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A PASSENGER TRANSPORT SCGE MODEL

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Abstract

The paper present a formal economic model aimed at describing passenger transport in a comparativ static spatial computable general equilibrium (SCGE) framework. The model should be seen as a tool to analyse user benefits of infrastructure projects, and especially passenger transport projects. Since the geography is explicitly represented in the model, it is possible to include transport as economic sectors, which allows us to distinguish production and demand by location. This further makes it possible to trace user benefits in the economic system that might arise due to transport infrastructure improvements.

The model is based on utility maximising indivduals, where households are assumed to optimise utility in a two-stage process. Firstly, by optimising short-term behaviour of shopping and leisure activities, and in a second stage, by optimising a strategic choice bundle including location and car ownership. Whereas, the first stage are handled analytically conditional on the strategic choice, the second stage are handled in a probabilistic manner.

The supply side of the economy, are represented by four sectors; a producer of local goods and services, a manufactoring sector, as well as two transport sectors, one for freight transport, and one for public passenger transport.

Keywords: Passanger transport; Project evaluation; Spatial SCGE models; Spatial benefit allocation
Topic area: D3 Integrated Supply / Demand Modelling

1 Introduction

Passenger transport represents a large economic sector, with large welfare costs accumulated in congestion. Since, total congestion costs for passenger transport are much higher than for freight transport, so are the potential benefit of travel time savings. However, whereas a number of regional economic models have been developed for analysing freight transport, no such models exist for passenger transport. It is not evidently clear why this is the case, especially because there are several ways in which such a model would improve desicion support for politicians.

- We would be able to analyse not only efficiency but also equity: Who gains and who loose?
- Better and easier derivation of consumer surplus measures.
- Double counting can be avoided.
- Direct as well as indirect effects are accounted for.

These four elements are either completely missing from a standard cost-benefit analysis or only partly taken care of. Especially, the spatial distribution of consumer surpluses is a relative complex task, which requires a completely different model setup than are used in most standard passanger transport models.

Generally speaking, changes in transport infrastructure will have impact on two fronts. Firstly, on how passengers move around in the transport system in the short run and in the long run, and secondly, how firms adopts to the change of the infrastructure in their optimisation. Furthermore, theres is the interaction between consumers and produceres in the system, which is handled through price mechanisms.

Historically, most models from the transport modelling community has considered passenger transport in a short-term perspective, in the sense that they are assumed, not to optimise strategically in their choice of location pattern. This is a strict assumption because, theoretically, it implies all commuter traffic to be inelastic. In practis, however, commuting is often handled by assuming a fixed trip generation (population formation) and attraction (labour demand) pattern. This, however, imposes several problems because neither the supply side nor the demand side is the result of an optimisation process. On the supply side firms are not assumed to take changes in the demand formation into account, neither are they assumed to react on the change in infrastructure, as are factor inputs (such as land) used without capacity constraints. Finally, markets are generally unbalanced, leading to inconsistencies between demand and supply.

The model laid out is of the SCGE type, with utility maximising agents on the one side, and profit maximising firms on the other. The model is intended for economic comparative static analysis of mainly passenger transport infrastructure improvements. Accordingly, the model will be a helpful tool in several situations, e.g. cost-benefit evaluation of metro projects, location of new subway stations, evaluation of structural changes in bus operations, and finally, as a tool to analyse structural impacts of various taxation policies. The later include road pricing scenarios as well as taxation related to car ownership. The ambition of the model is to try to integrate the SCGE tradition with passenger transport to answer some of the criticism of traditional passenger transport models. However, a high spatial resolution level, which is often required in transport planning, are rarely supported in the data foundation of especially supply quantities. As a result, limitations need to be imposed on especially intermediate commodity flows as well as on the production of manufacturing goods. Consequently, the model to be introduced will be less suited for analysing freight transport, mainly because of an insufficient description of intermediates and the fact that the manufacturing sector are assumed exogenous. To cope with freight a more rigorous data foundation are needed, which, as a minimum should distinguish between commodity types.

