MODELLING COMMODITY FLOWS ON TRADE NETWORKS: Retrospect and Prospect

by

David Batten and Lars Westin

Umeå Economic Studies No. 194

UNIVERSITY OF UMEÅ 1989

ISSN 0348-1018

UNIVERSITY OF UMEÅ

Department of Economics and
Centre for Regional Science Research (CERUM)

MODELLING COMMODITY FLOWS ON TRADE NETWORKS:
Retrospect and Prospect*

by

David Batten and Lars Westin

February 1989

ABSTRACT: *Various approaches to the estimation of commodity flow or trade share matrices across world trade networks are examined. Some serious drawbacks associated with the use of spatial price equilibrium models are identified, and a case is made for combining two or more individual approaches, such as may be found in "dispersed" spatial price equilibrium models or in computable general equilibrium models which cater for spatial heterogeneity. It is found that some variant of the gravity model may be a reliable guide to trade share patterns in the long run, particularly in a world of differentiated products and increasing returns to scale. A conclusive finding is that quite different models ought to be adopted for different commodities (i.e. markets) in the short and medium term perspective.*

* This paper has been written as a contribution to a forthcoming "Festschrift" in honour of Walter Isard (the founder of regional science). Financial support from the Swedish Transport Research Board (TFB) is acknowledged.

1. INTRODUCTION

In this paper we examine various analytical approaches which are pertinent to an important area of research in which, according to Isard and Dean (1987), regional scientists ought to be more actively involved. This is the estimation of commodity flow (or trade share) matrices across world trade networks. 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 ignored or downplayed by international economists. Our task is to partly redress this imbalance by strengthening the case for combined spatial interaction-equilibrium approaches to world trade analysis.

We begin with a short review of the pertinent contributions which have involved regional scientists. Second, we identify some serious drawbacks associated with the use of spatial price equilibrium models. Third, we make a case for combining the best features of two or more individual approaches, such as may be found in "dispersed" spatial price equilibrium models or in computable general equilibrium approaches which allow for spatial heterogeneity. Fourth, we demonstrate that the gravity model tends to fit the trade pattern better in a world of increasing returns to scale and greater product differentiation than in a world of homogeneity and constant returns. Finally, we ponder some useful new directions which could pave the way for a truly dynamic analysis of the trade adjustment process.

2. SPATIAL EQUILIBRIUM APPROACHES

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

- * Gravity and Entropy models,
- * Interregional Input-Output (IIO) models,
- * Spatial Price Equilibrium (SPE) models,
- * 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 Figure 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.

Figure 1: Some Contributors to the Spatial Analysis of Trade Flows

We shall not dwell in detail on the Fixprice methods, since they have been examined in a comprehensive manner elsewhere (e.g. Batten and Boyce (1986), Hewings and Jensen (1986)). Instead we shall concentrate on the SPE and ICGE models, and later on approaches which call for combinations of more than one tradition. Examples of the latter (represented in Figure 1) are (a) adaptations of the SPE model to consider gravity (Harker (1988), Bröcker (1988)) and entropy (Batten and Johansson (1985)), which have been termed "Dispersed Spatial Price Equilibrium" (DSPE) models, and (b) the inclusion of input-output matrices in the core of some ICGE models (e.g. Liew (1984), Buckley (1987), Westin (1987)). Input-output matrices have also been incorporated within SPE models (Fleischer et al (1988)). Furthermore, the IIO model may be regarded as a particular type of ICGE or SPE model featuring price-inelastic agents.

2.1 SPE and ICGE Models

Although they are rarely compared with each other, the SPE and ICGE approaches represent the two main spatial equilibrium modelling traditions. This independence may be explained by their emergence within different analytical environments¹⁾. While the SPE model is a familiar tool to regional scientists, only recently has serious attention been paid to the ICGE model. The latter work comprises interregional applications of a modelling approach developed by international trade modellers (Shoven and Whalley (1974), Whalley (1985)).

Traditionally, SPE and ICGE models have been applied to trade problems at different levels of commodity aggregation. SPE formulations usually treat a single commodity or set of "individual" commodities in a partial analysis. ICGE models have generally dealt with commodities aggregated to the sector level, just like input-output models. Thus ICGE models attempt an economy-wide analysis, characterized by equilibrium in most or all sector and factor markets.

1) The traditional optimization formulation of SPE models and the equilibrium formulation of ICGE models have most likely contributed to this isolation. Discussions of available solution algorithms may be found in Dervis et.al. (1980), Friesz et. al. (1983) and Mathiesen (1985).

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 (1971). Inverse functions have a slight advantage in programming formulations, although their existence is generally constrained to cases where the ordinary functions are separable (Friesz et al (1983)). The ICGE approach draws heavily on the Walrasian tradition of Arrow and Debreu (1954), Debreu (1959), Johansen (1960), Scarf (1963), and Shoven and Whalley (1974). This involves the use of traditional supply and demand functions and an endogeneous income-consumption feedback, which often precludes treatment as an optimization problem.

