Economics of Empty Trips and Collaborative Logistics

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1 INTRODUCTION

Unlike passenger transport, where travelers typically return to their starting point, most cargo shipments are one-way, complicating securing return loads. This results in a phenomenon known as the backhaul problem, where empty trucks often travel in both directions on a route. This situation contributes to congestion, accidents, and emissions while raising costs for producers and shippers without offering additional benefits. In Europe and the United States, empty trucks represent 15% to 38% of total kilometers traveled (Eurostat, 2018). Understanding the factors that lead to the generation of empty vehicles and the ability to model these phenomena for predictive insights supports a wide array of decisions—from public policy development to infrastructure planning and transportation regulation.

The literature has addressed the limitations of traditional models from multiple perspectives. Operations Research has concentrated on optimizing cargo flow to enhance operational efficiency, considering transportation costs, time constraints, capacity, and demand patterns (Meixell & Gargeya, 2005). Meanwhile, demand models have developed methods to predict the flow of both loaded and empty vehicles (Holguín-Veras *et al.*, 2013). Research on network equilibrium has aimed to capture actors' diverse roles and functions within the system using specific conceptual frameworks and approaches (Adler *et al.*, 2021). Lastly, horizontal collaboration strategies propose cooperative approaches to reduce empty trips (Serrano-Hernandez *et al.*, 2017). These approaches are helpful for modeling and optimizing supply chains and freight transportation but have limitations in understanding how competition influences empty trips, price formation, and social welfare. Additionally, they ignore equilibrium in a competitive multimodal context and the bidirectional flow of empty vehicles, both of which affect pricing and overall welfare. Furthermore, they fail to adequately explain the role of collaborative strategies in closing the efficiency gap in competitive markets.

This work aims to enhance the understanding of empty vehicle flows by examining factors beyond load imbalances, such as competition, demand structure, and service differentiation. It also seeks to develop a methodology that models equilibrium between geographically separated markets linked by a multimodal transportation network. The proposed model allows for predicting cargo and vehicle flows and determining transport prices.

2 METHODOLOGY

The proposed method is divided into two stages. The first stage involves developing a microeconomic model to analyze the generation and effects of empty vehicles in cargo transportation markets between two locations, focusing on the decision-making process of shippers selecting carriers. In the second stage, the model is expanded to include multiple geographically separated markets connected by a multimodal transportation network, integrating approaches from operations research, demand modeling, and equilibrium models.

First, we examine a region with two locations connected by a bidirectional route. A fixed group of shippers coordinates the transportation of goods between these locations and can choose from various carriers or opt not to hire any. Each shipper perceives carrier services differently, and our model assumes that carriers can only observe the choices made by shippers without knowing their underlying preferences. We represent these preferences using a random utility function for a representative shipper at each location. For the analysis of transportation supply, we assume that carriers operate within a circular corridor using a uniform type of vehicle to meet demand. This model enables us to derive operating costs and examine their characteristics. Using the demand and cost models, we formulate the expected profit function for carriers and establish conditions for free-entry equilibrium influenced by carriers' pricing strategies. These equilibrium conditions allow us to calculate prices, the quantities of empty and loaded vehicles, and the resulting number of carriers. We develop the welfare function as the sum of consumer surplus in both markets and the utility of operators. From this function, we derive the conditions that maximize social welfare, assuming a central planner coordinates the operations of various operators. Determining the social optimum includes the number of operators, pricing, and the quantity of loaded and empty vehicle trips in both markets. Since achieving the social optimum requires a subsidy, we focus on the second-best solution, where a central planner aims to maximize social benefit while ensuring that transportation companies remain self-financing.

