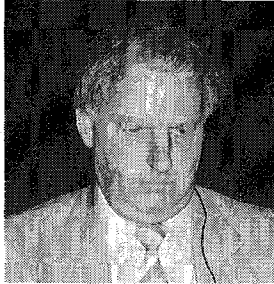


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COMBINATORIAL TRADE MODELLING : RETROSPECT AND PROSPECT



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1. INTRODUCTION

When reflecting on the achievements of transportation research over fifteen years ago, Walter Isard (1975) pointed to a number of seminal advances in gravity modelling and transportation analysis. He emphasized the importance of synthesizing economic thinking with geographical approaches and planning techniques. This unification has been favourably realized in the case of utility-maximizing and entropy-maximizing spatial interaction models, but only to a lesser extent in the case of transportation models which have been fused with multi-sectoral models for describing and projecting economic structure.

Isard also stressed that transportation should never be divorced from the problems of production and location. This might not be construed simply as a plea for a closer dialogue between various scientific disciplines. It might also be construed as a hint that fruitful progress might be possible by combining the more promising elements of two or more individual analytical approaches.

Although spatial variables such as distance, location and transport cost clearly have a significant impact on the quantity and structure of trade, these effects are often downplayed by international trade economists. My task is to redress this imbalance partly by strengthening the case for combined spatial interaction-equilibrium approaches to world trade analysis. I begin with a short review of classical approaches to trade equilibria in a spatial setting, followed by a discussion of the multiregional gravity trade model. Then I point out some weaknesses of the spatial price equilibrium model, as a forerunner to a more detailed review of the recently emerging family of dispersed spatial price equilibrium models. Draw-

ing widely on the work of various colleagues in addition to my own research, the paper concludes by probing some useful avenues which might pave the way for a truly dynamic analysis of the trade adjustment process.

2. CLASSICAL APPROACHES TO TRADE EQUILIBRIA IN SPACE

The contributions to trade analysis emanating from regional scientists mostly belong to the following four traditions :

1. Gravity and Entropy models
2. Interregional Input-Output (IIO) models
3. Spatial Price Equilibrium (SPE) models
4. Interregional Computable General Equilibrium (ICGE) models.

Versions of each of the above models address the mutual interaction between demand, supply and trade in single or multicommodity economies. When appropriately formulated, each type of model may be regarded as an equilibrium approach. Following Hicks (1965), they can be paired off according to their treatment of prices : traditional Gravity and IIO models may be classified as *Fixprice* methods, whereas SPE and ICGE models may be described as *Flexprice* methods. A historical portrait of some of the earlier contributors who are pertinent to our discussion is given in Fig.1. This selection of contributions is far from exhaustive, having been chosen partly to accentuate particular features of the models which are addressed later in this paper.

Although the Arrow-Debreu (1954) paper might be construed as one of the earliest 'combinatorial' approaches, their model is quite sophisticated and beyond the scope of this paper's discussion. Simpler and more digestible as the early forerunner

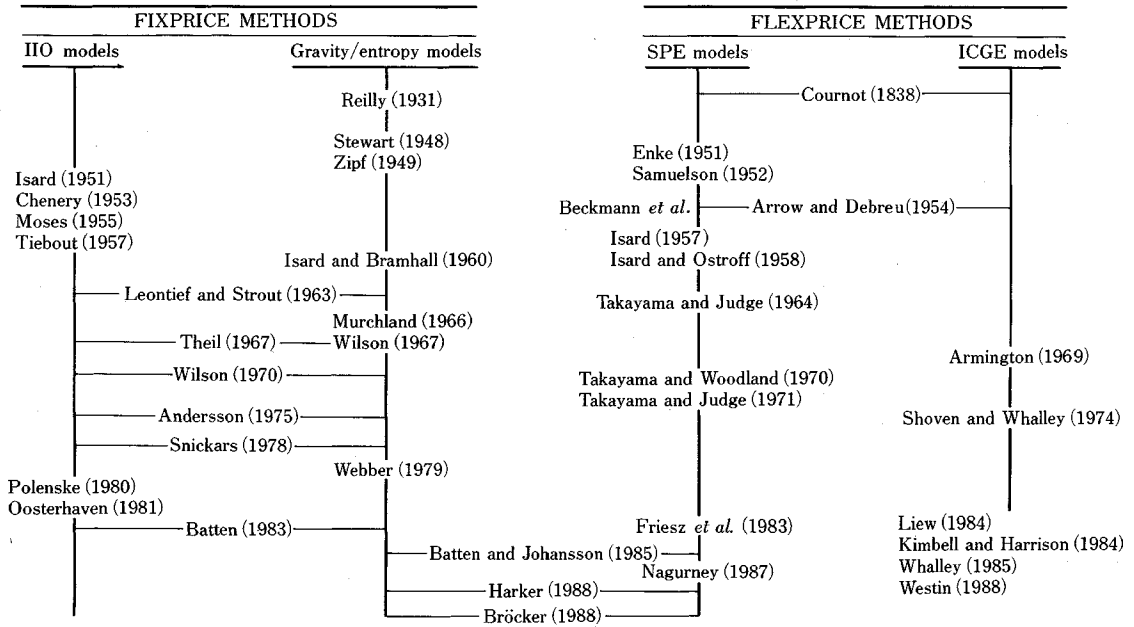


Fig.1 Some contributors to the spatial analysis of trade flows (Source : Batten and Westin, (1990)).

of other combinatorial approaches is the *gravity trade model*, which combines gravity and IIO approaches.

3. THE CLASSICAL COMBINATORIAL APPROACH : MULTIREGIONAL GRAVITY TRADE MODELS

The gravity model was first discussed for use with regional input-output models by Isard and Bramhall (1960), as a possible means of estimating commodity shipments. Soon thereafter, Leontief and Strout (1963) presented a form of the gravity trade model which can be readily implemented for multiregional trade analysis. Compared with the more extensive data on transportation costs required for a linear programming transportation model, only a limited amount of data is needed to implement the Leontief-Strout gravity trade model (hereafter referred to as the LSG model). The basic data include : technical input-output coefficients, preferably for each region ; final demands for each region ; and trade coefficients which reflect the costs of shipping a commodity from one region to another. The summary presented here is taken mostly from Polenske (1970) and Batten (1983) ; a more complete description may be found in Leontief and Strout (1963).

The notation used in the equations includes :

- a_{ij}^r the amount of commodity i required by industry j located in region r to produce one unit of output of commodity j ;
- x_i^{r*} the total amount of commodity i produced

- in region r ;
- x_i^{*r} the total amount of commodity i consumed by all intermediate and final users in region r ;
- x_i^{**} the total amount of commodity i produced (consumed) in all regions ;
- y_i^r the total amount of commodity i consumed by final users in region r ;
- x_i^{rs} the amount of commodity i produced in region r which is shipped to region s ;
- q_i^{rs} a trade parameter which is a function of the cost of transferring commodity i from region r to region s (where the transfer costs can reflect various factors which determine interregional trade, including transportation costs) .

(Superscripts in this section always refer to regions, while the subscripts always designate commodities.)

The LSG model is fully specified by the following set of equations :

$$x_i^{*r} = \sum_{j=1}^I a_{ij}^r x_j^{r*} + y_i^r \dots\dots\dots (1)$$

$$x_i^{r*} = \sum_{s=1}^S x_i^{rs} \dots\dots\dots (2)$$

$$x_i^{*r} = \sum_{s=1}^S x_i^{sr} \dots\dots\dots (3)$$

$$x_i^{rs} = \frac{x_i^{r*} x_i^{*s}}{x_i^{**}} q_i^{rs} \dots\dots\dots (4)$$

The nonlinear interregional equation (4) permits

crosshauling to occur between any two regions, which is a useful feature since data describing commodity shipments are rarely assembled for strictly homogeneous products. The multiregional system is completed by substituting (4) into (2) and (3). Assuming that the final demands, the technical coefficients and the trade parameters are known, a simplified solution to the model can be obtained to determine x_i^{r*} , x_i^{s*} and x_i^{**} . One can then obtain estimates of each interregional shipment, x_i^{rs} , from (4).

Theil (1967) formulated a similar gravity model for interregional shipments using (4) and known values of x_i^{r*} and x_i^{s*} . He postulated that the trade parameter was a function of historical patterns, namely

$$q_i^{rs} = \frac{\hat{x}_i^{rs} \hat{x}_i^{**}}{\hat{x}_i^{r*} \hat{x}_i^{s*}} \dots\dots\dots (5)$$

where the symbol $\hat{}$ refers to known values from the recent past. Theil minimized a measure of information inaccuracy :

$$\sum_{r=1}^R \sum_{s=1}^S \bar{x}_i^{rs} \ln(x_i^{rs} / \bar{x}_i^{rs}) \dots\dots\dots (6)$$

to obtain commodity flow estimates, \bar{x}_i^{rs} , which satisfied (2) and (3). His approach corresponds to the inverse of the standard information minimization procedure (see Batten, 1983).

Wilson (1970) later recognized the similarity of these two models and chose to integrate them using entropy-maximizing methods. He replaced the trade parameter equation (4) with the transportation cost constraint

$$\sum_{r=1}^R \sum_{s=1}^S t_i^{rs} x_i^{rs} = T_i, i=1, \dots, I \dots\dots\dots (7)$$

where t_i^{rs} is the unit cost of delivering commodity i from region r to region s and T_i is the total freight bill for commodity i . By maximizing entropy U defined as

$$U = - \sum_{r=1}^R \sum_{s=1}^S \sum_{i=1}^I x_i^{rs} \ln x_i^{rs} \dots\dots\dots (8)$$

subject to (1), (7) and all possible joint assignments of (2) and (3), he formulated four model versions : (i) unconstrained, (ii) production-constrained, (iii) attraction-constrained, and (iv) doubly-constrained. For further discussions of this family of commodity flow models, see Batten (1983).

