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Handling uncertainty in Multi Regional Input-Output models by entropy maximization and fuzzy programming

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ABSTRACT

Recently, great attention has been paid to the uncertainties associated with Multi Regional Input-Output (MRIO) models related to the available data sources. We propose a new method based on the entropy maximization principle and fuzzy optimization, which takes explicitly into account the uncertainty embedded in available information. It allows to estimate jointly the values of production level, the trade coefficients and the final demand values assuming the availability of incomplete and/or approximate data on some elements of trade coefficients and of final demand of goods. The model, applied to real scale problem, shows good estimation performances and robustness in different scenario.

1. Introduction

Freight transport is a complex system and a crucial node for the economic development in a given area. Thus, a proper design and management of such a system is an important and hard problem to face that depends also on the estimation of freight demand.

Consequently, several models and methods for freight demand estimation and/or correction of its parameters have been suggested in technical literature. One of the most used approaches is the Multi Region Input-Output (MRIO) analysis that allows to represent the economic interdependencies among regions (or zones) without their explicit modeling.

In addition, MRIO databases are appropriate bases for the analysis of environmental and wider sustainability impacts of traded goods and services (Minx et al., 2009; Wiedmann et al., 2011). Concerning the freight demand simulation problem, MRIO approach allows to consider some relationships between transport and economic systems; for example, in the Random Utility Based MRIO models (RUBMRIO) also elasticity in transport related variables can be considered (see for example Zhao and Kockelman, 2004; Cascetta et al., 2008).

Recently, great attention has been paid to the uncertainties associated with MRIO models, which include uncertainties in data source (survey), imputation and balancing, allocation, assuming proportionality and homogeneity, aggregation, temporal discrepancies, model inputs, and multipliers. In this field, there are many issues relevant to the use of MRIO model linked to uncertainty (Wiedmann et al., 2011). A relevant problem in MRIO modelling concerns the collection of input data and the combination of seemingly incompatible databases with the aim of taking as much advantage as possible from all available data (Park et al., 2009).

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Another key issue in MRIO models is the estimation of coefficients as well as some transformation multipliers. In fact, most of the MRIO models are based on specific coefficients, such as trade and technical coefficients, that are needed to estimate the production levels. Depending on the available data and resources, estimates of MRIO models coefficient can be obtained by direct surveys, by indirect methods (i.e. estimation by models) or by hybrid methods (i.e. mixed direct-indirect methods). Different sources of uncertainty affect the estimates of these coefficients depending on the combination given by the available/collected data and the relevant estimation method. In the following section the meaning of the coefficients of MRIO models and the model itself will be introduced. In addition to the model coefficients, another issue is relevant to multipliers parameter, for example: parameters that allow the conversion from production level to tons of goods and then to trade flows, or the conversion from production into carbon footprints emissions. A discussion on uncertainty of coefficients of MRIO is given in Morillas et al. (2011) where it is discussed the problem of propagation of uncertainty relevant to the errors related to the different coefficients.

In this paper we propose a novel method to estimate jointly (or improve the estimation of) trade coefficients and production levels for each economic sector considered in the MRIO model, starting from uncertain/imprecise information about the same trade coefficients and production level. The method allows the estimation of the final demand of goods accordingly to a MRIO model.

As it will be shown, the proposed approach is specified as a fuzzy fixed point problem, subjected to a set of constrains on available information and data. In particular, the estimation model is based on the maximization of Shannon's Entropy of consumptions and exports, which are input elements of the Multi Regional Input-Output (MRIO) model, a set of fuzzy relations among available data (assumed to be uncertain), and a crisp relation among known data.

The model returns the estimated vector of total production, the vector of trade coefficients and the vector of final demand of the study area. As far as it concerns the trade coefficients in the formulation presented here we assume the coefficients to be elastic and estimated by a Logit model.

The numerical application of the proposed method has shown very interesting results and the possible application of the method in a wide range of practical problems. Even if the method is devoted to the freight transport, it can be easily used in any fields where Input–Output (I–O) tables need to be estimated as it can be easily and properly specified. In particular, this method can be used in the supply-chains management (i.e. Life Cycle Assessment), in environmental issues of economy related to carbon footprinting evaluation and so on.

The paper is developed as follows: in the first part the paper introduces the formulation of MRIO model used in this study; in the second part, the problem of uncertainty in I–O models is highlighted considering the wide field of their application. In both sections the respective literature is also analyzed. In the third part, then the proposed method is presented and the experimental issues are investigated by different numerical applications. The method is first applied to a small study area, with a sensitivity analysis, then to a real sized one. The obtained results are there discussed. In the conclusive section remarks and further developments end the paper.

2. Theoretical background

This section refers to the main technical literature relevant to the freight transport estimation and, in particular, to the evaluation of trade coefficients that are important parameters representing variations of transport systems and production levels in a given area. Another important issue is the assessment of logistic services demand, but such a problem is out of the scope of this paper.

The current or future demand of freight transport can be estimated by means of different methodological approaches:

- direct approaches, based on surveys;
- indirect approaches, based on different classes of models;
- mixed approaches, which combines direct and indirect approaches and different sources of data as well.

The last approaches are largely discussed in literature with reference to passengers travel demand and just a few of them focus on freight transport.

For direct methods we refer to Revealed Preferences (RP) and Stated Preferences (SP) surveys. The former concern existing choice alternatives, while the latter are relevant to hypothetical alternatives. For further in-depth analysis we refer to the huge amount of literature on the topic: for instance, to TRB, 1997 and Allen et al. (2000) as regards SP surveys and to Bates (1988), Fowkes and Wardman (1988), Hensher et al. (1988), Ortuzar (1992) and Hensher (1994) as regards RP surveys.

Model-based freight demand evaluation has been a topic of interest in literature for years. An exhaustive overview of approaches and models can be carried out through the state-of-the-art contributions provided, among others, by Harker and Friesz (1986), Picard and Nguyen (1987), Zlatoper and Austrian (1989), Mazzarino (1997) and Regan and Garrido (2002).

At national and international level, freight system of models can be divided sub-systems: macro-economic and transportation models. Macro-economic models assess the production demand in a certain region as a function of socio-economic (**SE**) and transportation attributes (**T**), expressing the average flow $\boldsymbol{d}$ of goods of the sector *s*, traveling from an origin *o* to a destination *d*, in the time interval *h*, by using the transport mode *m* and the vehicle *l*, following the path *k*.

Let $\boldsymbol{\beta}$ be a vector of parameters determined in the model calibration phase, a freight-demand model can be in general represented as: