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A model for the formation of colloidal structures in freight transportation: The case of hinterland terminals

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ABSTRACT

An approach is presented to model the formation of spontaneously emerging associations of freight transport actors. Those agglomerations of logistics actors could be referred to as colloidal structures. The proposed approach combines insights from physics and economics. Typical logistics decisions are considered to be dynamic choices of consumers and providers resulting in temporally stable-market equilibria. The development of colloidal structures is driven by economies of scale on one hand and the preference for variety on the other hand. A case study with regards to intermodal terminals in Germany shows possible applications of the model for transport-policy analysis and planning.

1. Introduction and motivation

Freight transport markets are more difficult to analyze than other transportation markets due to the inclusion of logistics decisions. These decisions are not simply a question of mode, route, time, period or packaging, but a group of them that resume in a supply chain involving different service providers or associations of providers.

Even though many types of commodity transport demand models in literature cope with one or more of the previous aspects, most freight transport models consider the suppliers of transport logistics services as given and fixed. For this purpose, we want to model the market entries and exits of suppliers endogenously including agglomerations and cooperation-structures of logistics service providers.

When modelling market entries and exits, we consider returns to scale as the main driver of dynamics changing the decisions of both demand and supply actors. This modelling direction is similar to the one proposed by micro-simulation and multi-agent approaches (see, for example, Wisetjindawat et al., 2007; Ramstedt, 2008; Maurer, 2008; Liedtke, 2009; Samimi et al., 2011). However, we aim to contribute to the research by proposing a new way of modelling dynamic decisions and the formation of cooperation-structures or agglomerations of suppliers as a typical phenomenon in the freight transport and logistics sectors.

To the described logistics decisions we could easily add the heterogeneity and the intransparency of freight transport markets. They result from the heterogeneity of transport cases, decision-makers, negotiations and decision objects. In addition, they depend on the spatial dimension of transport and on the different time horizons of transport contracts.

Given all the dimensions of the problematic to model this market, we propose to start an approach to model the emergence of new transport service providers and their collaboration structures with the simplest concept in economics. Starting

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with the demand and supply interactions, we add progressively several approaches from research that contribute to the model developed in this paper.

On the demand side, consumers are increasingly accumulating market knowledge when negotiating with service providers. However, negotiations generate transaction costs and the change in a provider might create some risk for the shipper. Besides other reasons, this is why business relationships are stable over some time. Consumers can be shippers as well as logistics service providers hiring other service providers.

On the supply side, service providers could form some kind of monopoly in some countries, but they usually lose their market power as the market maturates. One solution some service providers use to cope with increased competition pressure is to outsource some tasks in order to reduce investments. Another solution is the horizontal collaboration with other transport service providers, forming simple and complex collaboration structures as a typical behavior in freight transport markets.

The previous premises represent a big challenge to model the freight transport market. An option to model this market could be in the form of a sequence of individual decisions similar to the classic four-step approach that is very common in transport modelling (Ortúzar and Willumsen, 1998). Especially on the trip distribution (second stage) and the mode choice (third stage), decisions are usually modelled using micro-economic choice models – usually discrete choice models (McFadden, 1968) – or the maximum entropy method of Wilson (1970), even though they are closely related (Anas, 1983). Both modelling approaches need to be adapted when it comes to mapping commodity flows due to the logistics negotiations and the intermediate steps of many manufacturing and transportation processes. When setting up a commodity transport model, a huge amount of time is needed to calibrate parameters manually and especially commercial data. The latter aspect causes problems due to data-privacy regulations and the limited willingness of firms to share information.

An alternative manner to model freight transport and logistics markets could be a behavioral approach considering the premises already mentioned and including a special consideration of returns to scale as the main driver for dynamic interactions between supply and demand. For this purpose, we shall identify two types of logistics-system structures to model: private logistics networks and collaboration.

The first type of structures relates to transport networks that have been setup by individual companies as their distribution networks. The second type of structures, explicitly modelled in this paper, are those emerging from horizontal collaboration of logistics actors.

This paper highlights the collaboration in several forms that are typical of the logistics and freight transport markets in order to reduce costs. "Colloidal structures" (McFadden, 2007) are formed by transport companies that often collaborate with their peers from other regions or with providers of complementary services. Mixed cargo networks are setup by associations among local forwarders to cover the whole demand needs. Local agglomerations of logistics services (clusters) result from the chain of services that attract more demand when associated in the same place. Even logistics infrastructure such as ports, airports or terminals, tends to enforce clusters of service providers as clustered firms perform a better production function than isolated producers (Hoover, 1948).

In order to understand the formation of supply structures in transport and logistics for the purpose of transport modelling, the research questions identified in this paper that contribute to the existing literature are how demand distributes over existing colloidal structures, and how collaboration among suppliers is formed. In this way, we propose to model the freight and logistics market combining concepts from physics and economics that form part of transportation models and sociodynamics. Then, we develop a welfare measure to assess the outcome of the dynamic market interactions.

Since logistics infrastructure is the classic environment for the formation of agglomerations of logistics actors, the model developed in this paper is applied to intermodal terminals in Germany in order to show its potential.

The paper is organized as follows: Section 1 provides a short overview of some streams in transport economics and current challenges. Section 2 presents a literature review covering the premises of the master equation and the entropy approach, building the basis for the new approach. In Section 3, the mathematical deductions of the Free Economic Energy (FEE) model and its hierarchical variant are explained. Section 4 presents the congruency of the FEE market equilibrium with the welfare optimum, including the same process for the hierarchical variant. Section 5 shows some applications of the FEE concept in transportation science. Finally, Section 6 concludes the paper.

2. Theoretical framework

The dilemma of whether to model each single actor in detail or focus on its contribution to the behavior of the population as a whole is covered by the master equation (Weidlich, 2000) and the entropy maximization (Wilson, 1970). The master equation considers all states of a system and assigns transitions between these states. Entropy maximization only considers the most probable states of a system without regarding to the way they change. Carrillo Murillo and Liedtke (2008) developed a link between both models in a concept called Free Economic Energy (FEE) in order to contribute to the literature with a mesoscopic model of freight transportation and logistics decisions. The name is used for the model due to its equivalent in physics – free energy in thermodynamics. It combines the preference for variety on the consumers' side (embodied by its caused entropy) and the effort to minimize costs. This trade-off also forms the basis of the market model of monopolistic competition (Chamberlin, 1933; Dixit and Stiglitz, 1977).