There is a precise relationship between the above family of gravity trade models and the transportation model of linear programming (Evans, 1973). The latter may be formulated as the following commodity flow problem :

$$\min \sum_{r=1}^R \sum_{s=1}^S t_i^{rs} x_i^{rs} \dots\dots\dots (9)$$

subject to (2), (3) and the usual non-negativity

conditions. As in Theil's (1967) trade model, the amounts of commodity i produced (x_i^{r*}) and consumed (x_i^{s*}) in each region are assumed given.

The solution to the above transportation problem is equivalent to the classical doubly-constrained gravity model in the limiting case where the distance deterrence parameter (β) approaches infinity (Evans, 1973 ; Bröcker, 1980)*1. In the gravity model, heterogeneity is formally represented by the parameter β in the distance function. By way of contrast, the transportation model of linear programming corresponds only to the assumption of perfect competition (Peschel, 1981). Because distance affects the economy as a monopolistic territorial influence, imperfect behaviour and agglomeration economies designed to overcome distance deterrence result in practice, thereby rendering the assumption of perfect competition to be unrealistic. Crosshauling is also excluded from the transportation model. Such drawbacks have been emphasized by those regional economists who advocate gravity or entropy approaches to interregional trade modelling (Batten, 1983). They have also been instrumental in motivating recent attempts to combine the best features of different approaches (see Section 6).

4. A CRITIQUE OF SPATIAL PRICE EQUILIBRIUM MODELS

To further emphasize the limitations of the classical cost-minimizing transportation model of linear programming, we now turn our attention to one of its most popular derivatives : the spatial price equilibrium (SPE) model. SPE models have commonly been formulated as optimization problems with Marshallian pricing and inverse supply and demand functions, in the tradition of Samuelson (1952) or Takayama and Judge (1964, 1971). In a single commodity SPE model, prices and flows are said to be in equilibrium if the following complementarity conditions hold :

$$w_a^r = p^{r*} - p^r (d^{r*}) \geq 0, d^{r*} w_a^r = 0, d^r \geq 0, \dots (10)$$

$$w_a^s = v^r (q^{r*}) - v^{r*} \geq 0, q^{r*} w_a^s = 0, q^r \geq 0, \dots (11)$$

$$w_x^{rs} = v^{r*} + t^{rs} - p^{s*} \geq 0, x^{rs*} w_x^{rs} = 0, x^{rs} \geq 0, \dots\dots\dots (12)$$

$$w_b^r = \sum_s x^{rs*} - d^{r*} \geq 0, p^{r*} w_b^r = 0, p^r \geq 0, \dots (13)$$

$$w_v^r = q^{r*} - \sum_s x^{rs*} \geq 0, v^{r*} w_v^r = 0, v^r \geq 0, \dots (14)$$

*1 Bröcker (1980) has shown that both approaches depend on the same behavioural assumption, the gravity model having the special characteristic that although the individual does not necessarily choose the supplier with the lowest inclusive price, it is still assumed that the probability of the product being chosen increases with decreasing price.

where t^{rs} ($r, s=1, \dots, NR$) is the unit transportation cost between region r and region s , $p^r(d^r)$ and $v^r(q^r)$ are inverse demand and supply functions in region r . Equilibrium demand prices are denoted by p^{r*} and equilibrium supply prices by v^{r*} . At the equilibrium solution, demand is d^{r*} and production is q^{r*} in region r . The equilibrium commodity flow between region r and s is denoted by x^{rs*} . Constraints (10) and (11) demonstrate the use of inverse demand and supply functions in traditional SPE models ; (12) is the spatial price equilibrium condition for positive flows on a link, while (13) and (14) are conservation-of-flows conditions.

As a generalisation of the Marshallian SPE model, Friesz *et al.* (1983) developed a model with a Walrasian price formulation^{*2}. A simplified version of such a single commodity equilibrium model includes the following complementarity conditions :

$$w_x^{rs} = p^{r*} + t^{rs} - p^{s*} \geq 0, x^{rs*} w_x^{rs} = 0, x^{rs} \geq 0 \dots\dots\dots (15)$$

$$w_p^r = q^r(p^{r*}) - d^r(p^{r*}) + \sum_s x^{rs*} - \sum_s x^{sr*} \geq 0$$

$$p^{r*} w_p^r = 0, p^{r*} \geq 0 \dots\dots\dots (16)$$

In this formulation, the transportation cost within a region is set to zero.

SPE models have been used on numerous occasions to predict interregional and international trade patterns (and regional prices, supplies and demands) for various raw materials and agricultural goods (see Takayama and Labys, 1986). Such models often generate quite unrealistic trade patterns when they are applied rigidly without any calibration or relaxation. This poor performance record may be attributed directly to their underlying assumptions, namely that

1. trade is in homogeneous, transport-sensitive commodities ;
2. such commodity markets are perfectly competitive in terms of cif prices (i.e. fob price plus transport cost) ; and
3. each buyer has complete and reliable information on prices and sources, so as to be able to secure the minimum cif price.

