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Pitfalls and solutions in the application of spatial computable general equilibrium models for transport appraisal

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Pitfalls and solutions in the application of spatial computable general equilibrium models for transport appraisal

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Abstract

The use of spatial equilibrium models for assessing the economic impacts of transport projects is one of the key items on the research agenda for project appraisal in the Netherlands. These models are particularly suitable to analyse indirect effects of transport projects through linkages between the transport sector and the wider economy (i.e. the transport using sectors). Potentially, according to the literature, these impacts can turn out to be up to 40% in magnitude of the direct impacts. There is, however, no general indication that indirect effects are always of this magnitude - this has to be proven on a case-by-case basis. After two years of applications of SCGE models for transport appraisal, we found that the conventional specification of spatial equilibrium models can lead to problems in project appraisal in terms of inaccuracies in the assessment of impacts. This paper discusses how to fine-tune these models to allow an accurate assessment of these indirect effects. These ideas should be of value for those practitioners or researchers who are developing SCGE applications for use in transport appraisal.

1 Background and objective of the paper

In the last decade, the use of spatial computable general equilibrium (SCGE) models for assessing the economic impacts of transport projects has become one of the key items on the research agenda for project appraisal, world-wide. These models are particularly suitable to analyse indirect effects of transport projects through linkages between the transport sector and the wider economy (i.e. the transport using sectors). Potentially, according to the literature, these impacts can turn out to be up to 40% in magnitude of the direct impacts. There is, however, no general indication that indirect effects are always of this magnitude - this has to be proven on a case-by-case basis.

After two years of applications of SCGE models for transport appraisal, we find that the conventional specification of spatial equilibrium models can lead to problems in project appraisal in terms of inaccuracies in the assessment of impacts. Our paper discusses these issues and proposes ways of improving these models. These ideas should be of value for those practitioners or researchers who are developing SCGE applications for use in transport appraisal.

After a short introduction to SCGE modelling and its use for transport policy analysis (Section 2) we discuss some pitfalls and, where appropriate, propose alternative specifications (Section 3-6). We summarise our findings and recommendations in section 7.

2 The advantages of SCGE modelling for transport appraisal

2.1 Introduction

There is a large amount of literature on the economic impacts of infrastructure (see Blonk, 1979, Rietveld and Bruinsma, 1998, for overviews) as well as a large variety of methods to estimate these impacts (see Oosterhaven, Sturm and Zwaneveld, 1998, Rietveld and Nijkamp, 2000, for overviews). The methods most used are the following:

- micro surveys with firms,
- estimations of quasi production functions,
- partial equilibrium potential models

- macro and regional economic models,
- land use/transportation interaction (LUTI) models, and
- spatial computable general equilibrium (SCGE) models.

SCGE models typically are comparative static equilibrium models of interregional trade and location based in microeconomics, using utility and production functions with substitution between inputs. Firms often operate under economies of scale in markets with monopolistic competition of the Dixit-Stiglitz (1977) type. The few empirical applications of this approach are Venables and Gasiorek (1996) and Bröcker (1998). Interesting theoretical simulations with a SCGE model with a land market are found in Fan *et al.* (1998). These models are part of the new economic geography school (Krugman, 1991, Fujita, Krugman and Venables, 1999) and have been around for less than a decade. In other words, we are comparing a mature methodology, possibly at the end of its life cycle, and a new methodology that is still in its infancy.

The present, still young SCGE models have opposite properties, namely a lack of detail and sound empirical foundation, but a sophisticated theoretical foundation and rather complex, non-linear mathematics. The latter is precisely the reason why SCGE models are able to model (dis)economies of scale, external economies of spatial clusters of activity, continuous substitution between capital, labour, energy and material inputs in the case of firms, and between different consumption goods in the case of households. Moreover, monopolistic competition of the Dixit-Stiglitz type allows for heterogeneous products implying variety, and therefore allows for cross hauling of close substitutes between regions.

Due to the fact that SCGE models are comparative static models, their main strengths in transport appraisal lie in the comparison of outcomes of different equilibrium states, such as:

- Benefits of generalised transport cost reductions due to changing prices, production, consumption and trade, while holding the number of workers per region constant; showing what could be labelled as the short-run effects, or the ‘planned’ effects considering the governments housing policy.

- Benefits when the number of workers is allowed to change too, showing the long-run effects of new transport infrastructure.

Below we discuss the basic characteristics of a typical SCGE model developed in the Netherlands (see Oosterhaven *et al*, 2001).

2.2 The RAEM model

Following recommendations from the Dutch OEEI study (Eijgenraam *et al*, 2000) concerning guidelines for Cost Benefit Analysis of transport projects, we have recently developed a new spatial CGE model (RAEM) for the Netherlands, tailored towards applications in transport project appraisal. Below we give the basic specification of the model based on (Oosterhaven *et al*, 2001). Further in the paper, we return to specific parts of this model, which deserve additional commenting. We show how the specification should be interpreted and how it can be improved.

In the RAEM model we assume that all markets are of the monopolistic competition type and each firm in each industry produces one and only one variety of the product of that industry. In all production and utility functions the varieties x_i are added to an aggregate Q_j with the following CES-function (see Dixit and Stiglitz, 1977):

$$Q_j = \left(\sum_{i=1}^n x_i^{1-1/s} \right)^{1/(1-1/s)} \quad (4)$$

In (4) s represents the elasticity of substitution among the n different varieties of industry j . All utility and production functions have a Cobb-Douglas specification. The production function only uses intermediate inputs and labour:

$$Y_j = L_j^a \left(\prod_{i=1}^m Q_i^{g_i} \right)^{1-a} \quad (5)$$

In (5) parameter a controls the division between labour and the total of the intermediate inputs and g_i gives the relative weight among the intermediate inputs from different sectors.

In the equilibrium all prices are a function of all other prices. In this solution the complement of the quantity aggregate (4) is the following price index function:

$$G_j(p_{1j}, \dots, p_{nj}) = \left[\sum_{i=1}^n p_{ij}^{1-s} \right]^{1/(1-s)} \quad (6)$$

In (6) p_{ij} is the price of variety i in sector j . This price index varies across different regions, as these purchasing prices are inclusive of the transport and communication cost of delivering the product.

In the monopolistic competition equilibrium, prices are a mark-up over marginal costs, including the transport costs. Thus, the way in which transport costs are included in the prices is decisive for the functioning of our model. We have followed standard practice and introduce transport costs as a mark-up over the regular f.o.b. price. Specifically, in view of the problem at hand, RAEM uses a new bi-modal (people/freight) transport cost mark-up:

$$p^* = [f_g(d_g)]^p \cdot [f_p(d_p)]^{1-p} \cdot p \quad (7)$$

In (7) p gives the importance of freight transport for the transportation costs of the sector at hand. Information on this parameter proved to be scarce. Hence, expert judgement was used to ‘guestimate’ the 14 sectoral p ’s needed. In (7) f follows the usual specification of *iceberg* transport cost (see e.g. Bröcker, 1998):

$$f(d) = 1 + \mathbf{J} \cdot d^w \quad (8)$$

In (8) u and w are parameters to be estimated and d is the distance between the producer and the customer. For freight, simple road kilometres used as distances do not change in the application. A new railway link for passenger transport is modelled as a decrease in ‘people-distance’ d_p .

2.3 Typical problems in the development of RAEM

After two applications of the multisector RAEM model to major Dutch transport infrastructure schemes, a number of lessons have emerged with respect to the applicability of such models to transport appraisal. These lessons concern, in broad

terms, the specification of the relations between the transport system and the spatial economic system of production, consumption and trade. More specifically, they have to do with

- Interfacing problems between SCGE and transport models
- The modelling of the influence of transport costs on sectoral production
- The interpretation of the conventional, micro-level specification of product variety in aggregate applications
- The problem of irrational agglomeration effects in economic activities

We treat these issues in more detail within Sections 3-6 of the paper.

3 On the interface between SCGE and transport models

3.1 Introduction

The transport system enters the spatial economy through the costs of transport services. Typically, in transport evaluation practice transport models are applied to feed SCGE models with cost changes in the transport sector as a result of policy measures. This section treats practical difficulties that can arise when linking SCGE models with transport models. Our assumption is that SCGE models treat spatial interactions between regions, based on a description of their production and consumption, and do not describe the choices made with respect to alternative services offered within the transport system. This is the main reason for complementarity between transport and SCGE models.