A spatial flexprice model determines equilibrium prices and quantities of demand and supply in a set of locations, as well as the equilibrium commodity flows between these locations. In a single-commodity SPE model, prices and flows are said to be in equilibrium if the following complementarity conditions hold (Takayama and Labys (1986));²⁾

$$w_d^r = p^{r*} - p^r(d^{r*}) > 0, \quad d^{r*} w_d^r = 0, \quad d^r > 0, \quad (1)$$

$$w_q^r = v^r(q^{r*}) - v^{r*} > 0, \quad q^{r*} w_q^r = 0, \quad q^r > 0, \quad (2)$$

$$w_x^{rs} = v^{r*} + h^{rs} - p^{s*} > 0, \quad x^{rs*} w_x^{rs} = 0, \quad x^{rs} > 0, \quad (3)$$

$$w_p^r = \sum_s x^{sr*} - d^{r*} > 0, \quad p^{r*} w_p^r = 0, \quad p^r > 0, \quad (4)$$

$$w_v^r = q^{r*} - \sum_s x^{rs*} > 0, \quad v^{r*} w_v^r = 0, \quad v^r > 0. \quad (5)$$

2) Under specific circumstances, equilibrium models may be formulated as optimization models (See also Takayama et al (1984)). Conditions (1)-(5) are then Kuhn-Tucker conditions, with the w 's as slack variables.

where h^{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 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 as x^{rs*} . Constraints (1) and (2) demonstrate the use of inverse demand supply functions in traditional SPE models; (3) is the spatial price equilibrium condition for positive flows on a link, while (4) and (5) are conservation of flows conditions.

The advantage of a Walrasian formulation is the possibility to utilize more general (e.g. nonlinear) nonseparable demand and supply functions which have no inverses. As a generalization of the Marshallian SPE model, Friesz et al (1983) developed a model with a Walrasian price formulation.³⁾ A simplified version of such a single commodity equilibrium model includes the following complementarity conditions:

$$w_x^{rs} = p^{r*} + h^{rs} - p^{s*} > 0, \quad x^{rs*} w_x^{rs} = 0, \quad x^{rs} > 0, \quad (6)$$

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

$$p^{r*} w_p^r = 0, \quad p^{r*} > 0. \quad (7)$$

In this formulation the transportation cost within a node or region, h^{rr} , is set to zero.

3) The model by Friesz et al is a transport-oriented model with path flows and transshipments through nodes.

2.2 A Critique of SPE Models

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 Judge and Takayama, 1973). 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 minimization of cif prices forces a solution in which all but a few trade flows vanish.⁴⁾ 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 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 (e.g. less than SEK 10 per kg), and thus 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 Figure 2). The trend towards more road and air freight movement at the expense of sea and rail is also

4) This problem is akin to the diagonalization tendency in the transportation model of linear programming. Both approaches depend heavily on the assumption of perfect competition (Peschel, 1981), and both may be seen as equivalent to a "homogenized" version of the doubly-constrained gravity model in which the distance deterrence parameter approaches infinity.

Figure 2: The Changing Market Structure of Traded Goods

Source: Yearbook of International Trade Statistics, UN, New York (various volumes)

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

Transport mode across the border	Average freight value of Swedish exports	Market share by value of Swedish exports		
	1986	1967	1975	1986
Ship	4.6 SEK/kg	76%	64%	45%
Train	4.8 SEK/kg			
Road vehicle	16.1 SEK/kg	24%	36%	55%
Aeroplane	537. SEK/kg			

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

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 tend 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 USA, spokesmen for the remaining firms (67%) admitted that they did not add fully freight cost to their mill price on all their distant sales.

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%	33

Source: Adapted from Greenhut et al, 1987.

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

- * increasing returns to scale
- * taste for variety and differentiated products
- * imperfect information

- * political and cultural affinities
- * multilateral cartels
- * bartering and negotiated trade "packages"
- * long-term bilateral trade agreements
- * multiproduct firms and scope economies

In its traditional form, the SPE model is unable to cater for 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), Harker (1985). Pressing is the need for an integrated approach to the analysis of trade in a world characterized by increasing returns to scale, imperfect competition and significant intraindustry trade in differentiated products. Concerted efforts in these directions may be found in the recent literature on international trade theory (e.g. Dixit and Norman (1986), Helpman and Krugman (1985), Kierzkowski (1984)), as well as in the recent work of some spatial economists (e.g. Greenhut et al (1987), Kuenne (1988)).

2.3 Spatial Heterogeneity in Flexprice Models

In the analyses of trade conducted with the help of computable general equilibrium (CGE) models (e.g. Shoven and Whalley (1974, 1984), Whalley (1985), Srinivasan and Whalley (1986)), heterogeneity is generally introduced by recognizing 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)).⁵ It provides more

5) 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) and later extended by Debreu (1959). Kuenne (1963) also noted that Isard's multiregional input-output model (Isard (1951)) included spatially heterogeneous commodities.

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

During the eighties, experimental versions of the interregional (ICGE) model incorporating the Armington assumption have been developed (e.g. Liew (1984), Buckley (1987), Higgs et al (1987), Madden (1987), Suknam and Hewings (1987), Westin (1988)). In these models, a Walrasian spatial equilibrium among heterogeneous commodities may be defined in terms of origin-destination (i.e. link) demand functions and fulfills the following complementarity condition:

$$w_p^r = q^r(p^{r*}) - \sum_s d^{rs}(p^{rs}) > 0, \quad p^{r*} w_p^r = 0, \quad p^r > 0 \quad (8)$$

where

$$p^{r*} + h^{rs} = p^{rs}. \quad (9)$$

The equilibrium prices are supply (or sellers) prices. There are NR of these, while the number of demand prices is NR². However, in each region, the agents may only choose among NR commodities and prices.

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 Figure 3, this means that CES functions constrain the elasticities to points along the diagonal line.