The minimisation of cif prices forces a solution in which all but a few trade flows vanish^{*3}. If we exclude the degenerate cases, only $2n - 1$ out of n^2 possible flows will be strictly positive (Bröcker, 1988). Although a few markets dealing in strictly homogeneous products might behave in this way, the vast majority do not. At the more aggregated

^{*2} The model by Friesz *et al.* (1983) is a network-oriented model with path flows and transshipments through nodes.

^{*3} This problem is akin to the diagonalization tendency in the transportation model of liner programming, as discussed in the latter part of Section 3.

Table 1 Freight Value and Market Share of Swedish Exports by Transport Mode

Transport mode across the border	Average freight value of Swedish exports (in Swedish krone per kilogram)	Market share by value of Swedish exports			
		1986	1967	1975	1986
			%	%	%
Ship	4.6	76	64	45	
Train	4.8				
Road vehicle	16.1	24	36	55	
Aeroplane	537.				

Source : Swedish Central Bureau of Statistics, Foreign Trade and Transportation Statistics (various years).

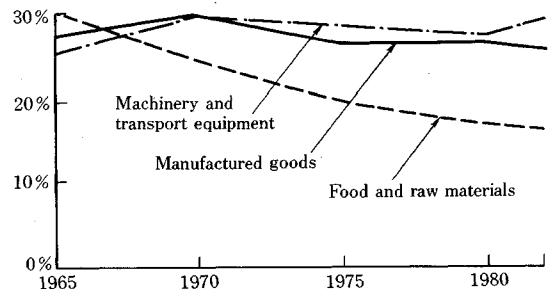


Fig.2 The changing market structure of traded goods (Source : Yearbook of International Trade Statistics, UN, New York (various volumes)).

level where trade data are generally available, or under the commonly prevailing conditions of imperfect information, cif prices and trade flows will be more dispersed than the SPE model permits.

Homogeneous commodities of low freight value, and thus with relatively high sensitivity to transport cost, are in any case steadily losing their share of both interregional and international goods trade (see Table 1 and Fig.2). The trend towards more road and air freight movement at the expense of sea and rail is also indicative of a trend towards more sophisticated trade in goods of higher freight value, and is further evidence of more transnational firms marketing differentiated products. The qualitative (non-price) attributes of these products are assuming greater importance, so much so that the incidence of crosshauling appears to be increasing.

Unfortunately, the assumptions of product homogeneity and spatial price equilibrium preclude the possibility of cross-hauling, or even flow dispersion onto 'non-optimal' trading links. In the face of observed patterns of trade, such assumptions are unrealistic.

The validity of the perfectly competitive market assumption is also quite tenuous. Modern firms

Table 2 Comparison of pricing strategies in different nations

Nation	Mill Pricing %	Discriminatory pricing		Number of firms surveyed
		Uniform %	Other %	
USA	33	21	46	174
West Germany	21	32	47	34
Japan	18	27	55	34

Source : Adapted from Greenhut *et al.* (1987).

find to price discriminatorily over the differentiated markets they serve. Of 241 firms sampled in a recent survey conducted in the USA, West Germany and Japan, less than one-third priced nondiscriminatorily (Table 2). In the case of the U.S.A., spokesmen for the remaining firms (67 per cent) admitted that they did not add full freight cost to their mill price on all their distant sales.

There are many reasons for the dominance of imperfectly competitive market behaviour in the trade world. Notable among these are :

1. increasing returns to scale
2. taste for variety and differentiated products
3. imperfect information
4. political and cultural affinities
5. multilateral cartels
6. bartering and negotiated trade 'packages'
7. long-term bilateral trade agreements
8. multiproduct firms and scope economies

In its traditional form, the SPE model is unable to accommodate price distortive mechanisms of the monopolistic or oligopolistic variety (Sheppard and Curry, 1982), although various writers have proposed modifications to cater for special forms of imperfect competition (e.g. Takayama and Judge, 1971 ; Batten and Johansson, 1985 ; Harker, 1985). Pressing is the need for an integrated approach to the analysis of trade in a world characterised by increasing returns to scale, imperfect competition and significant intraindustry trade in differentiated products.

5. SPATIAL HETEROGENEITY IN FLEXPRISE MODELS

In the analyses of trade conducted with the help of computable general equilibrium (CGE) models, heterogeneity is generally introduced by recognising that commodities of a similar type, but from different locations, may be imperfect substitutes. This notion of spatial heterogeneity is commonly referred to as the 'Armington assumption' (see Armington, 1969)*⁴. It provides more empirical tractability within general equilibrium models, caters for cross-hauling and generates greater dispersion of buyer-seller combinations in the trade share matrix. Unrealistic preoccupation with the

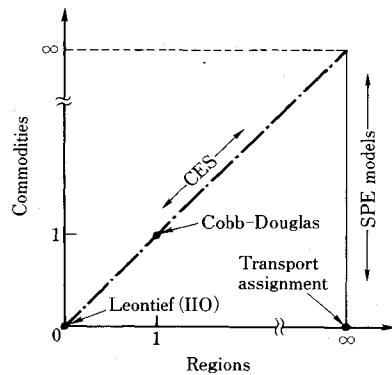


Fig.3 Elasticities of substitution between different commodities and locations as reflected in various spatial equilibrium models (Source : Batten and Westin, 1990)

most cost-efficient trading sources and partners—a major weakness of SPE and LP models—is avoided.

