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PRICES AND QUANTITIES IN SPATIAL ACTIVITY MODELS
Between Engineering and Economics*

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1. Introduction

Major infrastructure investments, particularly in transportation, can not only considerably reduce interregional transport costs and delivery times, but can also facilitate face-to-face business contacts. Thus, such investments can influence the comparative advantage of regions and countries over wide sections of the economy. This implies that major projects should not be evaluated in isolation, but within a coordinated framework of economy-wide analysis. Such a framework should therefore encompass Computable General Equilibrium (CGE), or at least, partial equilibrium. In practice, this analysis needs to be generalised to handle infrastructure planning, where the interdependencies created by transport and communication networks must be recognised explicitly. This calls for inter-disciplinary contributions from engineering and economics.

Physical scientists and engineers working in the field of infrastructure planning have mainly concentrated on development of models which determine network flows, as well as the associated supply required at trip origins and the demand expected at trip destinations. The models are of the [production cost + transport cost] minimising type, with calibration possible if a structured 'dispersion' is introduced with respect to pure cost-minimising behaviour. For instance, gravity models based on entropy maximisation have produced quite reliable forecasts of interregional and international trade flows, as shown by Wilson[1] and Nagy[2]. However, when modelling the behaviour of firms, this cost criterion is only plausible in terms of depicting profit maximisation if the origin (fob) prices are everywhere constant. Due to both product differentiation and spatial income variability, prices for the same class of commodity can vary marketly between regions and countries. Thus, the required models need not only to be based on profit maximisation with spatially differentiated prices, but mechanisms need to be introduced to handle endogenous price adjustments over time.

In modelling the flows, prices, regional supplies and demands for single commodities, economists have developed the framework of Spatial Price Equilibrium (SPE), as described in Takayama and Judge[3]. Although this framework has been generalised to include imperfect competition and dynamics in recent work, such as in Nagurney[4], it suffers from the weakness of its deterministic structure. For instance, in the competitive model, most flows turn out to be zero, with non-zero flows from any origin occurring only to the region(s) with the lowest delivered (cif) price. Also, cross-hauling is intrinsically impossible, that is, the existence of a non-zero flow from region r to region s implies zero flow from region s to region r. Whilst this approach sometimes works reasonably for trade in relatively homogeneous goods, it not only works poorly for the increasing volume of trade involving more differentiated goods and markets, but also is not capable of calibration in any way to try to 'fit' the observed patterns. Thus, if network infrastructure were to be evaluated by integrating the SPE model structure into an interregional CGE model framework, the combined model would still suffer the weaknesses described above. In other words, the key deterministic assumption in the SPE model that regional production is performed by an aggregation of identical firms with perfect information must be replaced by a more realistic criterion which also allows calibration to observed quantities and prices.

It is not surprising that scholars under the unifying mantle of *Regional Science* were the first to attempt to overcome the empirical limitations of the SPE model. In 1985, Batten and Johansson[5] developed a trade model where cross-hauling and dispersed flows were produced. This became recognised as the first major contribution to a new class of model called Dispersed Spatial Price Equilibrium (DSPE) models. Further contributions came from Bröcker[6], who developed a model to analyse the effects of European integration on European trade. Harker[7] introduced an explicit transport network into the analysis and Roy[8] generalised the model to handle uniform delivered pricing, where the producers pay the transport and tariff costs. In parallel with these developments in DSPE models to more realistically depict interregional flows, others were attempting to include transport network analysis in an interregional CGE framework. This includes current work in Italy by Roson and Vianelli[9], as well as ongoing work in Japan by Miyagi[10] and Okuda and Hayashi[11]. Finally, the recognition of some commodity flows as representing the transport of intermediate inputs to another sector has resulted in the development of calibrated production functions by Miyagi[12] and calibrated input demand functions by Roy[13], as required for a more calibration-based interregional CGE model framework. In this brief paper, the first section will deal with recent advances in DSPE models, especially those carried out by the author and his colleagues. The final section will discuss efforts to develop a calibrated interregional CGE model framework adapted to the requirements of evaluation of the economy-wide impacts of major infrastructure investments, as well as summarising some remaining challenges.

2. Price-Responsive Commodity Flow and Location Models

At the outset, it should be stated that the classical DSPE framework, as described by Bröcker [6], consists of three major components:

(i) exogenously given supply functions for each region
(ii) exogenously given demand functions for each region
(iii) an abstract dispersed exchange mechanism linking (i) and (ii), expressed relatively in terms of either regional demand shares or regional supply shares.

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These three components usually permit determination of a dispersed spatial price equilibrium. In order to develop the DSPE model framework further, certain key properties are listed, including recent efforts at improvement in each area.