Figure 3 Elasticities of Substitution between Different Commodities and Locations, as Reflected in Various Spatial Equilibrium Models.

Nested CES, CRESH and translog functions have been suggested to overcome the limitation of CES functions (Dervis et al (1980), Liew (1983), Whalley (1985), Isard and Dean (1987), Madden (1987)). The increased flexibility associated with the use of nested CES functions must be traded off against the increased data required to obtain parameter estimates. The Leontief approach of fixed coefficients (e.g. the IIO model) and the Cobb-Douglas function are special cases of the CES function (as depicted in Figure 3). By assuming unit elasticities and utilizing a Cobb-Douglas function, Liew and Liew (1984) developed a price equilibrium formulation which relaxes the rigidity of the IIO models without any increase in data needs.

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 recognized 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 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)).

2.4 A Classification of Spatial Flexprice Models

From the above, we may classify spatial flexprice models into four classes according to their use of inverse or ordinary supply/demand functions and their analysis of spatially homogeneous or heterogeneous commodities (see Figure 4).

	MARSHALLIAN FORMULATION	WALRASIAN FORMULATION
SPATIALLY HOMOGENEOUS COMMODITIES	Samuelson (1952) Takayama and Judge (1964)	Takayama and Woodland (1970) Friesz et al (1983)
SPATIALLY HETEROGENEOUS COMMODITIES		Shoven and Whalley (1974) Liew (1984) Buckley (1987)

Figure 4 A Classification of Spatial Flexprice Models

In this figure, some key references are also given. Note the recent tendency towards more model development activity in the bottom right hand corner (i.e. ICGE models). This reflects a growing awareness of the need to approximate the dispersed pattern of real trade flows, as well as the movement from partial equilibrium towards general equilibrium analysis in applied modelling. Regrettably, a similar tendency does not yet apply with respect to the development of solution algorithms. Although both SPE and ICGE models can be represented as nonlinear complementarity problems (Mathiesen (1985), Friesz et al (1983)), the bulk of the algorithmic effort expended by regional scientists has been concentrated on the SPE model and its derivatives (see, e.g. Dafermos (1980), Friesz et al (1983), Harker (1985), Nagurney (1987)).

3. COMBINED APPROACHES

In attempting to consolidate our discussion, it is evident that none of the four modelling traditions mentioned at the beginning of Section 2 are likely to be satisfactory for the detailed estimation of trade flows in all commodities throughout an entire world economy. Although the use of the classical SPE model will be inappropriate for trade in differentiated products, an "Armington" ICGE model is capable of catering for consumers' taste for variety.⁶⁾ Much of the explanation for observed patterns of crosshauling between similar products may be attributed to a taste for variety. Although individual preferences for regular variety may only apply to certain types of products, if a regional population consists of consumers with different views about the most desirable variety, there will still be a taste for variety in that population on aggregate. It is the existence of this taste for variety on aggregate which generates considerable crosshauling in trade flow patterns.

There would seem to be two plausible ways to proceed in order to make further progress. First, we could try to adopt different methods for the analysis of different commodities, only combining the results at the end. This approach corresponds roughly to the multimethod procedure described by Isard and Dean (1987). Second, we could try to improve the existing SPE framework by combining it with the best attributes of the other modelling traditions. This was the motivation for the integrated approaches mentioned near the outset of Section 2. We shall briefly discuss some examples of combined approaches which may be grouped under the heading "Dispersed Spatial Price Equilibrium" (DSPE) models.

6) Beginning with the work of Spence (1976) and Dixit and Stiglitz (1977), consumer preferences for commodity variety have generally been specified in the form of a concave and symmetrical **subutility** function $u_i(D_{i1}, D_{i2}, \dots)$, where D_{iw} is the quantity of variety w that is being consumed. In fact $u_i(\cdot)$ sometimes does take the CES form: $u_i(D_{i1}, D_{i2}, \dots) = (\sum_w D_{iw}^{\beta_i})^{1/\beta_i}$, $\beta_i = 1 - 1/\sigma_i$, $\sigma_i > 1$, where σ_i is the elasticity of substitution.

3.1 Dispersed Spatial Price Equilibrium (DSPE) Models

A desire to shore up some of the major deficiencies in the SPE model (see Section 2.2) has led to the development of some integrated approaches which generate a "dispersed" set of prices or flows and thus more realistic trade patterns (e.g. Batten and Johansson (1985), Bröcker (1988), Harker (1988)). In each of these frameworks, some version of the gravity model - with its firmly established theoretical foundation as a cost-efficient macro-based behavioural principle (Smith (1978)) - is combined with particular pricing mechanisms to produce a more dispersed result.

Each DSPE model takes the general form:

$$x^{rs} = y^{rs} \exp[\beta(\rho^s - v^r - h^{rs})] \quad (10)$$

where β is a parameter which may be interpreted as the marginal utility of profit when equation (10) is considered in its equivalent form of a logit model (Anas (1983), Batten and Boyce (1986)), and y^{rs} and ρ^s have different definitions for each model.⁷⁾ Their virtue is that they allow for varying degrees of dispersion around an equilibrium solution so as to reflect imperfections in the marketplace.