The Armington assumption is introduced in practice using spatial versions of CES functions and demand systems. The use of CES functions is limited to cases where constant and equal elasticities of substitution between all commodities from all locations turns out to be a reasonable assumption. In Fig.3, this means that CES functions constrain the elasticities to points along the diagonal line. The Leontief model employing fixed coefficients (e.g. the IIO model) and the Cobb-Douglas function are special cases of the CES function (depicted as points in Fig.3).

The implicit assumption in SPE models is that of perfect substitution between different locations, but a variable degree of substitution between commodities. This model's elasticity properties correspond to the vertical line through the point of infinite locational elasticity. The perfectly linear substitution function is also equivalent to an extreme form of a CES function. By a suitable choice of parameters and appropriate nesting of CES functions, the Walrasian SPE model may be recognised as a special case of an ICGE model. Alternatively, inclusion of the Armington assumption in SPE models, with a corresponding increase in the number of commodities (by the number of regions), would allow spatial heterogeneity to be

*⁴ Spatial heterogeneity is not purely a recent consideration. Ohlin (1933) discussed the possibility of differentiating commodities by origin to cater for qualitative differences. At that time, such discussions were viewed mostly as small refinements to the widely-accepted model of homogeneous goods. A notation with commodities differentiated by location was introduced by Arrow and Debreu (1954). Kuenne (1963) also noted that Isard's multiregional input-output model included spatially heterogeneous commodities.

represented in these models. This confirms the existence of opportunities to develop multicommodity models with flexible, non-uniform behavioural assumptions (compare Isard and Dean, 1987).

6. DISPERSED SPATIAL PRICE EQUILIBRIUM MODELS

Instead of implanting the Armington assumption into the SPE model framework, we could alternatively try to do away with some of its limitations by embellishing the SPE approach with some complementary elements from other modelling traditions. In the following section, we shall outline some combined approaches which generate a 'dispersed' set of prices of flows and thus more realistic trade patterns (e.g. Batten and Johansson, 1985 ; Bröcker, 1988 ; Harker, 1988). In each of these frameworks, the chosen form of link function which is consistent with the gravity model and its firmly established theoretical foundation as a cost-efficient macro-based behavioural principle (Smith, 1978). This link function is combined with particular pricing mechanisms to produce a more dispersed result than the classical SPE model.

Each DSPE model takes the general form :

$$x^{rs} = y^{rs} \exp [\beta(p^s - v^r - t^{rs})] \dots\dots\dots(17)$$

where β is a parameter which may be interpreted as the marginal utility of profit when equation (17) is considered in its equivalent form of a logit model (Anas, 1983 ; Batten and Boyce, 1986), and y^{rs} differs for each model. Their virtue is that they allow for varying degrees of dispersion around an equilibrium solution so as to reflect imperfections in the marketplace. In addition to the trio of DSPE models discussed herein, the interested reader is also directed to further recent developments proposed by Roy (1990), and Miyagi (1990).

Harker's (1988) model is an unconstrained gravity trade model (see Section 3) for which $y^{rs} = \alpha^r \gamma^s q^r d^s$. It simulates a perfectly competitive marketplace in which regional supplies q^r and demands d^s are determined endogenously, with the parameters α^r, γ^s and β being derived from historical trade patterns. Bröcker's (1988) model assumes inelastic constraints on the demand side, has $y^{rs} = \alpha^r$ defining the relative attractiveness of region r as a supply source, and includes tariffs in t^{rs} . Both these models are Marshallian in character and return to the classical SPE model as β approaches infinity.

Although it was not initially regarded as a dispersed SPE model, the Walrasian trade model developed earlier by Batten and Johansson (1985) may be seen as the conceptual forerunner of this class of model. By way of contrast, the price

constraints governing the behaviour of buyers and sellers in the B-J model are characteristic of an oligopolistic marketplace in which products may be differentiated. In this case the y^{rs} are estimated from historical trade patterns, whereas the chosen supply and demand constraints define a marketplace where prices cover costs *on average only*. As the rationale for this type of model stems partly from a need to allow for structural adjustments over time, it is instructive to look more closely at the formulation.

In Batten and Johansson (1985), two alternative market structures are examined. The first model formulation is designed to reflect price-setting conditions from the viewpoint of buyers (or destination regions), which yields the following explicit solution :

$$x^{rs} = d^s(p^s) \frac{y^{rs} \exp \{-\gamma^s(v^r + t^{rs})\}}{\sum_k y^{ks} \exp \{-\gamma^s(v^k + t^{ks})\}} \dots\dots\dots(18)$$

where $d^s(p^s)$ denotes the demand function in regions and γ^s is a shadow variable associated with the delivery pattern optimization.