In the model, what happens, when travel time are reduced as a consequence of infrastructure improvements, is that households will start an optimisation process, which can be thought off as a two-stage strategy. Firstly, they optimise their non-strategic behaviour represented by shopping and leisure activities conditional on their strategic choice. Then, in a second step they optimise strategically by choosing the strategic bundle with the highest (indirect) utility. The level of locally produces goods and services are assumed to adjust to the new location pattern of households and market equilibrium conditions are brought into play to ensure balance on all markets. The fact that also car ownership status is represented in the strategic choice bundle opens for a number of interesting circles to be analysed. As an example, it becomes possible to analyse tax scenarios related to car ownership. Furthermore, various interesting trade-offs can be analysed, such as the combination of low accessibility, low land rent, and car availability versus high accessibility, high land rent, and no car. This is interesting from a Danish perspective (as well as most European countries) because, in a period of 10 to 20 years, housing costs has expanded whereas transport costs has decreased measured in real terms. In such a situation, utility maximising households will tend to locate further out at the cost of additional transport. Looking at the region of Copenhagen this is exactly what has happened.

In the literature, only few contributions exist. Bröcker, which has been responsible for a number of papers concerning freight transport in a SCGE context (Bröcker, 1999, 1998), has recently formulated a passenger flow CGE model for transport project evaluation, Bröcker (2002). The paper include private and business passenger travel and aims at an operational model deriving passenger flows from optimising behaviour of firms and passengers. Ivanova (2003), represent another contribution in a fairly general SCGE model for passenger transport. Especially two features of the model are of interest. Firstly, it incorporates an explicit representation of transport networks allowing for potential congestion effects. Secondly, it represents endogenous agglomeration effects in the choice of location at the household level. The present paper intentionally adopted a more minimalistic approach to minimise problems related to data and calibration. Firstly, on the supply side, we adopt a design that corresponds to Lowry (1964). As a result, we distinguish between a manufacturing sector and a local service sector. The first are assumed exogenous, whereas the production level of the latter, are determined endogenously in interaction with households. Furthermore, the production technology is assumed to be simple in the way intermediates are used. The service sector conveys a single intermediate into a composite good using land, labour, and capital. Intermediates are used under Armington conditions, Armington (1969). A third simplification is that households are not assumed to react on agglomeration effects as in Ivanova (2003). Instead, households react according to an exogenous taste variation pattern, which will be calibrated from the base year.

2 Model structure

The model structure correspond closely to a standard SCGE approach in the representation of geography into regions and the linkage between demand and supply through market equilibrium conditions. Households are utility maximising agents; on the on side consuming a composite local good as well as land, leisure, and transport, and on the other supplying labour. On the supply side four sectors are represented. Firstly, a producer of local goods and services, referred to as sector S. Sector S uses labour, land, intermediates, and capital in production. Secondly, a manufacturing sector M, which produce a manufactured good used for export and as input in sector S. Thirdly, a public transport sector T that uses labour and capital to produce a public transport service. Finally, a freight transport sector F, using labour and capital to produce freight transport. Sector F will transport intermediates from M to S and between manufacturing units at different locations.

In the demand for transport, households have the option of using a private transport mode as an alternative to the public transport service. The production of private transport is assumed to be handled internally in the household, e.g. the household supply the labour and capital needed subject to their budget constraint. The price of private transport is exogenous and will not dependent of the respective demand. In general, households will use a mix of private and public transport depending on the relative competitiveness between modes conditional on their strategic choices, e.g. location pattern and car ownership status.

The supply side of the economy is deliberately made simple to keep focus on the demand side and retain simplicity in the data and calibration process. As mentioned in the introduction, the mechanism is somewhat similar to a Lowry set-up in the sense that the manufacturing sector within each region is considered the engine for regional growth. Hence, the manufacturing sector will require labour in production, which will affect the location of household. When the formations of household change so do the formation of locally produced goods and services, which acts as a "follower". The level of production in sector M is assumed exogenous to the model, whereas the output level of sector S is determined endogenously in the interaction with households. The distinctions between exogenous and endogenous elements are shown in figure 1 below.

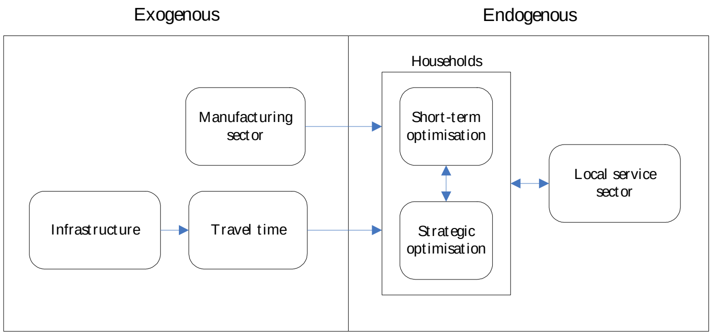

Figure 1: Overall model structure.