We also describe some problems that haven't yet been solved – and cannot be on the short term – due to limitations in data availability. Our aim here is to gain clarity in conceptual terms of how these modelling difficulties arise and to raise a discussion about how these could be solved.

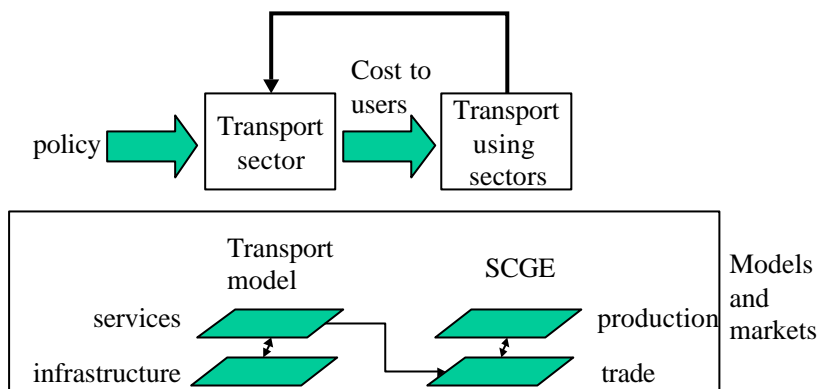


Figure 1: Linking scheme for the transport and SCGE models

Linking these models can reveal problems that are not visible when one only considers one type of model. They are however in part well known to the Land Use-Transport Interaction or LUTI type models (see e.g. Wilson, 1998). In part, as these models do not share the rigorous economic framework of CGE models (see Oosterhaven *et al*, 2001 for a discussion). We treat the following common problems:

- differences in linkages required between freight and passenger transport
- the choice of a correct specification of the costs of transport
- possible inconsistencies between SCGE and transport models in the description of trade patterns

3.2 *Transport costs by sector*

Passenger and freight transport are linked to transport using sectors by different mechanisms. Freight transport is needed to acquire goods and is thus directly linked to sectoral inputs. Passenger transport is a complex of different motives: business traffic for the delivery of services (we distinguish 2 types of services: those sourced directly by the firm – e.g the cleaning company – and those related to goods delivered to the firm, e.g. the traveling salesman), commuting traffic of employees. Apart from the general question about the degree to which efficiency gains in transport are made productive in the transport using industry, there is a much more commonplace problem that deserves attention: the contribution of transport costs to product value. For freight transport these costs are well identifiable and existing statistics indicate that depending on the sector these lie between 5% and 25% of the value of the product. As a significant share of firms uses transport on an own account basis (in NL this share is estimated at 30% for low valued goods and 60% for high valued goods), we cannot in general rely on

aggregate industry statistics – as own account transport is not noted in I/O tables as a separate flow, the input to industry from the transport sectors which appears in these statistics simply does not give the full picture.

For commuting, these relationships between transport spending and sectoral turnover can be identified using labour costs statistics per sector. Business traffic is the most difficult category. For services sourced directly by firms, a similar problem as with freight transport arises in terms of own account transport, which is usually the case with services. Additional services that go with the acquisition of goods (advisory services, sales) are to a large part considered as an overhead to the costs of production and delivery of goods. No general indicators exist, however, on the proportion of the costs of business trips in the product costs.

As the spendings on transport services concern a key assumption in the application of SCGE models for transport appraisal, we recommend that additional research is undertaken in this area to produce relevant and representative indicators

3.3 Which transport costs?

The meaning of “transport costs” varies across disciplines. In transport appraisal, where the transport engineering and regional economics disciplines collide, the definition of transport costs for SCGE modelling can in many cases be too wide or too narrow:

- Firstly, the costs that the transport using sectors incur have nothing to do with generalised costs (as e.g. a weighted sum of costs and times) of transport. The market price that firms pay for transport – a structural relationship between the transport sector T and the transport using sectors TU - is something different than the shadow price of services assumed in transport choice models – a behavioural relationship between T and TU. It should be clear what is included in the value of time used in transport models (drivers’ wages? capital loss in transport? costs of fulfillment downstream?) in order to avoid double counting.
- Secondly, on the other hand, we must take care not to limit ourselves to transport costs only. In broad terms, it is the cost of interaction between regions that interests us, i.e. the costs to get goods in the right shape, in the right quantities and on the right time between A and B. This includes easily discarded, but highly relevant categories like “physical distribution costs” or “border crossing costs”.