(1) The exchange process

In practice, the exchange of goods between buyers and sellers is often carried out via intermediate exchange agents, who should be perceived as profit-maximisers who both buy and sell. The quantities which they handle must thus be directly price-responsive, and not just shares of some given total. This means that, in such cases, the classical DSPE exchange mechanism summarised in (iii) above is inadequate. In Roy and Johansson[14], exchange agent behaviour is expressed as a true economic model, with flexible exchange quantities. This specification has the advantage that it allows determination of two sets of prices, one related to equilibrium between the producers and the exchange agents, and the other to equilibrium between the exchange agents and buyers-consumers. This permits price mark-ups or mark-downs, circumventing the rigid exogenous relationship between origin (fob) and destination (cif) prices, which cannot account for different consumer budgets in different regions/countries.

(2) Regional supply functions

One disadvantage of the classical DSPE (or SPE) approach is that the aggregate regional supply (and demand) functions must be provided exogenously. However, as discussed by Hotelling[15], the generic form of such aggregate supply functions can be regarded as logistic, reflecting the different efficiency levels of the firms producing the good in a region or (sometimes) the different 'vintages' of plant within a large establishment. If it is possible to enumerate all the available production capacity for the good in each region and to determine average costs and prices, the use of entropy with all the available units of production capacity defined as distinguishable yields aggregate regional supply functions with a logistic form [Roy and Johansson[14]]. In cases of uniform delivered pricing, where the producers pay the transport costs and tariffs, the above procedure yields non-separable dispersed spatial supply functions.

(3) Regional demand functions

a)Differentiated goods

In modelling trade in differentiated goods, a relatively high selling price of a good may not deter sales if the good is also perceived as of high value. In these cases, the classical DSPE model must be broadened to model the surplus between willingness-to-pay and price in a dispersed sense. The willingness-to-pay values can be obtained, à la Lancaster, in terms of relevant characteristics of the good, using a log-linear approach, as described in Roy and Johansson[14].

b)Choice and demand

Although Hotelling[15] justified logistic forms of aggregate demand functions, it is difficult in practice to establish a demand capacity limit, which was instrumental in obtaining the supply functions in terms of a supply capacity[14]. Instead, it is suggested that recent work by Morisugi *et al.* [16] be adapted to this task. In that work, multinomial logit choice models are expanded into spatial demand functions by introduction of a composite good and a corresponding budget constraint. This procedure would yield dispersed demand functions within a framework which allows calibration.

(4) Congestion-sensitive demand

In a recent paper, Erlander and Lundgren[17] introduced a dispersed model of exchange agents, where the volume exchanged is endogenous, with an upper bound dependent on the level of congestion in the transport network. This is the first model in the DSPE class to introduce congestion feedback.

(5) Direct bargaining arrangements

For some goods, sales are performed directly by the producer firm to the buyers, without the intervention of exchange agents. Of course, shippers may still be required, but their role is more limited, and does not involve price mediation. For uniform delivered pricing, the producer model is a true spatial model, as illustrated in Roy[18]. The converse is true for mill pricing, where the buyers pay the transport costs and tariffs, and whose behaviour is thus depicted spatially.

(6) Imperfect competition

Whilst Miyagi[19] and Nagurney[4] expanded the SPE framework to include imperfect competition, the only related work for DSPE models is by Roy[20]. It turns out that if the demand functions can be represented as singly-constrained spatial interaction models, they are analytically invertible to express price as a function of flow quantities. This simplifies the numerical solution for the oligopolistic equilibrium, either of the Cournot or Stackelberg type. On the other hand, these models are confronted with the same difficulties facing most modelling of imperfect competition, including the multiplicity of possible collusive arrangements and conjectures about the behaviour of competitors.

(7) Production scale economies

Although production scale economies can be handled in models of imperfect competition, there do not seem to have yet been concerted efforts to do so in the DSPE tradition. However, there is a wide body of literature on such topics by the trade economists, such as by Helpman and Krugman[21] and Krugman[22]. Such work must be opened up to the engineering and regional science communities if agglomeration effects are to be identified in interregional trade.

3. Interregional CGE Models for Infrastructure Planning

In evaluation of major infrastructure investments, there is interest in the relative regional impacts, as well as the impacts on the country's overall competitive position. Clearly a multi-sector and multi-region model is required to account for both sectoral and spatial interdependencies. The parameters of such a model should be capable of calibration on observed data. Also, with a workable dynamic disequilibrium framework not yet developed to an operational level, a lagged sequential dynamic approach should be used. In the author's opinion, a fully satisfactory interregional CGE model for infrastructure planning still awaits development. Nevertheless, the potential unification of key elements of some recent contributions[9,10,11,12,13] may eventually yield a flexible and tractable model. The highlights of these contributions are now summarised.

