Management' term. The firms have been pushed by consumers and legislators to redesign their processes and mitigate the negative environmental effects of their activities (Neto et al., 2008). Many leading firms such as IBM, Walmart, and Tesco have adopted strategies to reduce carbon emissions and fuel consumption (Sundarakani et al., 2010). Also they use performance indicators to quantify the environmental effects of different business models (Hervani et al., 2005).

The fundamental question in supply chain management remains, how the different decision makers could act in a decentralized manner, but still reduce their individual costs. In addition to the classical models for cost minimization, the research efforts in recent years focused on additional aspects such as social impact including traffic congestion (Shao et al., 2016), the number of accidents and the road safety considerations (Sarkis et al., 2010), as well as environmental impact such as CO_2, CO, HC, NO_x, and PM emissions (Sundarakani et al., 2010). Many studies try to re-design a supply chain to mitigate all or most of the above consequences; an indicative example is provided by Cachon (2014) showing how the retail store density affects emissions. According to Cachon (2014) if a retailer designs the layout of his/her network, focusing only to minimize the operational costs this can significantly increase emissions. Thus, there are cases in which the economic and the environmental costs are not be aligned.

Ideally, company policies should minimize the environmental costs whilst minimizing the total supply chain cost. Our objective is to examine the environmental impact of logistics activities on a two-node supply chain developing a coordination mechanism to

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minimize at the same time the operational cost.

Various models are proposed and analysed to reduce the costs in a supply chain. A basic question is under which circumstances it is possible to apply a decentralized model and well approximate or even obtain the optimal solution of a centralized model. This, in fact, is supply chain coordination. In a centralized model all decisions are made by a single decision maker; thus, the minimum total cost is achieved. This is the theoretical ideal situation in terms of cost reduction, but it is almost infeasible to achieve it under free market conditions, and independent, decentralised decision makers. This happens because individual nodes of the supply chain are decision makers with competing objectives, conflicting preferences, and private information.

A centralized solution in a decentralized approach means that the individual incentives of each decision maker are aligned with the incentives of the whole system. This could happen if the decision makers coordinate their individual decisions and share their private information (Viswanathan and Wang, 2003). The most common solutions to achieve coordination in the literature are: (i) nodes' signing of a contract and then all nodes making subsequent decisions in line with the contract parameters (Corbett et al., 2004) and (ii) nodes' participating in a coalition and acting as a single decision maker (Nagarajan and Sosic, 2008).

The literature on supply chain coordination is vast; however, the interrelationship between supply chain coordination and environmental sustainability still needs further investigation. Therefore, our objective is to quantify the environmental benefits of a potential coordination between two nodes. More specifically, we examine the environmental impact of logistics activities because transportation is a key factor for the competitiveness of the world economy and a considerable amount of research has been carried out to optimise logistics systems. The growing freight transport (RITA, 2010) has an increasing level of negative impact; such as traffic congestion, air and noise pollution, and threat to road safety due to higher number of vehicles. It is well known that the transport sector has the fastest growing emissions with the road transport subsector being the largest contributor to global warming through CO_2 emissions (EC, 2011; EPA, 2015). Especially, the urban freight traffic accounts for about 10–15% of kilometres travelled and emits approximately 6% of all transport-related greenhouse gas emissions (CIVITAS, 2015). Therefore, a potential reduction of total kilometres travelled will have a significant impact on the environment and the society.

Coordination leads to larger order quantities, reducing the frequency of deliveries between the nodes. This means less total distance travelled; i.e. less trips between the nodes, but with more load. Thus, it is not sufficient to consider only the total kilometres travelled as a performance indicator but also to use emission models to quantify the environmental impact of overall transportation activities.

This work examines the environmental impact of road transportation on supply chains. To the best of our knowledge, this is the first research study analysing the role of interrelationship between supply chain coordination and environmental sustainability. The main contribution of our work is twofold: (i) to show that environmentally friendly policies are also cost saving and (ii) to quantify the impact of supply chain coordination on the environment in terms of fuel consumption and emissions, applying an emission model.

The remainder of the paper is organized as follows: Section 2 describes the emission calculation model that will be used in this work. Section 3 presents a specific two-node supply chain, defines the modelling approach adopted for the decentralized solution, and gives an analytical expression of the reduction in the number of trips between the nodes under complete and incomplete information. Section 4 provides numerical experiments to evaluate the environmental effects of a potential coordination. Section 5 summarizes the conclusions and sets questions for future research.

2. Emission model

Our objective is to examine the environmental impact of potential coordination on a supply chain, focusing on fuel consumption and emissions. An emission model is needed to quantify the environmental impact of transportation activities between the nodes. There are several emission models that can be categorised into macroscopic and microscopic models. Emission models can be complex and diverse; thus, some knowledge of their fundamental functionality is essential. The calculation of energy consumption and emissions are directly linked to each other. There are many factors such as driving behaviour, road conditions, and vehicle conditions that can affect fuel consumption and subsequently emissions. However, it may be difficult to fully reflect all these factors in an emission model (Demir et al., 2014). Many models can only incorporate a small number of input factors. In general, the emission calculation models are categorized as follows:

1. **Aggregated emission factor models.** These are the simplest models with only a single emission factor being used to represent a specific type of vehicle and type of road, i.e. urban, rural or highway (COST, 2006).
2. **Average speed models (non-adjusted and adjusted).** These models are based on the principle that the average emission factor for a certain pollutant and a specific type of vehicle depends on the average speed of that vehicle. Therefore, emissions can be calculated by taking into consideration only the average speed. Then an emission factor is stated in terms of the grams per travelled kilometers (g/km). Adjusted models on the other hand use a correction factor to reconstruct the speed profile by estimating fractions of time spent during cruising, acceleration, deceleration, and idling to incorporate the effect of traffic congestion (Boulter et al., 2007).
3. **Traffic situation models.** This category incorporates both speed and cycle dynamics into emission estimations through traffic situation modelling, where the cycle average emission rates are correlated with various driving cycle parameters, such as: load, slope or gearshift strategies (Ajtay, 2005).
4. **Multiple linear regression models.** These models employ a weighted-least-squares multiple regression approach to modeling emissions, based on the data from tests with a large number of different vehicle types and a variety of driving cycles, usually more than 50 different combinations of vehicle types and driving cycles (Smit et al., 2007).