7) Harker's (1988) model is an unconstrained gravity trade model for which $v^r = v^r(q^r)$, $\rho^s = p^s(d^s)$ and $y^{rs} = \alpha^r \gamma^s q^r d^s$. It simulates a perfectly competitive market in which regional supplies q^r and demands d^r are determined endogenously, with the parameters α^r , γ^s and β being estimated from historical flow patterns. Bröcker's (1988) model also has $\rho^s = p^s$, but 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 h^{rs} . Both these models are Marshallian in nature and return to a SPE model as $\beta \rightarrow \infty$. By way of contrast, the Batten-Johansson (1985) model is Walrasian, with price constraints on buyers or sellers that are more typical of oligopolistic competition with product differentiation. In their case, the y^{rs} are estimated from historical flow patterns, and $\beta = \beta^s$ and ρ^s are Lagrange multipliers associated with supply/demand constraints in a marketplace where prices cover costs on average only. Thus we may have $p^s \leq v^r + h^{rs}$ yet $x^{rs} > 0$ for a few links (r,s) .

3.2 Increasing Returns, Differentiated Products and the Gravity Model

As we mentioned earlier, a parallel search for new theories to explain the effects of differentiated products, economies of scale and imperfect competition is currently underway among those international trade theorists who are less preoccupied with the spatial dimension. One such approach is to regard the Heckscher-Ohlin model of comparative advantage as the driving force for international specialization at the aggregate, sectoral level but to assume that scale economies cause specialization at the disaggregated level of individual products (see, e.g. Helpman and Krugman (1985, Chapter 7)). If the demand structure embraces a taste for variety and monopolistic competition prevails, then each region (nation) will produce different varieties of a product while every variety may still be demanded in all regions (nations). Thus differentiated products provide a simple rationale for the existence of cross-hauling and intraindustry trade. They are also an incentive for the existence of multinational firms (Lyons (1984)). From the spatial analysts viewpoint, they provide a further explanation for the empirical success of the gravity model.

In contrast to the standard Heckscher-Ohlin world economy (which focuses predominantly on differences in relative factor endowments), the existence of differentiated products implies an important relationship between the volume of trade and relative regional size. Consider the following popular version of the gravity trade equation:⁸⁾

$$x^{rs} = \beta_0 (Y^r)^{\beta_1} (Y^s)^{\beta_2} (d^{rs})^{\beta_3} (A^{rs})^{\beta_4} u^{rs} \quad (11)$$

where Y^r is the value of income or GDP in region r , d^{rs} is the distance between regions r and s , A^{rs} is any other factor(s) aiding or resisting trade between r and

8) This specification has been used, among others, by Tinbergen (1962), Poyhonen (1963), Pulliainen (1963), Geraci and Prewo (1977), and Bergstrand (1985).

s, and u^{rs} is a lognormally distributed error term with $E(\ln u^{rs})=0$. Typical estimates produce income elasticities, β_1 and β_2 , not too far from one and significantly different from zero (see, e.g. Aitken (1983), Anderson (1979)). Consolidation of the (r,s) terms leads to the simplified equation:

$$x^{rs} = \beta_0 Y^r Y^s (q^{rs})^{\beta_3} \quad (12)$$

in which Y^r "represents" the supply-related factors, Y^s the demand-related factors and q^{rs} the link-related factors. Whenever there is complete specialization in production - which is assured in the case of differentiated products - then identical homothetic preferences and access to the same prices by all consumers leads to the following:

$$x^{rs} = g^s Y^r = g^s f^r Y \quad (13)$$

where f^r denotes the fraction of every good produced in the (world) economy which is consumed by region r, with a fraction g^s of its output being exported to region s, and where $Y = \sum_r Y^r$.⁹⁾ This biproportional (or RAS) version of the gravity models allows the following proposition:

Proposition : If a group of industrial regions (countries) maintains an approximately fixed relative size in the world economy, then this group's own volume of trade will grow faster than the group's own income if and only if the relative size of these industrial regions (countries) becomes more equalized over time.

Proof (see also Helpman and Krugman (1985)): From (13) we know that the volume of interregional trade within a group of regions G, say VT_G , is given by

$$\begin{aligned} VT_G &= \sum_{r \in G} \sum_{s \in G} x^{rs} \\ &= \sum_{r \in G} \sum_{\substack{s \in G \\ s \neq r}} g_G^s f_G^r (Y_G)^2 / Y \end{aligned}$$

9) More detailed discussion of this model can be found in Helpman and Krugman (1985, Chapter 8).

where $Y_G = \sum_{r \in G} Y^r$ is the group's aggregate income or GDP and $f_G^r = Y^r/Y_G$ is the within group share of region r in income or GDP. Since we know that

$$\sum_{\substack{s \in G \\ s \neq r}} g_G^s = 1 - f_G^r$$

it then follows that

$$VT_G = f_G \left(1 - \sum_{r \in G} (f_G^r)^2 \right) Y_G$$

where f_G is the share of the group in world income or GDP. The expression within the square parentheses will be larger when regions (countries) are of equal size. If f_G is approximately constant over time, then the ratio VT_G/Y_G will grow larger as the regions grow closer in size.¹⁰⁾ This ends the proof.