This logit-like expression may be interpreted as the outcome of search behavior designed to establish "elementary contracts". The coefficients y^{rs} reflect the historical probability that a specific bilateral contract for the exchange of commodities will be established between regions r and s . Assuming that each elementary contract or agreement has an identical probability over the complete set of regional combinations, we can determine the probability $P(x^{rs})$ of a specific flow distributions, $\{x^{rs}\}$, using the following combinatorial calculus :

$$P(x^{rs}) = N^{rs} \prod_{r,s} [y^{rs}]^{x^{rs}} / \prod_{r,s} x^{rs} ! \dots\dots\dots(19)$$

where N^{rs} is a parameter which depends on the total number of elementary contracts and the number of regional combinations.

Let $x^{rs}(t-\tau)$ denote flows realized τ periods before t , and let $z^{rs}(t)$ denote the normalized trade distribution in any period t , namely

$$z^{rs}(t) = x^{rs}(t) / \sum_{r,s} x^{rs}(t) \dots\dots\dots(20)$$

We shall assume that the a priori pattern $q^{rs}(t)$ is formed by a sequence of historical contracts and established market channels. Moreover, as time develops within the model exercise, the pattern is assumed to be renewed for each time period. Formally, we have that

$$y^{rs}(t) = F^r [z^{rs}(t-1), z^{rs}(t-2), \dots] \dots\dots\dots(21)$$

where F^r depicts the cumulative effect of the sequence of past trade patterns, with a diminishing contribution from patterns which are more historical in time. For example, F^r may be represented by a weighting operator of the following type :

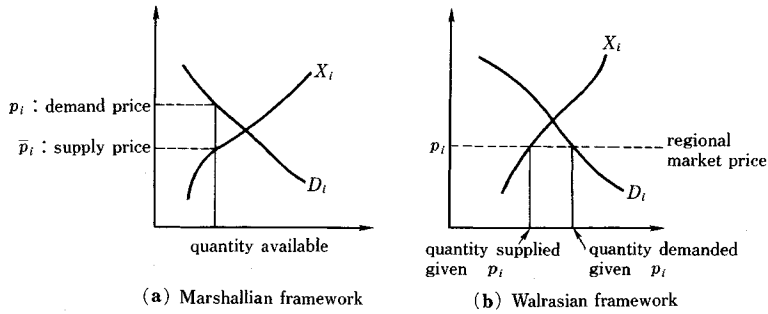


Fig.4 Illustration of (a) Marshallian, and (b) Walrasian Frameworks

$$q^{rs}(t) = \sum_{\tau=1}^T w(\tau) z^{rs}(t-\tau) \dots \dots \dots (22)$$

where $\sum w(\tau) = 1$ and all $w(\tau) \geq 0$. To summarize, the above assumption implies that actual trade flows reflect the establishment and maintenance of specific communication channels and information flows between buyers and sellers in different regions. The larger the value of z^{rs} , the greater the probability of a continuation of this communication and future exchange; the higher the weighting $w(1)$, the greater the influence of current patterns. The existence of a significant degree of inertia in the trading patterns of many nations has been confirmed empirically (see, e.g. Andersson and Persson, 1982; Batten, Johansson and Kallio, 1983). These bilateral trade preferences can be taken into account using the above probabilistic approach, which also provides a foundation for dynamic analysis.

When the constraints on price dispersion are applied to the suppliers rather than to the buyers, an alternative model emerges. The flow solution to this model follows:

$$x^{rs} = q^r(v^r) \frac{y^{rs} \exp\{\lambda^r(p^s - t^{rs})\}}{\sum_k y^{rk} \exp\{\lambda^r(p^k - t^{rk})\}} \dots \dots \dots (23)$$

where $q^r(v^r)$ denotes the supply function in region r and λ^r is a shadow variable associated with the optimal delivery pattern. The constraints associated with γ^s and λ^r are respectively

$$\sum_r (v^r + t^{rs}) x^{rs} \leq p^s d^s(p^s) \dots \dots \dots (24)$$

and

$$\sum_s (p^s - t^{rs}) x^{rs} \geq v^r q^r(v^r) \dots \dots \dots (25)$$

Observing that $(p^s - t^{rs})$ stands for the net price obtained in region r when selling commodities in region s , the above expressions may be interpreted as two alternative versions of the principle of nonnegative profits on aggregate.

The two price conditions in (24) and (25) cannot be compared directly with those in the Takayama-Judge SPE model. One reason for this is that the

SPE model adheres to the Marshallian framework, which means that for each quantity supplied and demanded one determines a supply price and a demand price (as depicted in Fig.4 (a) for a single region). The B-J approach is Walrasian in nature, which means that there is one regional (market) price and this determines the quantity supplied and the quantity demanded (see Fig.4(b)). Hence, the prices in (24) and (25) cannot be interpreted as supply and demand prices.