(1) Contribution of Rosen and the Italian group

In Italy, the Italian National Research Council is currently funding a major project on development of a general modelling system for freight transport. This is an interdisciplinary project, with an economist team led by Roson and a civil engineering team led by Cascetta. Whilst interregional trade is modelled by the Chenery-Moses approach with coefficients estimated via a RAS procedure applied to O-D freight flow matrices, CRESH production functions are used to simulate interindustrial substitution processes. This allows estimation of interindustral substitution elasticities at the national level. The network assignment model simulates a Nash equilibrium among freight shippers. Although dispersion is not introduced in a unified way into the input/output formulation, the Italian set of models may currently be the most advanced in integrating interregional transport investment into a CGE framework.

(2) Contributions by Miyagi

a) An entropy production function

In development of an entropy production function from the dispersed profit maximising behaviour of firms, Miyagi[12] developed a form which can be calibrated on real data. By attributing the stochastic effects in the profit maximising behaviour of firms just to the production function, he has assumed implicitly that the cost part of the profit relation, that is the cost of intermediate and factor inputs, is deterministic, and not subject to averaging error when the firms are aggregated to regions. The reasonableness of this assumption would need to be tested empirically. A statistical model of the technological transformation of inputs to output in each sector within a region is an alternative approach, which may not only overcome the limitations of the classical production functions, but avoid the cost homogeneity assumption in Miyagi's procedure.

b) An urban CGE model for land use/transport planning

In Miyagi[10], a spatial CGE approach is applied to the land-use/transport allocation problem within an urban region. This transcends the restrictive input/output approach which has been linked with the classical Lowry model by previous authors. In particular, CES production functions are introduced and transport agents or shippers are identified explicitly. Also, different calibration procedures are applied to the different submodels. Currently, there is no proof of convergence to a unique equilibrium and the model just projects from a 'before' state to one 'after' state. An extension to a lagged sequential dynamic approach would not be difficult.

(3) Contributions by Okuda and Hayashi

Okuda and Hayashi[11] have included the dispersed approach comprehensively throughout their formulations. Their DSPE model in the first part of the paper represents a further development of the work of Bröcker[6]. The second part of the paper formulates a probabilistic interregional input/output model using the regional input/output coefficients as input data. This approach allows calibration of flow parameters and uses readily available data. In the third section on a probabilistic multiregional CGE model, the behaviour of households and traders is included. However, there is a difficulty in the use of land consumption by households when <u>averaged</u> across a region - this quantity may have very large variance across the urban area of cities in the region. One approach may be to apply the urban model of Miyagi[10] in a bottom up sense with the multiregional model. The unit consumption of land could then be treated as a stochastic variable in the multi-regional model or its values chosen within a microsimulation framework. This is a challenging area for future research.

(4) Contribution by Roy

Although the DSPE models just deal with supply, transport and demand for a certain commodity, the dispersed approach is potentially applicable at the earlier level of determination of the input demand functions of firms within a given sector in a given region. Whereas the costs of inputs and the associated tariffs and transport costs to bring the inputs to the regions of production can be recognised explicitly in the input demand approach, they are coalesced into a single cost function in the DSPE approach when the commodity is a finished good (final demand). In other words, the DSPE models just consider explicit transport costs and tariffs for the commodity being modelled, without being able to identify the prices, transport costs and tariffs of the intermediate inputs, which influence the prices of the final goods. For this reason, Roy[13] has generalised the dispersed approach at the input demand level, allowing for the varying prices, tariffs and transport costs of the intermediate inputs. However, at this level, it is necessary to introduce production functions into the analysis. This has been performed for the case of linear production functions, as well as for a non-spatial national or regional analysis based on the input-output production function. Extensions to non-linear production functions such as Cobb-Douglas and CES are just partially developed. As before, the advantage of the dispersed approach is that it allows <u>calibration</u> of certain model parameters to fit observed flows and prices. The next major step is to use the spatial supply functions emerging from the work of Roy[13], together with the spatial demand functions described earlier for final demand, to obtain a dispersed multi-sectoral interregional equilibrium.

(5) Towards a unification

Clearly, much can be gained by a deeper and more detailed comparison of the relative merits of the contributions (1) to (4). One unifying element is the inclusion of dispersion or a probabilistic representation. However, this is used at different levels by different authors, and some empirical work should be done to check in which areas dispersion is most critical for reliable prediction. Whilst we are in the process of development of interregional CGE models, we should nevertheless cast our minds forward to eventually embrace a dynamic disequilibrium framework. Unfortunately, space limitations have precluded a comprehensive review of this important field, with the comparisons being restricted to description, and not reinforced by overt mathematical analysis.

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