The above formulae provide better approximations the greater is the degree of specialization or the larger is the relative importance of differentiated products industries. Economies of scale tend to lead to more specialization than would occur in a world of constant returns. Thus the gravity equation will tend to fit the trade pattern better the more significant are increasing returns. We have already presented some evidence denying the perfectly competitive market assumption, and thus implying the presence of scale economies (see part 2 of this paper). Further supporting evidence may be found in the work of industrial economists (e.g. Scherer (1980)) who have revised their evaluation of the importance of scale economies upwards. Recently, more subtle forms of scale economies have been recognized - such as dynamic scale economies of the "learning curve" type (see, e.g. Krugman (1984)). To some extent, these dynamic effects strengthen the notion that the usefulness of the gravity model may be greatest in making long-run projections of trade; when erratic fluctuations in exchange rates and discriminatory pricing strategies can largely be ignored (Isard and Dean (1987)). In the short and medium term may equilibrium models, extended to incorporate transportation and imperfect competition, be more useful tools.

10) This partly explains the observed fact that during the postwar period the volume of trade has grown faster than income. As noted in Helpman and Krugman (1985), the above relative regional size measure has increased among those industrial countries dominating world trade.

4. SPATIAL EQUILIBRIA AND TIME

Traditionally, general equilibrium models are based on simplifying assumptions typical of a perfectly competitive economy. In the previous sections we have noted the shortcomings of this approach to trade analysis, largely from a static perspective. The need for a more realistic theory grows even more pressing when we take the dynamics of the situation into account. Sunk costs in existing locations and production capacities create temporary spatial monopolies. They also serve partly as barriers to new entrants who are unwilling to spend heavily on new plant & capital equipment. Thus we may observe nonuniform profit levels and uneven cost differentials (in addition to those in transportation) between producers, contradicting most of the assumptions of a competitive economy.

In Takayama and Judge (1971), extremal SPE models with monopoly were solved; while Hashimoto (1985) and Harker (1985) adopted noncooperative and cooperative game-theoretic models so as to relax the assumption of price-taking actors and to focus on spatial advantages among producers. Other dynamic SPE models have also been proposed.

4.1 Vintage Models

A vintage production function (Johansson and Strömqvist (1981), Johansson and Westin (1986), Westin (1988)) has also been adopted to implant structural rigidities into the equilibrium framework. The vintage approach assumes that each sector consists of a set of establishments, denoted by τ or grouped according to their vintage τ . Each vintage produces a quantity $q^r(\tau)$, up to a given capacity, $\bar{q}^r(\tau)$. Existing vintages are assumed to have a fixed production technique of the Leontief type. A unit profit or quasi-rent (Marshall (1920)), $\pi^r(\tau)$, may be calculated at given prices.

In Figure 5, the supply curve of such a sector is depicted.

Figure 5 A Vintage Supply Function

The activity level of each establishment is obtained from the complementarity conditions:

$$w_{\tau}^r = \bar{q}^r(\tau) - q^r(\tau) > 0, \pi^r(\tau)w_{\tau}^r = 0, \pi^r(\tau) > 0 \quad (14)$$

Establishments producing at full capacity are earning a "scarcity" profit, while negative profits imply shut down. Hence the approach not only has a clear relation to the ideas of Marshall but also strong similarities to Ricardian land rent theory. New capacities, in the form of new techniques, may be introduced as new vintages in a putty-clay fashion. The new technique may be chosen from an ex-ante function, given the expected prices at the time of investment (Johansen (1972)). In Johansson and Westin (1986), the vintage approach is further related to product cycle theory and the dynamics of spatial flows.

The explicit consideration of investment in production capacities focuses our attention on the time horizon in equilibrium models. Discrete time equilibrium models may be seen as adiabatic approximations of a dynamic economy in

continuous time. Differences in the durability of capital, the speed of information diffusion and adaptability to changes in the environment, jointly determine the time it takes to reach a new equilibrium for different processes.

4.2 Slow-Fast Adjustments and Discontinuous Change

Given the length of the chosen time period, some processes may be regarded as invariant whereas others may reach their equilibrium within the given period. Deviants may establish a new equilibrium in a shorter space of time. This suggests that in trade modeling, various change processes need to be distinguished by their adjustment time. Consideration of the "slaving principle", as suggested by Haken (1987), may provide useful insights. The slaving principle implies an ordering of processes in accordance with their adjustment on a time scale from slow to fast. We may demonstrate this principle within the context of a medium term model for analysing trade and transportation by referring to Figure 6.

Figure 6: Nesting of Slow-Fast Adjustment Processes in a Dynamic Equilibrium Framework for Modelling Trade and Transportation

In such a model, the physical structure of the infrastructure network will change very slowly and thus it can be assumed as fixed. Together with some other slow adjustment processes, such as observed rigidities in the bilateral preferences of certain trading partners, the network structure may be treated as exogenous and will therefore delimit or "enslave" all other adjustment processes operating at a faster pace. Furthermore, any process which cannot be explained convincingly within the given modelling framework must also be treated exogenously. An example of this in the trade context might be such factor endowments as the supply of labour by location and skill category.

Endogenous treatment will apply to all those variables which affect the equilibrium of trade in the medium term. Marginal investments in capacity expansion and in link improvements, commodity supplies, intermediate and final demands, and interregional flows are included here. Embedded within this equilibrium solution will be all those fast adjustment processes which fluctuate more quickly than the endogenous group. Examples worth mentioning are the day-to-day peaks and troughs in traffic flow volumes, information exchange levels, commodity prices, exchange rates and other sensitive signals of supply-demand imbalances at a variety of scales.