In the second stage, we analyze the equilibrium among multiple geographically separated markets linked by a multimodal transportation network. This approach combines game theory models with vehicle route choice models, fulfilling cargo transportation demand between different locations while considering various operational constraints. Similar to the previous model, we assume that transportation services are differentiated, with preferences represented by the random utility function of a representative shipper at each location. To determine the equilibrium conditions, we evaluate two distinct scenarios: the first, where equilibrium is achieved through carriers' pricing strategies, is termed Bertrand Equilibrium; the second, based on production levels, is known as Cournot Equilibrium. Building on this foundation, we identify the equilibrium conditions within the context of free entry for competitors.

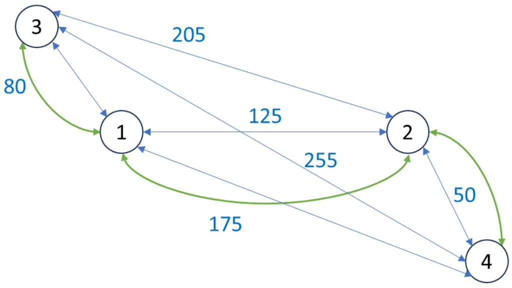
We apply the proposed model to determine the equilibrium in the transportation market of a geographical region divided into multiple locations. We developed a computational model from this conceptual framework to analyze three cases.

In the first case, we analyze a simple network with two locations and two markets to validate the robustness of our computational model, comparing the results with the analytical solutions derived in the previous stage (Farren *et al.*, 2024). In the second case, we examine a more complex network of four locations and twelve markets, focusing on truck transportation (mode t) to determine prices, quantities, and the number of operators in equilibrium. In the third case, we build on the previous scenario by introducing a multimodal network that integrates rail (mode r) and road transport, which competes with truck-only transportation (Figures 1 & 2). We evaluate the model's results by comparing the equilibrium outcomes in Cases 2 and 3, focusing on critical elements such as prices, quantities transported, and the incidence of empty trips.

3 RESULTS

The results of the two-locality model reveal that freight transport production inherently generates a flow of empty vehicles in both directions, in addition to those caused by load imbalances towards lower traffic. These additional empty vehicles arise from the random nature of demand, which the model accounts for. This phenomenon is known as the "business stealing effect," a negative

Figure 1 – *Case 3: Four-Location and Multi-modality Models.*



The figure presents the operation of the multi-modal network, which connects Locations 3-1 and 2-4 by truck, while Locations 1-2 are linked by rail. Transfer centers between rail and trucks are established at Locations 1 and 2.

Figure 2 – *Potential Demand Cases 2 & 3.*

	L_1	L_2	L_3	L_4	Total
L_1	0	928	252	321	1501
L_2	465	0	77	330	872
L_3	163	377	0	322	862
L_4	350	146	164	0	660
Total	978	1451	493	973	3895

The table presents the potential demand for carriers in each market (origin-destination pair) for Cases 2 & 3

externality resulting from new carriers entering the market. This increase in empty trips distorts equilibrium prices, quantities, and the number of carriers, moving the system away from socially optimal outcomes. However, coordinated efforts among carriers can help reduce empty trips stemming from the business stealing effect, bringing the market closer to the social optimum.

The results of the multiple-locality model illustrate varying market dynamics across different scenarios. In Case 1, the model is validated, as outcomes align with the analytical model. In Case 2, a single-mode transportation market under Bertrand equilibrium leads to more significant firm fragmentation than Cournot equilibrium. Although Bertrand's competition intensifies, prices remain elevated due to the increased empty trips, which reduce capacity utilization and raise operational costs, while profit margins persist despite heightened competition. Both models indicate that prices increase with distance due to higher costs but decrease with more empty trips, highlighting the need for capacity optimization. The price per kilometer also tends to drop on longer routes, indicating greater efficiency over extended distances.

In Case 3, Bertrand's competition shows that the entry of a multimodal competitor reduces the number of trucking carriers, although the market remains fragmented, and the volume per carrier stays stable. While empty trips in trucking remain constant, the overall market experiences a reduction due to multimodal efficiency, with minimal impact on prices. Conversely, under Cournot's competition, trucking sees a lower market share, reduced carrier numbers, and higher market concentration, leading to larger average firm sizes, fewer empty trips, and lower prices than Bertrand. The multimodal network captures higher prices and a larger market share under Cournot's competition in this setting. Table 1 presents the results for the Bertrand equilibrium for Cases 2 and 3.

