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Dynamic cost functions and freight transport modal split evolution

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ABSTRACT

The paper studies the characteristics of the evolution over time of modal split for a transport system in which various modes compete with each other and face the freight flow increase in different ways. It is shown that the modal split evolution is constituted by a sequence of time periods, in each of which the dynamic characteristics of the system are different. An equilibrium, stable or unstable, is reached after a transition phase, whose length depends on the characteristics of the system, and in some cases exceeds the length of the period, so that an equilibrium is not reached.

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1. Introduction

A recent paper published in this Journal (Ferrari, 2014) has presented a dynamic model of modal split for freight transport. The model supposes that a carrier, who sends regularly goods between two territories connected by various transport modes, tends to use the mode that he deems to be the best. Thus the carrier arranges the transport alternatives in a *choice set* and, with the purpose of ordering this set, he assigns to each alternative a number: the higher it is, the less preferable the alternative is. This number is named *transport cost* per transport unit, which is supposed to be the weight unit. A relationship, named *dynamic cost function*, between average transport cost and freight flow is introduced for each transport mode. This relationship supposes, differently from the cost functions of the freight transport models proposed in the literature (see e.g. Abdelwahab and Sargious, 1992; Cascetta, 2001; Chow et al., 2010; Dalla Chiara et al., 2008; de Jong and Ben-Akiva, 2007; Masiero and Rose, 2013; Norojono and Joung, 2003; Winston, 1983), that the characteristics of the transport mode are not fixed, but they change progressively over time accompanying the evolution of freight flow.

The evolution over time of transport costs of the various modes of a freight transport system brings about the evolution of modal split, but it is not the only cause of this evolution. An important role is played by the evolution of the overall freight flow and by the delay with which users shift from a transport mode to another deemed more suitable. Such lag is due to many factors, including limited confidence in the future possibilities of a new transport mode, difficulties in adapting the logistical organisation, and simple inertia, in general.

The model was applied in Ferrari (2014) to the study of two freight transport systems between Northern Italy and Central-Northern Europe, for which it was found that modal split evolves towards a stable equilibrium. However, as it was pointed out in the conclusions of that paper, we know from the theory of the dynamic systems that the evolution over

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time of a system depends on its parameters, and varies as the parameters change. The system can evolve towards a unique stable equilibrium, or towards situations characterised by periodic repetitions over time of different equilibrium points – with various period lengths – up to a chaotic behaviour. Moreover one should consider that the equilibrium in many cases is reached after a quite long period of time starting from the initial conditions, so the life of a transport system is contained, at least in part, in this time period. Thus the characteristics of the transition phases from the initial conditions to the equilibrium have great importance in the evolution of modal split for freight transport.

The research of the conditions that determine both the type of equilibrium and the length of the transition phases for the modal split of a transport system in which various mode compete with each other is the purpose of this paper. It considers the cases in which the evolution of the modal split depends on the dynamics of the transport system, i.e. it is "an inherent attribute at the root of the nature of a transport system" (Rodrigue et al., 1997), when freight flow increases over time, and does not consider the cases in which this dynamic evolution is driven by external factors, e.g. the fluctuations of overall freight flow due to variability of the economic conditions. Thus the paper studies the relation between the dynamic characteristics of a freight transport system – i.e. the increase rate over time of the overall freight flow, the delay with which users react to changes in transport costs, the difference among the dynamic cost functions of the various modes – and the patterns of the modal split evolution.

This method of analysis has been applied to the study of modal split evolution of three transport systems that travel through three Alpine passes: the Frejus pass that connects North-Western Italy with the Rhone-Alps region in France; the Tauern pass that connects North-Eastern Italy with Western Austria; the Gotthard–Symplon pass through the Swiss Alps which connects North-Western Italy with Switzerland. Each transport system is constituted by three modes: wagonload rail, road haulage and intermodal transport. The data used in these applications are the yearly numbers of tons carried by each transport mode in the three transport systems, surveyed by ALPINFO between 1984 and 2012 (ALPINFO, 1984–2012).

Using these data the trajectories of the proportions of freight flow that use the three modes have been computed in a time period of different length for each transport mode: they fit well the experimental data, showing that the dynamic characteristics of the transport systems have remained unchanged during each period, as supposed by the model. At the end of each of these periods a marked change in the modal split evolution shows that there has been a substantial change in the dynamic characteristics of each mode, which gives rise to a new period with new dynamic cost functions. The trajectories for the Frejus and the Tauern transport systems are constituted by short transition phases followed by chaotic equilibrium, while the transition phases for the system of the Swiss Alps are very long, tending to an asymptotic equilibrium. This means that for the latter system an equilibrium condition cannot be reached in a finite time period beyond which the dynamic characteristics of the transport system change. Thus these applications of the proposed method have shown that, for the transport systems we have examined, the evolution over time of modal split is constituted by a sequence of periods each with different dynamic characteristics, during which it is possible that an equilibrium is not reached. And we can suppose that this result is typical of the modal split evolution for any transport system that carries freight between two territories. In fact, even if the reasons that determine at a certain time a substantial modification in the dynamic characteristics, and the length of time period after which it happens, can be very different for any transport system, such modifications certainly occur, as a consequence of technology and economics transformations, and give rise to a new period with different dynamic cost functions.

The paper is organised in this way. A review of the main literature on freight transport modal split is put forward in Section 2. Section 3 presents a synthesis of the model that will be used, which is necessary to understand its applications in the paper, while Section 4 is dedicated to the study of the various types of bifurcations and chaotic equilibrium that take place when a parameter of a transport system changes. Section 5 analyses the ways in which the differences among the dynamic cost functions of the various modes of a freight transport system influence the dynamics of modal split. Section 6 examines the way in which the dynamic cost functions, the users' delay and the increase rate of freight flow influence the characteristics of the transition phases. The method illustrated in the previous sections is then applied in Section 7 to the analysis of the dynamics of three freight transport systems that travel trough three Alpine passes. Lastly, a brief summary of the main points is presented, and some conclusions are put forward in Section 8.

2. Review of the main literature on freight transport modal split

Many models have been proposed in the literature of freight transport to simulate the decision-makers' choices concerning the mode of transport and other production decisions. Such models are often used in transport planning as a means to forecast modifications in the distribution of overall freight flows among the various modes of a transport system due to changes in some attributes of level of service (de Jong et al., 2004). These models can be classified as aggregate or disaggregate, depending on whether the basic unit of observation is an aggregate share of a particular transport mode at the regional or national level, or an individual decision-maker's distinct choice of a particular freight mode for a given shipment. Disaggregate models are of two types: behavioural and inventory. The first are behavioural choice models, whose analyses are based on the pursuit of utility maximisation by the decision-maker involved. The basic difference between behavioural and inventory models is that, while behavioural models deal with only one decision, the mode choice, inventory models attempt to integrate the mode choice and some other production decision, in general shipment size (Winston, 1983; Abdelwahab and Sargious, 1992).

Aggregate models deal only with the modal choice and are of two types: multinomial models, estimated on the data on the shares of different modes for a number of zones, and neoclassical models, which are based on the economic theory of the

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