When a relatively slow process - such as the evolution of network infrastructure - enters into a critical phase of transformation, this may result in a relatively swift and discontinuous shift in the value of certain parameters in the models at lower level (s). For example, the construction of a critical link (bridge, highway) in the transportation system may result in unexpectedly large changes in the equilibrium value of commodity production in certain locations. Such discontinuous and unbalanced development has been observed on many occasions in many different places, and assumes a more plausible status once the nonlinear nature of network interdependencies is fully appreciated. This type of dynamics has definite implications for changes in specialization and for other trade adjustment mechanisms.

Some dynamic effects are not discontinuous but rather counterintuitive. For example, Chichilnisky demonstrated that an oil importing region might benefit from an exogenous increase in the price of the oil it imports if, by paying more for oil imports, it increases the income of the oil exporter to such an extent that the oil exporter rapidly expands its imports from the oil importing region (see

Hartwick (1988)). Through such a bilateral substitution effect, the oil importer's economy may gain more revenue than it loses through increased payments for oil imports. Examples like this emphasize the importance of integrated approaches which take various (multi-commodity) adjustment mechanisms into account. In such models, differences in the time horizon may be accommodated by choosing appropriate elasticities for the pertinent parameters. The use of Leontief functions ought to be constrained to the short run, whereas price equilibrium models could extend to the medium term, and gravity models may prove superior for the long run (see also Isard and Dean (1987)). Different approaches for different commodities may also be appropriate in order to cater for substantial differences in market structures and adjustment mechanisms.

5. CONCLUSIONS

The nature and structure of trade between regions is changing fundamentally. Thus there is a need for our tools of trade analysis to change in a complementary manner. Regional science has tools to offer in the pursuit of explanations for this emerging trade regime, although very few regional scientists have taken up this challenge so far.

Among the four trade modelling traditions generally associated with regional science, we have identified some inherent weaknesses in the future applicability of the spatial price equilibrium (SPE) group. Not only do these models have a poor performance record when applied rigidly, but trade in homogeneous commodities of low freight value (where SPE models may provide reasonable estimates) is a steadily declining component of total international goods trade. The main virtue of SPE models may lie in their well-developed synthesis with network-based models of transportation (mode and route) choice.

In attempting to improve on these individual traditions currently driving the trade analysis work, a case can be made for combining their best attributes. Dispersed spatial price equilibrium (DSPE) models are one example of this approach, in which the gravity model provides a more realistic dispersal of flows and/or prices away from the rigid SPE "boundary" solution. Inclusion of the Armington assumption to introduce spatial heterogeneity is appropriate for a growing share of the commodity space, where the trend is towards an increasing taste for variety. ICGE models with recognition of market imperfections would be another example. Gravity models will also tend to fit the trade pattern better the more significant are increasing returns and differentiated products. Given the observable trends in the trade world today, considerable scope now exists for wider application of combined spatial interaction-equilibrium models by a greater number of regional scientists.

Nevertheless the ultimate challenge still awaits us: to unravel the dynamics of trade. Here as well the explanatory power of the gravity equation should not be underestimated. The existence of structural rigidities and the nesting of fast adjustment mechanisms within slower ones may certainly call for novel methods of nonlinear analysis, some of which have their roots in synergetics and dynamic systems theory. But beyond this lies a contextual need to fully understand the

dynamics of regional specialization in relation to demand, supply, networks of interaction and investment behaviour. Regional scientists are certainly needed to pull all the pertinent threads together.

REFERENCES

- Aitken, N.D. The Effect of the EEC and EFTA on European Trade: A Temporal Cross-Section Analysis. *American Economic Review*, vol. 63 (1973) 881-892.
- Anderson, J.E. A Theoretical Foundation for the Gravity Equation. *American Economic Review*, vol. 69 (1979) 106-116.
- Anas, A. Discrete Choice Theory, Information Theory and the Multinomial Logit and Gravity Models. *Transportation Research B*, 17B (1983) 13-23.
- Armington, P.S. "A Theory of Demand for Products Distinguished by Place of Production". *IMF Staff Papers* (1969).
- Arrow, K.J. and G. Debreu. Existence of an Equilibrium for a Competitive Economy. *Econometrica*, vol. 22 (1954) 265-290.
- Batten, D. and D. Boyce. Spatial Interaction, Transportation, and Interregional Commodity Flow Models. In Nijkamp, P. (ed.) *Handbook of Regional and Urban Economics*, vol. I. (Amsterdam: North-Holland 1986).
- Batten, D. and B. Johansson. Price Adjustments and Multiregional Rigidities in the Analysis of World Trade. *Papers of the Regional Science Association*, vol. 56 (1985) 145-166.
- Bergstrand, J.H. The Gravity Equation in International Trade: Some Micro-economic Foundations and Empirical Evidence. *The Review of Economics and Statistics*, vol. 67 (1985) 474-481.
- Bröcker, J. Interregional Trade and Economic Integration. A Partial Equilibrium Analysis. *Regional Science and Urban Economics*, vol. 18 (1988) 261-281.
- Buckley, P.A. An Interregional Computable General Equilibrium Model for National - Regional Policy Impact Analysis. (Umeå: CERUM Working Paper 1987:5).
- Dafermos, S. Traffic Equilibrium and Variational Inequalities. *Transportation Science*, vol. 14 (1980) 42-54.
- Debreu, G. *The Theory of Value*. (New York: Wiley, 1959).
- Dervis, K., J. de Melo and S. Robinson. *General Equilibrium Models for Development Policy*. (New York: Cambridge University Press, 1982).
- Dixit, A.K. and V. Norman. *Theory of International Trade*. (Cambridge University Press, 1980).
- Dixit, A.K. and J.E. Stiglitz. Monopolistic Competition and Optimum Product Diversity. *American Economic Review*, vol. 67 (1977) 297-308.
- Friesz, T.L., R.L. Tobin, T.E. Smith and P.T. Harker. A Nonlinear Complementarity Formulation and Solution Procedure for the General Derived Demand Network Equilibrium Problem. *Journal of Regional Science*, vol. 23 (1983).