3.4 Consistency with 4 step transport models

Most transport models are not limited to the markets of transport services but also describe the patterns of trade between regions. This introduces a source of inconsistencies between SCGE and transport models. The fact that, conceptually at least, the most common model form for describing these patterns, is implicitly also part of the SCGE mechanism (the gravity model), is of little comfort. SCGE models are fundamentally different in the sense that – in transport modelling terms – the production and attraction rates are elastic. The total flows leaving or entering a region will thus differ between the two types of models.

These elasticities are endogenous in SCGE models which places limits on the transferability to transport models. This problem can in principle be solved by attempting to let the two models reach convergence in these spatial patterns, by feeding back spatial patterns of transport flows from the SCGE model to the transport model.

4 Modelling the influence of transport costs on sectoral production

4.1 Introduction

Samuelson's (1952) iceberg approach is commonly used in regional general equilibrium models. The approach, in which it is assumed that transport costs can be modeled as produce 'melting' while being transported, is theoretically elegant for one-sector models but inappropriate in case of multi-sector models. The iceberg approach will cause a severe mis-specification of the production costs in the transport sector. Moreover, as argued in Oosterhaven and Knaap, (2002), the iceberg approach mixes up volume and price effects and may even lead to incorrect perverse model results.

4.2 Transport production

The first mis-specification of modeling the transport sector using the iceberg approach in a multi-sector framework is due to the implicit production function that is used in producing transport. The iceberg approach implicitly assumes that the transport of goods is produced in the same way as the product transported. For, transport is expressed in units of the product transported. One only has to think of the mining sector to understand that this is a fundamental mis-specification, which may have severe

consequences for factor use in the economy. In a one sector economy it is assumed that all products have the same production function. Obviously, the iceberg approach will not lead to any (additional) mis-specification in a one sector model.

4.3 Price and volume effects

Reducing iceberg transport costs implies that the suppliers need to produce less to satisfy the same level of demand on the part of the customers. Hence, consumption is able to increase more than production. This may even lead to perverse effects where a reduction in the transport costs leads to increased consumption of a good, while production actually declines. This is caused by the basic assumption of the iceberg approach that a reduction in transport costs may be modeled as an increase in the amount of produce that arrives in a certain region.

When a macro SCGE is used, this property does not pose a serious problem as the macro economic output is inclusive of transportation output that does (implicitly) reduce. In a multi-sectoral SCGE, however, this iceberg type transport costs imply a serious mis-specification as they lead to an underestimation of the output effects in the non-transport sectors, especially in those sectors for which transport costs reduce most, whereas the opposite should be the case.

5 On the interpretation of micro level variables

5.1 Introduction

In the specification of SCGE models, the firm is the basic entity whose behaviour we want to describe. At this level, which we will call the micro level, the SCGE framework is unambiguous. The interpretation of variables related to firms and products are, however, less easy to interpret when we apply the SCGE framework on the meso level, i.e. regional or sectoral level. Such applications are necessary for transport project appraisal, as we will typically want to know about the behaviour of an aggregate set of firms, e.g. all firms within a region. In these applications, we will typically not have the empirical data available to describe (or estimate) the characteristics of individual firms or products. The micro level variables will thus need to be re-interpreted as variables at the meso level. The question is whether this conflict in definitions forces us to

reconsider the specification of our model. We answer this question in the remainder of this section.

5.2 *The number n : varieties, firms and geographical scale*

In the literature there is much confusion about the interpretation of the variable ‘ $n_{r,s}$ ’ in the Krugman style regional equilibrium model (Fujita, 1999).ⁱ Normally $n_{r,s}$ is associated with the number of varieties and the number of firms in a region. In this chapter we will argue that, although the relative size of $n_{r,s}$ compared to different regions stands into a relation to the number of firms in a region, it should not be interpreted as the number of firms or varieties in a region. Associating $n_{r,s}$ with the number of firms is a misleading simplification. Moreover, it is argued that the exact interpretation of $n_{r,s}$ is not clear and of only little importance.

