Socio-Economic Planning Sciences 41 (2007) 147–162

SOCIO-ECONOMIC PLANNING SCIENCES

www.elsevier.com/locate/seps

# Spatial interaction modeling of interregional commodity flows

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Available online 5 December 2005

**Abstract**

Drawing from both the spatial price equilibrium theoretical framework and the empirical literature on spatial interaction modeling, this paper expands models of interregional commodity flows (CFs) by incorporating new variables and using a flexible Box–Cox functional form. The 1993 US commodity flows survey provides the empirical basis for estimating state-to-state flow models for 16 commodity groups over the 48 continental US states. The optimized Box–Cox specification proves to be superior to the multiplicative one in all cases, while selected variables provide new insights into the determinants of state-to-state CFs.


*Keywords:* Spatial interaction models; Interregional commodity flows; Freight transportation; Box–Cox estimation

## 1. Introduction

Understanding the determinants of interregional commodity flows (CFs) is critical for both national transportation infrastructure planning (highways, railroad tracks, river/port facilities) and regional development policies (location of activities, reducing regional disparities). Unfortunately, limited data availability has, in the past, hindered empirical research in this area. Prior to the 1993 US commodity flows survey (CFS), the 1977 survey was the most recent one. There has also been a dearth of similar data in other countries (see Section 2). However, the US Bureau of Transportation Statistics has released the results of the 1993 CFS, making them widely available. The structure of these flow data is very suitable for empirical analyses.

Using Bröcker's [1] theoretical framework, this paper expands past empirical research on interregional CFs. It specifies a spatial interaction model that incorporates: (1) variables similar to those used in past CF studies, (2) variables used in international trade models, and (3) a set of completely new variables. The selection of the variables is consistent with Bröcker's framework and with inter-industry transactions considerations. For instance, the origins and destinations are characterized by proxy variables representing final and intermediate demands. Adjacency and customs district dummy, distance, competing destination (Fotheringham [2]), and intervening opportunities (Guldmann [3]) variables are also considered.

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0038-0121/$ - see front matter 
doi:10.1016/j.seps.2005.10.003

Instead of the multiplicative functional form used in the past, a flexible Box–Cox transformation specification is estimated with 1993 CFS data in the current paper. The geographical coverage is the 48 US continental states, while the industry coverage is 16 two-digit manufacturing groups. Interregional service flows, which take primarily the form of information flows, are not part of the CFS and are thus not included in our analysis. These flows are indeed becoming more important in the new information economy, but comprehensive data on them are not available. Therefore, the results obtained here for commodity flows cannot be transferred to service flows, which are likely determined by other factors.

The remainder of the paper is organized as follows. Section 2 consists of a literature review. The modeling methodology is presented in Section 3. Data are described in Section 4. The results are discussed in Section 5. Section 6 is devoted to an elasticity analysis, and Section 7 concludes the paper.

## 2. Literature review

### 2.1. Input– output models

Input–output analysis, originally developed to model inter-industry relationships, has been extended to analyze interregional relationships, including the ‘‘pure inter-regional input–output model’’ by Isard [4], the ‘‘column coefficient input–output model’’ by Moses [5], and the ‘‘multi-regional input–output model’’ by Leontief and Strout [6]. In these models, regional (e.g., state) input–output tables are linked via interregional flows, the structure of which is assumed *a priori* (e.g., the percentage distribution of outgoing flows remains fixed across all possible destinations) and is not derived from empirical analyses. Some of these assumptions lead to inconsistent forecasts (e.g., negative ouputs). In any case, input–output models are data-hungry, and building a multi-region and multi-industry structure is prohibitively expensive. Further, because of ever-changing production technologies, these models are not dependable for long-term forecasting.

### 2.2. Spatial price equilibrium models

Spatial price equilibrium (SPE) models are primarily theoretical, and represent the processes of production and consumption of various commodities in several regions, as well as the resulting trade among these regions. Some of these models have been made computable. Two streams can be distinguished: (1) traditional SPE models, where each region is characterized, for any product, by supply and demand functions, and where the interactions between these functions and interregional transportation costs determine the equilibrium in each region and the pattern of trade; and (2) ‘‘new economic geography’’ (NEG) models, based on the micro-behavior of individual consumers and producing firms, and on assumptions of internal plant economies of scale and monopolistic competition.

The SPE model developed by Samuelson [7] is the early prototype of the traditional stream. It is formulated as an optimization model, where the objective function is equal to the sum of all regional consumers' and producers' surpluses, net of transportation costs. The solution represents an equilibrium, where commodities flow from high-price regions to low-price ones, with price differentials between regions equal to transportation costs. In this model, opportunities for trade are created by differences in production and consumption structures across regions (e.g., Ricardian comparative advantage). Autarky, with no trade at all, would result if the regional supply and demand functions were all the same.

Takayama and Judge [8] propose a quadratic programming approach to solving Samuelson's SPE model, using linear regional demand and supply functions. Another SPE approach is illustrated by the Tinbergen–Bos models developed by Paelinck et al. [9]. These models assume multiple sectors, multiple production centers, and multiple market areas. Centers are ranked according to the types of goods they produce, the lowest producing only agricultural goods, and the highest producing all types of industrial goods. The models consist of four types of relations: (1) trade equations, where imports are set equal to exports for each type of center; (2) product equations, with equilibrium between supply and demand for each sector; (3) income equations; and (4) relationships between the numbers of firms in the various centers.

These constructs clearly combine standard equilibrium modeling with hierarchical concepts borrowed from central place theory. The minimization of transportation costs leads to the concentration of industrial