4 DISCUSSION

The two-locality model shows that freight transportation generates a bidirectional flow of empty vehicles, exacerbated by the entry of new carriers, which decreases the likelihood of returning cargo. This phenomenon increases operational costs and prices, moving the equilibrium away from the social optimum. The model introduces a novel equilibrium price formula that integrates classical models and suggests that centralized coordination could effectively reduce empty vehicle flows, thereby enhancing social welfare. While this model provides valuable insights into the generation of empty trips and their impact on equilibrium and social welfare, it has limitations in predicting flows within more complex networks. We extend the model to a multimodal freight transport network encompassing multiple origin-destination pairs to overcome

Table 1 – *Bertrand Equilibrium Results. Cases 2 & 3.*

	Case 2			Case 3							
	Mode t			Mode t				Mode r			
Market	y_{tj} (un)	e_{tj} (veh)	p_{tj} (US$/ un)	y_{tj} (un)	e_{tj} (veh)	p_{tj} (US$/ un)	MS (%)	y_{rj} (un)	e_{rj} (veh)	p_{rj} (US$/ un)	MS (%)
M 12	0.43	0.14	547	0.34	0.17	566	79%	121.60	0.00	1003	13%
M 13	0.13	0.27	468	0.10	0.27	485	76%	41.80	17.01	801	17%
M 14	0.10	0.15	689	0.10	0.11	692	80%	37.17	0.00	1131	12%
M 21	0.21	0.41	483	0.17	0.33	488	76%	74.33	64.30	830	16%
M 23	0.02	0.00	738	0.03	0.00	769	75%	12.24	0.00	913	16%
M 24	0.17	0.06	511	0.11	0.05	553	77%	50.40	0.00	881	15%
M 31	0.04	0.18	457	0.07	0.13	482	78%	22.63	0.00	935	14%
M 32	0.14	0.00	791	0.10	0.00	797	80%	41.70	0.00	1193	11%
M 34	0.14	0.00	912	0.13	0.00	922	79%	33.98	0.00	1281	11%
M 41	0.11	0.27	606	0.12	0.27	591	76%	56.32	0.00	858	16%
M 42	0.09	0.06	482	0.05	0.03	519	76%	23.88	14.08	830	16%
M 43	0.08	0.00	848	0.04	0.00	815	74%	27.26	0.00	895	17%

The table presents Bertrand's equilibrium prices and quantities under free entry for Cases 2 and 3. The variable y_{tj} *and* y_{rj} *represent the expected number of cargo units transported by each carrier in equilibrium on arc* j*. Meanwhile,* e_{tj} *and* e_{rj} *indicate the expected number of empty vehicles each carrier moves across arc* j*. The equilibrium price in market* j *is denoted as* p_{tj} *and* p_{rj}*. All of the above applies to modes* t *and* r*, respectively. MS corresponds to Market Share. The number of carriers in equilibrium in Case 2 is 2,250 and 2,080 in Case 3.*

this. This enhanced model captures the decision-making processes and strategies of shippers and carriers, including route choice, mode selection, and rate negotiation, offering a comprehensive view of transportation market equilibrium. It accounts for empty vehicles' flow and influence on cargo movement, pricing, and competition, which is crucial for understanding how capacity and resource allocation decisions dynamically shape the market.

The proposed model facilitates equilibrium analysis in multimodal contexts, adapting to each market's unique characteristics. A significant advantage of this model is its potential for experimental validation by estimating demand parameters through surveys, and calibrating vehicle flows with traffic and load data from weigh stations. Furthermore, it can incorporate factors such as weight, volume, types of goods, specific transportation requirements, and various shipper segments and carrier types.

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