A second observation is that the price responsiveness postulated is of the smooth kind, which is often associated with oligopolistic competition and product differentiation (see, for example, Friedman 1977). This is consistent with the trade inertia which is modelled as a set of probabilistic supplier-customer ties. The result of this is that the SPE condition

$$p^s < \tilde{p}^r + t^{rs} \rightarrow x^{rs} = 0$$

does not apply to this setting, where p^s are demand and \tilde{p}^r are supply price for the contracting pair of region (r, s) . Because of variations in production cost within region, as well as trade inertia effects, we may obtain a small flow for an individual link (r, s) which does not satisfy the principle of non-negative profits. That is, we may have in a solution

$$p^s - t^{rs} \leq v^s \text{ and } x^{rs} \geq 0$$

The non-negative profit condition applies at the aggregate level, as shown in (24) and (25). When we sum over flows, profits are associated with prices that cover costs on the average. Although we avoid stipulating any definite relation between market prices, p^r , and "marginal" cost levels or producer prices, v^r , it is obviously possible to reflect oligopolistic or monopolistic elements in price formation by setting

$$p^s = v^s + t^{rs} + \xi^s \dots \dots \dots (26)$$

so that

$$\sum_s p^s x^{rs} \geq \sum_s [v^r + t^{rs} + \xi^s(x^{rs})] x^{rs} \dots \dots \dots (27)$$

or

$$\sum_r p^s x^{rs} \geq \sum_r [v^r + t^{rs} + \xi^s(x^{rs})] x^{rs} \dots \dots \dots (28)$$

which could reflect a relation between the size of the flow, x^{rs} , and the degree of oligopolistic price margin.

7. TOWARDS A DYNAMIC TRADE ADJUSTMENT MODEL

The rationale behind the principle of non-negative profits on average becomes apparent once we distinguish between short-and long-term supply adjustments. This distinction is necessary in order to recognize that comparative advantage is nowadays created by research and development, diffusion of knowledge, and investments over time.

(1) Vintage Models

The production capacity of a sector is fixed in the short run, although the production level may vary. A sector consists of a set of production units or plants with varying production costs. These units may be ordered in a sequence $k=1, 2, \dots$ such that $v^{rk} > v^{r,k+1} > \dots$, where v^{rk} denotes the cost level of unit k . Such cost differentials arise from differences in production techniques which largely reflect the vintage of the technology embodied in the fixed capital design of each unit. We may then form a cost function, $v^r(q^r)$, describing the structure of these units in region r :

$$v^r(q^r) = v^{rk} \text{ for } q^r = \sum_k \bar{q}^{rk} \dots \dots \dots (29)$$

where \bar{q}^{rk} is the production capacity of unit k . For each single unit, the prevailing price, p^r , together with the cost level, v^{rk} , determines the surplus or loss associated with operating that unit. This distribution of different cost levels within a sector or a region may also lead to nonzero flows for a loss-making trading routes (r, s) , since some trading pairs may be loss-making even when the region as a whole is trading profitably.

The underlying cost structure is illustrated by step function in Fig.5. As this figure shows, (29) implies that in the short run marginal cost increases as the production level approaches the temporary capacity limit \bar{q}^r . During intervals which are long enough to allow for new investment, new capacities, Δq^r , with a reduced cost may be introduced. Hence, the cost effect of increased production changes as the time interval varies. These arguments can be extended to situations in which production costs are derived from the technical characteristics of the different production units together with the price structure of production inputs (see, for example, Johansson and Strömquist 1981). Estimates of the time invariance of industrial cost structures are presented in Johansson and

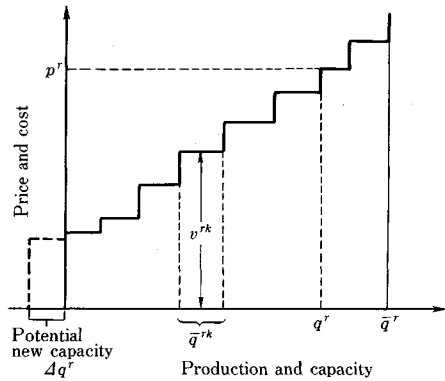


Fig.5 Cost Structure in a Region

Marksjö (1983).

The type of cost structure depicted in Fig.5 may be delineated over the set of production sectors and interacting regions. It is on the basis of such a structure that comparative advantages must be evaluated. Comparative advantage will change over time in accordance with the investment profiles of the interacting regions and shifts in location of the most efficient factors of production.

The model I have sketched also sheds light on the relevant time scale for our linkage mechanism. If we analyse only one commodity class in isolation, we may choose time intervals for our trade model which correspond to the time period required to create new capacity. In such a case, the supply function will refer to a single time period, and it will change between time periods in response to investments in new capacities and closure of old ones. If we extend the time period beyond this, the supply function must be altered so as to incorporate capacity change behavior, which, for example, may be modeled as a response to changing prices and cost opportunities.

(2) Changing Origin-Destination Relationships

In order to study the changing patterns of trade between regions, it is necessary to augment the supply-related adjustments (discussed above) with a set of link-related adjustments. For example, each region of supply has a greater incentive to trade on those links which offer higher profits. Thus we may assume that the pattern of deliveries will gradually redistribute over time in response to the profit differentials of alternative links (r, s) compared with (r, k) .