Geraci, V.J. and W. Prewo. Bilateral Trade Flows and Transport Cost. **The Review of Economics and Statistics**, vol.59 (1977) 67-74.

Ginsburgh, V.A. and J.L. Waelbroeck. **Activity Analysis and General Equilibrium Modelling**. (Amsterdam; North-Holland, 1981).

Greenhut, M.L., Norman, G. and C-S Hung. **The Economics of Imperfect Competition: a Spatial Approach** (Cambridge University Press, 1987).

Haken, **Advanced Synergetics**. (Berlin, Heidelberg: Springer-Verlag, 1987).

Harker, P.T. (ed.) **Spatial Price Equilibrium: Advances in Theory, Computation and Application**. (Berlin, Heidelberg: Springer-Verlag 1985).

Harker, P. Dispersed Spatial Price Equilibrium. **Environment and Planning A**, vol. 20 (1988) 353-368.

Hartwick, J.M. and M. Spencer. An Oil-Exporting versus an Industrialized Region. In: Å.E. Andersson, D.F. Batten, B. Johansson and P. Nijkamp (eds.) **Advances in Spatial Theory and Dynamics** (Amsterdam: North-Holland 1988).

Hashimoto, H. A Spatial Nash Equilibrium Model. In: Harker, P.T. (ed.) **Spatial Price Equilibrium: Advances in Theory, Computation and Application**. Lecture Notes in Economics and Mathematical Systems, 249. (Berlin, Heidelberg: Springer-Verlag 1985).

Helpman, E. and P.R. Krugman. **Market Structure and Foreign Trade**. (Cambridge, Massachusetts: The MIT Press, 1985).

Hewings, G.J.D. and R.C. Jensen. Regional, Interregional and Multiregional Input-Output Analysis. In Nijkamp, P. (ed.) **Handbook of Regional and Urban Economics**, vol I. (Amsterdam: North-Holland, 1986).

Hicks, J.R. **Capital and Growth** (Oxford University Press, London, 1965).

Higgs P.J., B.R. Parmenter and R.J. Rimmer. A Hybrid Bottoms-up Regional Computable General Equilibrium Model. Working Paper from the Impact Project at the University of Melbourne (1987).

Isard, W. Interregional and Regional Input-Output Analysis: A Model of a Space-Economy. **The Review of Economics and Statistics**, vol. 33 (1951) 318-328.

Isard, W. and W. Dean. The Projection of World (Multiregional) Trade Matrices. **Environment and Planning A**, vol. 19 (1987) 1059-1066.

Isard, W. and Ostroff, D.J. Existence of Competitive Interregional Equilibrium. **Papers and Proceedings of the RSA**, vol. 4 (1958) 49-76.

Johansen, L. **A Multisectoral Study of Economic Growth**, (Amsterdam: North-Holland 1960).

Johansen, L. **Production Functions**, (Amsterdam: North-Holland 1972).

Johansson, B. and U. Strömquist. Regional Rigidities in the Process of Economic Structural Development. **Regional Science and Urban Economics**, vol. 11 (1981).

Johansson, B. and L. Westin. Technical Change, Location and Trade. **Papers of the Regional Science Association**, vol. 62 (1987) 13-25.

Judge, G.G. and T. Takayama (eds.) **Studies in Economic Planning over Space and Time**, (Amsterdam: North-Holland, 1973).

Krugman, P. Import Protection as Export Promotion: International Competition in the Presence of Oligopoly and Economies of Scale. In: Kierzkowski (ed.). **Monopolistic Competition and International Trade**, (Oxford: Clarendon Press, 1984).

Kuenne, R. E. **The Theory of General Economic Equilibrium**, (Princeton: Princeton University Press, 1963).

Kuenne, R.E. The Dynamics of Oligopolistic Location: Present Status and Future Directions. In: A.E. Andersson et. al. (eds.). **Advances in Spatial Theory and Dynamics** (Amsterdam: North-holland, 1988).

Liew, L.H. A Johansen Model for Regional Analyses. **Regional Science and Urban Economics**, vol. 14 (1984) 129-146.

Liew, C.K. and C.J. Liew. Multi-Modal, Multi-Output, Multi-Regional Variable Input-Output Model. **Regional Science and Urban Economics**, vol. 14 (1984) 265-281.

Lyons, B.R. The Pattern of International Trade in Differentiated Products: An Incentive for the Existence of Multinational Firms. In: H. Kierzkowski (ed.) **Monopolistic Competition and International Trade**, (Oxford: Clarendon Press, 1984).

Madden, J.R. **The Structure of the Tasmain Model**, IAESR, University of Melbourne (1987).

Mathiesen, L. Marginal Cost Pricing in a Linear Programming Model: A Case with Constraints on Dual Variables. **Scandinavian Journal of Economics**, (1977) 468-477.

Mathiesen, L. Computation of Economic Equilibria by a Sequence of Linear Complementarity Problems. **Mathematical Programming Study** 23, (1985) 144-162.