5.3 *Calibrating n : the substitution elasticity and fixed costs*

To understand what is the meaning of $n_{r,s}$ we have to look a bit more careful to the model and the way $n_{r,s}$ is determined. In general $n_{r,s}$ is estimated based on the flow of goods d between regions r and rr of a sector s good. This flow of goods is a function of the relative price of a good in region rr vis-à-vis the price of a good in region r , the substitution elasticity \mathbf{s}_s between varieties of this good in sector s and the absorption A in receiving region rr . This is mathematically described in equation (0.1).

$$(0.1) \quad d_{r,rr,s} = f \left(\frac{p_{rr,s}}{p_{r,s}}, \mathbf{s}_s, \overline{A_{rr,s}} \right)$$

The price in a region is a function of the prices in all regions, the variable $n_{r,s}$ and the substitution elasticity \mathbf{s}_s . The variable $n_{r,s}$ is a function of the fixed costs \mathbf{y}_s the substitution elasticity \mathbf{s}_s and the production in a region $\sum_{rr} d_{r,rr,s}$. This is described in the following two equations.

$$(0.2) \quad P_{r,s} = f \left(n_{r,s}, p_{r,s}, \mathbf{s}_s \right)$$

$$(0.3) \quad n_{r,s} = f \left(\mathbf{s}_s, \mathbf{y}_s, \sum_{rr} d_{r,rr,s} \right)$$

It is normal procedure to calibrate $n_{r,s}$ (Bröcker, 1995 and Elhorst *et al.*, 2000). This implies looking for values of \mathbf{s}_s and \mathbf{y}_s such that the simulated values for the trade flows are as close as possible to the observed trade flows, given the absorption in all regions. The actual calibration involves only the substitution elasticity and the fixed costs as equation (0.3) can be easily substituted into equation (0.2).

It should be noted that the system of equations (0.1), (0.2) and (0.3) is independent with respect to the sectors. In other words, the parameters can be calibrated sequentially for all sectors because there are no inter sector flows.ⁱⁱ The calibrated parameters are therefore sector specific. They are and *not* region specific because in that case the system would be underdetermined.

5.4 What is n ?

The variable $n_{r,s}$ is based on a the fixed costs of making a variety and the substitution elasticity for this variety vis-à-vis other varieties and the regional production. First, we define N as the aggregate of $n_{r,s}$ over the regions.ⁱⁱⁱ This N depends only on the national production level and is equal to the total production divided by the (optimal) production for a variety. Thus, N is the number of varieties in the economy. This number of varieties (or this combination of \mathbf{s}_s and \mathbf{y}_s) fits best the observed flow of goods between regions for this product category. It should be emphasized that this number of varieties is an average of the combination of ‘actual’ observed varieties and their agglomeration effect. It is not possible to decompose this variety concept into observed varieties and the agglomeration effect.

This leaves us with the commonly used variable $n_{r,s}$ on the regional level. The only meaning of this variable is the share of this region’s production in the production of a variety. In other words, varieties have no regional component but are calibrated on the aggregate level only (for the economy as a whole). The question remains however whether the variable $n_{r,s}$ tells us something about the agglomeration effect in this region.

The agglomeration effect in a region is a function of the supply in this region *and* in all neighboring regions. This is best described by the price of an aggregate good in a region as defined in equation (0.2). The variable $n_{r,s}$ is the weight in this CES price aggregation and tells us only something about the region's 'own' contribution to the regional agglomeration effect. However, the exact interpretation of $n_{r,s}$ is not obvious because of the non-linearity in the aggregation function. It should therefore be concluded that $n_{r,s}$ tells us little about the regional agglomeration effect.

5.5 Conditions for N and n

The variable $n_{r,s}$ is continuous and should be larger than 0. The actual size of $n_{r,s}$ depends on the geographical scale of the analysis. The argumentation is straightforward. Given the substitution elasticity and the fixed costs of producing a variety there is an amount of varieties N in the economy. The more regions you distinguish within this economy, the smaller your $n_{r,s}$ will be.