The profit derived from a link (r, s) is defined as $\pi^{rs} = p^s - v^r - t^{rs} \dots \dots \dots (30)$ and the ruling market price in region s , p^s , will reflect the cost structures of all the different suppliers in such a way that

$$p^s = \sum_r p^{rs} x^{rs} / \sum_r x^{rs} \dots\dots\dots (31)$$

where $p^{rs} = t^{rs} + v^r + \bar{\pi}^r$ and $\bar{\pi}^r$ is the minimum mark-up level in region r . Note that $\bar{\pi}^r$ serves as a threshold profit level below which no investments in new capacity, Δq^r , will be undertaken. If the price p^s falls below $(t^{rs} + v^r + \bar{\pi}^r)$, then such investments are postponed. During phases of decline, the price-setting condition $p^s \geq t^{rs} + v^r$ will be sufficient (i.e. $\bar{\pi}^r = 0$). We must reflect this basic asymmetry between phases of expansion and decline in our dynamic model of trade and output. This aspect is taken up in further detail in Batten and Johansson (1989).

From (31), it is clear that development of p^s is affected by changes in both p^{rs} and x^{rs} . With two suppliers to region s , say 1 and 2, note that $\dot{p}^s < 0$ if $\dot{p}^{1s} < \dot{p}^{2s}$ and $\dot{x}^{1s} > \dot{x}^{2s}$. Then the rate of growth will be faster for flows x^{rs} which have a cost advantage in the sense that $\dot{p}^{rs} < \dot{p}^s$. These are the flows with the highest link profits π^{rs} .

Next, observe that

$$\dot{p}^s \sum_r x^{rs} = \sum_r \dot{p}^{rs} x^{rs} + \sum_r (p^{rs} - p^s) \dot{x}^{rs} \dots\dots\dots (32)$$

We know that flows which expand have $\dot{p}^{rs} < \dot{p}^s$. Hence, the last term on the right hand side never positive. This implies that \dot{p}^s declines gradually if $\sum_r \dot{p}^{rs} x^{rs} \leq 0$.

(3) Spatial Product Cycles

One explanation for a gradual reduction in the value of p^s over time is the arrival of a new supplier in the proximity of region s whose delivery costs are lower than those of the established suppliers. If the production technique has matured to such an extent that $v^r \approx v^k$ in many different locations r and k , the establishment of production in a new location k closer to the purchaser (i.e. where $t^{ks} < t^{rs}$) will result in a lower value of p^{ks} than that for p^{rs} in expression (31).

This type of spatial relocation of production is a rather typical strategy in the case of a mature product (see, eg. Norton and Rees, 1979 ; Johansson and Karlsson, 1987; Batten and Johansson, 1989). The spatial model outlined above has specific implications for the initiation of production in any region r . We know that deliveries will be directed to destinations where π^{rs} is higher than elsewhere. In general we may assume that $t^{rs} < t^{rs}$ for each $s \neq r$. If $\dot{p}^r = \dot{p}^s$, this means that the deliveries from a producer in region r (i.e. q^r) will initially expand more rapidly on the intraregional (r, r) than on any interregional link (r, s) . As production expands and production costs are reduced, the interregional deliveries may increase

very quickly in a later phase. When the relative factor costs, v^k , of other regions k begin to fall over time, the link-related profitability criterion (30) ensures that locations outside \hat{r} may gradually become more attractive.

Some further exploration in this direction may be found in Batten and Johansson (1989).

8. CONCLUDING REMARKS

The existence of link-specific infrastructure is a fundamental precondition for trade between regions. On the other hand, a proper understanding of the dynamic processes which govern the location of production units and the expansion of trade between regions is necessary in order to plan for infrastructure investment. Thus trade and infrastructure analyses are interdependent.

In this review paper, I have endeavoured to strengthen the case for adopting combined approaches to world trade analysis. The classical example of a combinatorial approach is the Leontief-Strout gravity trade model. More recent and equally promising examples include dispersed spatial price equilibrium (DSPE) models, the inclusion of input-output matrices in the case of some interregional computable general equilibrium (ICGE) models, and network-based input-output models. Such approaches may be classified under the general heading of *Combinatorial trade models*.

My main focus has been on the DSPE model and some important elements of the future family of dynamic trade models. In this discussion, I have drawn on the work of many scientific colleagues as well as some of my own research. The interested reader who may wish to follow up certain aspects in greater detail is directed to Batten (1983, 1984), Batten and Johansson (1985, 1989), Batten and Boyce (1986), Batten and Westin (1990). Nevertheless, the ultimate challenge still lies ahead of us : to fully unravel the dynamics of trade. Combinatorial approaches would seem to offer considerable potential, as we try to integrate the dynamics of regional specialization with demand, supply, global networks of interaction and investment behaviour in the short and longer term.

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*5 In this section, derivatives with respect to time are denoted thus : $dp/dt = \dot{p}$, etc.

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