Calibration of the Tranus land use module: Optimisation-based algorithms, their validation, and parameter selection by statistical model selection

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\textbf{ABSTRACT}

Instantiating land use and transport integrated models (LUTI modelling) is a complicated task, requiring substantial data collection, parameter estimation and expert analysis. In this work, we present a partial effort towards the automation of the calibration of Tranus, one of the most popular LUTI models. First, we give a detailed mathematical description of the activity module and the usual calibration approach. Secondly, we reformulate the estimation of the endogenous parameters called shadow prices as an optimisation problem. We also propose an optimisation algorithm for the calibration of the substitution submodel, setting a base for future fully integrated calibration. We analyse the case of transportable and non-transportable economic sectors and propose a detailed mathematical scheme for each case. We also discuss how to validate calibration results and propose to use synthetic data generated from real world problems in order to assess convergence properties and accuracy of calibration methods. Results of this methodology are presented for realistic scenarios. Finally, we propose a model selection scheme to reduce the number of shadow prices that need to be calibrated, with the aim of reducing the risk of overfitting to data.

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1. Introduction

LUTI (land-use and transportation integrated) models aim at representing the complex interactions between land use and transportation offer and demand within a territory. They are mainly used to evaluate different alternative planning scenarios, by simulating their tendential impacts on patterns of land use and travel behaviour. Since the early 60's LUTI modelling has attracted researchers that aimed to model the complex economic relations in urban areas; a good overview of the evolution and history of LUTI modelling can be found in Wegener (2004). Setting up a LUTI model requires the estimation of several types of parameters to reproduce as closely as possible, observations gathered on the studied area (socio-economic data, transport surveys, etc.). The vast majority of available calibration approaches are semi-automatic, estimating one subset of parameters at a time, without a global integrated estimation. Automatic calibration of LUTI model is not a common practice; an exception has been proposed for the Meplan model (Abraham, 2000).

We consider Tranus (de la Barra, 1982, 1989), an open source LUTI model that is widely used. Tranus is a classical LUTI model, with two separated modules: the activity module and the transport module. The activity module, is an equilibrium type model based on micro-economic principles that balance the offer and demand of the different economic sectors that interact at each level. Economic sectors are considered in the broad sense, amongst them we have: land, goods, salaries, housing, transportation demand, etc. Also, the price paid for each economic sector has to be balanced with respect to offer and demand, thus there are two equilibria that have to be achieved, offer versus demand and (production) cost versus prices. The transportation module, computes the costs of transportation and assigns the demand to the network. Both modules interact back and forth until a general equilibrium is achieved.

The calibration process is usually done by an expert modeller who iteratively tunes a group of parameters to reproduce as closely as possible the observations gathered in the area of study. This process is usually done manually, with little to no automation, adjusting the different economic parameters (for example, the demand curves for different goods in a specific geographical zone). At the same time,
Transus computes internally a set of adjustment coefficients (called shadow prices in Transus) that correct the utilities and account for un-modelled effects. These endogenous variables help the model achieve a better response and fit more precisely to the observed data.

In this paper we address several shortcomings of the classical approach of calibration used in Transus. In our previous work (Capelle, Sturm, Vidard, & Morton, 2015) we proposed a first approach for the reformulation of the heuristic algorithm used in the land use and activity module as an optimisation problem. In this paper we extend this approach by having a closer look at the inner loop that computes the shadow prices and proposes an efficient methodology for their estimation by decoupling the calibration in smaller problems. To be able to do this, we have to carefully investigate the system of equations that are computed in the activity module. We also introduce auxiliary variables, which enable a closed form computation instead of an iterative one. This in turn makes it possible to use sophisticated numerical optimisation methods and opens the door to the simultaneous estimation of different parameter types of the model. The ultimate goal of this approach is to simultaneously calibrate the various parameters of Transus’ inner and outer loops. In this direction, this scheme gives valuable results for usually hard-to-calibrate parameters (so-called penalising factors).

We also present a detailed methodology for the construction of synthetic scenarios based on real calibrated study areas. These synthetic scenarios have a perfect fit without the need of the so-called shadow prices (usually we set their value to zero), enabling us to validate our optimisation algorithms knowing the ground truth values of the shadow prices. A simple example is presented to understand the problematic synthetic scenario generation and the corresponding equilibrium prices problem.

Finally, we question the rationale of usual calibration approaches for Transus (and other LUTI models), which consist of estimating parameters for which the model reproduces observations exactly. In Transus, this is achieved by enriching the underlying macro-economic model with the already mentioned auxiliary variables, the shadow prices. While this allows to correct for unavoidable un-modelled effects, it also bears the risk of over-parameterisation and overfitting. We propose a model selection scheme, aiming at a compromise between model complexity (here, number of shadow prices) and goodness of fit to observations, reducing the risk of overfitting and increasing the likelihood of achieving good predictions with a model. These issues are related to the question of model sensitivity; indeed sensitivity analyses are valuable tools to understand how uncertainties in a model’s outputs can be apportioned to different sources of uncertainty, such as the uncertainty in calibrated model parameters.

2. Description of Transus

Transus is a land use and transportation integrated model (LUTI), providing a framework for modelling land use and transportation in an integrated manner. It can be used at urban, regional or even national scale. The area of study is divided in spatial zones and economic sectors; the basic concepts of the original input-output model (see Leontief & Strout, 1963) have been generalised and given a spatial dimension. The concept of sectors is more general than in the traditional definition. It may include the classical sectors in which the economy is divided (agriculture, manufacturing, mining, etc.), factors of production (capital, land and labour), population groups, employment, floorspace, land, energy, or any other that is relevant to the spatial system being represented. Transus combines two main modules: the land use and activity and the transportation modules.

The land use and activity module simulates a spatial economic system by modelling the locations of activities and the interactions between economic sectors for a specific time period. The location of activities is determined by the land use and activity module based on various factors, such as land prices/rents and transportation costs and disutilities (such as time spent in transportation), the latter being provided by the transportation module. The transportation module, on the other hand, dispatches the travel demand induced by the activity model (such as home-to-work and shopping trips) and assigns it to the transport supply. Based on this, transportation disutilities (such as caused by traffic congestion) are re-calculated and output by the transportation module. Both modules are thus linked together, serving both as input and output to each other. In this way the movements of people or freight are explained as the results of the economic and spatial interaction between activities, the transport system and the real estate market. In turn, the accessibility that results from the transport system influences the location and interaction between activities, also affecting land rent. The two modules use discrete choice logit models (McFadden, 1973; McFadden & Train, 2000), linked together in a consistent way. This includes activity-location, land-choice, and multi-modal path choice and trip assignment.

To attain a convergence status, Transus runs both modules iteratively until an equilibrium is found. The land use and transportation modules need to reach their own respective equilibrium status. First, the land use module needs to achieve equilibrium between offer and demand, and equilibrium between the price paid and the cost of producing each economic sector. This is done at current transportation costs and disutilities. Secondly, the transportation module takes as input the transport demand and equilibrates the transportation network to satisfy the given demand. Both modules are run iteratively until a general equilibrium status is found. This is achieved when neither land use nor transportation, evolve anymore, as illustrated in Fig. 1.

2.1. The land use and activity module

In this paper we only work with the land use and activity module, (from now on land use module). Our main goal is to improve this module and make the calibration of the parameters involved easier. We will consider the input needed (for the calibration of

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