In general it is argued that N should be larger than 1. This is directly derived from the CES Price aggregation and is related to the assumption that every firm produces one variety. In this case N should be much higher than 1 because we assume monopolistic competition as a prerequisite for the model with agglomeration effects. However, if we assume that a variety is made by many firms, which is not unlikely in the empirical case given the variety concept used (see above), there seems to be no reason for N to be larger than 1. In this case N is a continuous variable and should simply be larger than zero.

6 Irrational agglomeration effects

6.1 Introduction

Changes in land use are simulated by SCGE models through changes in the volume of regional production and consumption. One can experience problems with the traditional specification of these functions, however, if constraints upon changes in land use are neglected. More specifically, such irrational agglomeration effects can occur in SCGE models if hysteresis and locational boundedness is not adequately taken into account.

This may take several forms:

- Hysteresis: Past decisions affect the future. Setting up a new plant in another location instead of extending an existing plant may for some sectors be very costly. Investments in the past should in this case be seen as 'sunk costs' in the production process and should be treated in that way if compared to new investments.
- Locational boundedness due to locational inputs; in other words, production factors may be only locally available. An example is the availability of natural resources. In this case one can think about natural gas, but also about the factor land in the agricultural sector.
- Locational boundedness due to locational outputs: these are mainly government-regulated products. For instance, services supplied by municipalities cannot be substituted. That is, one has to consume municipality services from one's own municipality. This is exogenous local production.

6.2 *Preventing irrational agglomeration effects in RAEM*

Locational boundedness can best be modeled by explicitly taking factor markets into account, or by fixing some of the production y ^{iv}. Hysteresis, however, asks for a more sophisticated approach. Hysteresis affect the productivity of production, because it is inefficient to produce a different amount than the 'normal' capacity of the firm \bar{y} . In other words: costs have to be made to reduce or increase production in a region. This captures the 'sunk' costs idea. It is usually more costly to build a new factory than it is to improve an existing factory. This implies that although it would be more efficient to produce in other regions this will not take place because it is costly to move a plant. It can be argued that in the very long run these effects will be zero. However, over the period of policy analysis RAEM (a period of approximately 25 years) these effects are definitely not equal to zero. Of course these effects are sector specific and depend on the 'footlooseness' of a sector $I_{r,s}$ (varies between 0.1 and 1).

Given a 'normal' Cobb-Douglas production factor with scaling parameter $\overline{A_{r,s}}$, we propose the following function to capture hysteresis:

$$(0.4) \quad A_{r,s} = e^{-I_{r,s} \left(\ln \left(\frac{y_{r,s}}{y_{r,s}} \right) \right)^2} \frac{1}{A_{r,s}}$$

This idea of productivity effects depending on a ‘normal production level’ draws heavily from the structuralist post-Keynesian tradition. In model simulations we may assume that the normal production is equal to the production in the base-run. The function is plotted for the two extreme cases for $I_{r,s}$ in Figure 2. This function has the property of being equal to 1 if the production is equal to the normal production. A becomes less than 1 if production deviates from the normal production. The productivity in the sector declines in when A becomes less than 1.

This function can also partly be used to capture locational boundedness in case of locally available production factors.^v For example, given the amount of land available the production may be extended at the cost of a loss in productivity (more intensive use of land) or reduced with a loss in productivity (taking valuable land out of production). Especially in the case of land there is a clear limit to the amount available.