Nagurney, A. Competitive Equilibrium Problems, Variational Inequalities and Regional Science. **Journal of Regional Science** vol. 27, (1987) 503-517.

Ohlin, B. **Interregional and International Trade**. (Cambridge: Harvard University Press, 1933).

Peschel, K. On the Impact of Geographic Distance on the Interregional Patterns of Production and Trade. **Environment and Planning A**, vol. 13 (1981) 605-622.

Samuelson, P.A. Spatial Price Equilibrium and Linear Programming. **American Economic Review**, vol. 42 (1952) 283-303.

Scarf, H. (With T. Hansen) **The Computation of Economic Equilibrium**. (New Haven, Conn.: Yale University Press 1973).

- Scherer, F. **Industrial Market Structure and Economic Performance** (Chicago: Rand McNally, 1980).
- Sheppard, E. and L. Curry. Spatial Price Equilibria. **Geographical Analysis**, vol. 14 (1982) 279-304.
- Shoven, J.B. and J. Whalley. On the Computation of Competitive Equilibrium on International Markets with Tariffs, vol. 4 (1974) 341-354.
- Shoven, J.B. and J. Whalley. Applied General-Equilibrium Models of Taxation and International Trade. An Introduction and Survey. **Journal of Economic Literature**, vol. 22 (1984) 1007-1051.
- Smith, T.E. A Cost-Efficiency Principle of Spatial Interaction Behaviour. **Regional Science and Urban Economics**, vol.8 (1978) 313-338.
- Spence, M.E. Product Selection, Fixed Costs, and Monopolistic Competition. **Review of Economic Studies**, vol. 43 (1976) 217-236.
- Srinivasan T.N. and J. Whalley (eds.). **General Equilibrium Trade Policy Modelling**, (Cambridge, Mass.: The MIT Press, 1986).
- Suknam, Ko and G.J.D. Hewings. A Regional Computable General Equilibrium Model for Korea. **Korean Journal of Regional Science**, vol. 2 (1987).
- Takayama, T. and G.G. Judge. Equilibrium among spatially separated markets. A Reformulation. **Econometrica**, vol. 32 (1964) 510-524.
- Takayama, T. and G.G. Judge. **Spatial and Temporal Price and Allocation Models**, (Amsterdam: North-Holland, 1971).
- Takayama, T.H. Hasimoto and N.D. Uri. Spatial and Temporal Price and Allocation Modelling: Some Extensions. **Socio-Econ. Plan. Sci.**, vol. 18 (1984) 227-234.
- Takayama, T. and W.C. Labys. Spatial Equilibrium Analysis. In Nijkamp, P. (ed.) **Handbook of Regional and Urban Economics**, vol. I. (Amsterdam: North-Holland, 1986).
- Takayma, T. and A.D. Woodland. Equivalence of Price and Quantity Formulations of Spatial Equilibrium: Purified Duality in Quadratic and Concave Programming. **Econometrica**, vol. 38 (1970) 889-906.
- Tinbergen, J. **Shaping the World Economy: Suggestions for an International Economic Policy** (New York: Twentieth Century Fund, 1962).
- Whalley, J. **Trade Liberalization among Major World Trading Areas**. (Cambridge, Mass.: The MIT Press, 1985).
- Westin, L. An Applied Short Run Interregional Equilibrium Vintage Model. Forthcoming in **Australian Journal of Regional Studies** (1988).

- 179 Sarafoglou, Nikias : A contribution to population dynamics in space, 1987.
- 180 Löfström, Åsa: Könsdiskriminering på arbetsmarknaden - en kvantitativ analys, 1988.
- 181 Andersson, Åke och Kobayashi, Kiyoshi: Some Theoretical Aspects of Spatial Equilibria with Public Goods, 1988.
- 182 Ohlsson, Henry: Cost-Benefit Analysis of Labor Market Programs - applied to a temporary program in northern Sweden, 1988.
- 183 Zhang, Wei-Bin: Limit Cycles in an Optimal Employment Policy Model, 1988.
- 184 Zhang, Wei-Bin: Oscillations of Population Migration in Developing Countries, 1988.
- 185 Karlsson, Charlie: Innovation Adoption and a Product Life Cycle, 1988.
- 186 Engström, Lars, Löfgren, Karl-Gustaf and Westerlund, Olle: Intensified Employment Services, Unemployment Durations, and Unemployment Risks, 1988.
- 187 Aronsson, Thomas: Progressive Income Taxation and the Supply of Roundwood, 1988.
- 188 Ohlsson, Henry: Beredskapsarbeten 1970-1987 - sysselsättning, anslag, utgifter och kostnader, 1988.
- 189 Löfgren, Karl-Gustaf: Buying and Selling Behavior in Stochastic Environments with Back-Stop Markets, 1988.
- 190 Zhang, Wei-Bin: Spatial and Temporal Urban Pattern: Interpretations of the FitzHugh-Nagumo Equations, 1989.
- 191 Zhang, Wei-Bin: Urban Structural Changes in Continuous Time and Space, 1989.
- 192 Löfgren, Karl-Gustaf, Ranneby, Bo and Sjöstedt, Sara: Forecasting the Business Cycle Using Min/Max Autocorrelation Factors, 1989.
- 193 Ohlsson, Henry: Job Creation Measures as Activist Fiscal Policy - an empirical analysis of policy reaction behavior, 1989.
- 194 Batten, David and Westin, Lars: Modelling Commodity Flows on Trade Networks: Retrospect and Prospect, 1989.