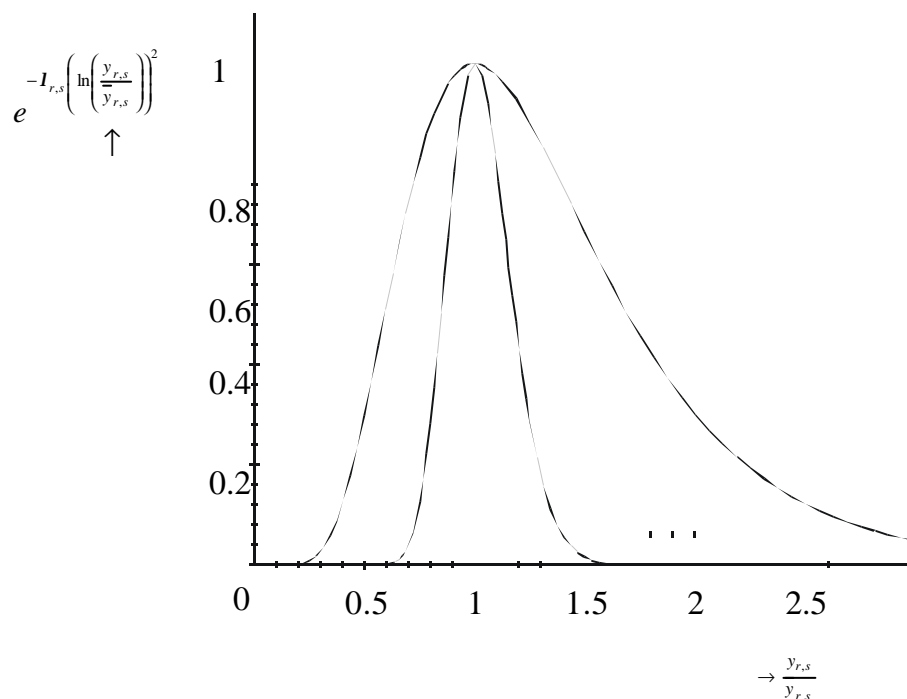


Figure 2 Scaling of production to capture hysteresis

7 Conclusions and recommendations

In this paper we discuss a number of complexities in modelling changes in the economy of regions. We focus in particular on

- changes that arise as a result of changes in the efficiency of transport processes
- the modelling approach using transport and SCGE models.

These problems in modelling have not yet received widespread attention, as the application of SCGE models for the appraisal of transport investments and policies is a new phenomenon. We describe 4 types of issues, explain the possible implications of neglecting these issues and, where relevant, propose approaches for their resolution. These issues concern 1) interfacing problems between SCGE and transport models, 2) the modelling of the influence of transport costs on sectoral production, 3) the interpretation of the conventional, micro-level specification of product variety in aggregate applications and 4) the problem of irrational agglomeration effects in economic activities.

Our main conclusion concerning these points are as follows:

1. In order to have a consistent linkage between transport and SCGE models, the main variable that forms this linkage – transport costs- deserves special attention. We firstly observe that there is a severe lack of empirical data on the consumption of transport services by various sectors of industry. Secondly, we identify two cases of a possible mismatch in the definition of transport costs, as they are produced by transport models, and as they should enter SCGE models. Thirdly, we describe how the use of 4 step transport models may introduce inconsistencies in appraisal results.
2. The use of iceberg transport costs is theoretically convenient and empirically acceptable in the case of a one-sector economy. In a multi-sector economy, it may lead to strange results: an underestimation of the impacts in precisely those sectors that are most sensitive to the reduction of transport costs at hand. Moreover, estimations of factor costs involved in transport are based on the wrong production functions and therefore incorrect.
3. We find that the interpretation of the variable $n_{r,s}$ is less straightforward for our purpose of application than often presented in the literature. This variable seems to be merely a scaling factor useful in calculating the model outcome but of no great

importance in policy analysis. Moreover it was found that this variable should only be larger than 0 and not larger than 1 because its size only depends on the geographical scale of the analysis.

4. We propose a new method to take hysteresis and locational boundedness of production into account. This is necessary to have a more realistic policy analysis, particularly when it comes to predicting changes in spatial patterns of production and consumption.

As a concluding remark, we feel that such a critical and, hopefully constructive, evaluation of the application of SCGE modelling for transport appraisal purposes is a necessary task for the research community. The advent of SCGE modelling, beside improving our insight in how regional economies interact, also includes a promise of improved quality of appraisal results for transport investments and policies. New research into the critical interface with transport modelling is needed, however, for this promise to materialize.

NOTES

ⁱ See among others Venables and Gasiorek (1996), Bröcker, J. (1999) and Elhorst *et al.* (2000).

ⁱⁱ In the model the relative sector prices affect the demand for sector inputs. This is however not the case in the calibration.

ⁱⁱⁱ Thus, $N = \sum_r n_{r,s}$.

^{iv} Note that in an empirical application of the model fixing production to zero will have large numerical consequences. These sectors should be completely removed from the model for these regions because otherwise prices would reach infinity.

^v Note that the normal production may be to a small figure if the production is zero.

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