Considering that the main focus of the model is passenger transport, the exogeneity of the production level of the manufacturing sector is not a critical limitation. In fact, it conform well with Danish planning practis in the sense that the use of land are strictly monitored, controlled, and planned in a fairly long-term horizon. Land reserved for a particular purpose, say residential location, can not be converted to other purposes easily. The benefit of this control from a model perspective is that the land use schedule can be put into the model. Hence, in the competition for land, there will be limits on the amount of land available for each purpose in all regions. If limits are met by demand, the limit will act as a capacity constraint and the corresponding price for land will increase.

A cycle of the model could be the following;

Travel time ↓ ⇨ Accessibility ↑ ⇨ ΔTransport costs / ΔLand rents ⇨ Spatial reallocation

Of course, this simple scenario could be combined with various taxation policies and/or land use restrictions depending on the purpose.

2.1 Notation and concepts

The geographical space is divided into R non-overlapping regions. The land available in each region is dedicated to four activities. Residential location, manufacturing, production of local goods and services, and recreative purposes. Each household are differentiated according to their residential location $r = 1,\ldots,R$ and workplace location $j = 1,\ldots,R$. In addition households choose whether to have a car or not, $b = 1,2$. Furthermore, to adopt differences in preferences households are separated into a number of sociogroups, $\rho = 1,\ldots,\Lambda$. The distribution between sociogroups will be exogenous. Each household work at a regional wage rate $w(j)$ and pays a fixed percentage $\tau_w(r)$ in tax according to place of residence[1].

In the short run households put together a consumption bundle $\mathbf{x}$, consisting of commodities Q, leisure F, land A_h as well as transport T. In the long run, however, they act strategically choosing a strategic consumption bundle $\mathbf{l}=\{r,j,b\}$. In this sense, households can be characterised by a (direct) utility function $U_\rho(\mathbf{x},\mathbf{l})$ which they will seek to maximise under budget constraint $M_\rho(\mathbf{x},\mathbf{l})$.

Four production sectors exist. A manufacturing sector M, which produce a good according to production function $Y_m(r)$, a local producer of good and services with output $Y_s(r)$, a public transport sector T producing public transport services according to production function $Y_t(r,r')$, and a freight transport sector F producing freight transport $Y_f(r,r')$. Sector S convey intermediates from the manufacturing sector (under Armington conditions) using labour L, land A_s, and capital C. Sector M, which is assumed exogenous to the model, produce a manufactured good using labour, land A_m, capital and intermediates from industries in other regions. Finally, the public transport sector as well as the freight transport sector, uses labour and capital to produce transport services between regions for passengers and goods respectively.

2.2 Households

The way location and demand is handled at the household level can be thought of as a two-step strategy even though all equations are solved simultaneously. In the first step, households optimise their consumption of $\mathbf{x}$ conditional on their strategic long-term choice $\mathbf{l}$. This optimisation is done analytically by solving

$$\max_{\{\mathbf{x}\}} U_\rho(\mathbf{x}\,|\,\mathbf{l}) \\ s.t.\quad M_\rho(\mathbf{x}\,|\,\mathbf{l})=0 \tag{1}$$

Hereby follows optimal demands of $\mathbf{x}$ as a function of $\mathbf{l}$ denoted by $\mathbf{x}^*(\mathbf{l})$. Substituting $\mathbf{x}^*(\mathbf{l})$ into U_ρ result in the indirect utility function expressed in terms of prices and $\mathbf{l}$, e.g. $V_\rho(\mathbf{l})$. Now, in the second step, household will try to optimise their strategic choice pattern $\mathbf{l}$ by seeking an optimal strategic configuration $\mathbf{l}^*$. Speaking in utility terminology, they will choose $\mathbf{l}^*$ if and only if

$$V_\rho(\mathbf{l}^*)\geq V_\rho(\mathbf{l})\ \forall\mathbf{l}$$

Whereas the first step (1) was handled analytically, the second step is handled in a probabilistic manner due to the discontinuity of $\mathbf{l}$. We assume a decomposition of the utility function into a deterministic part approximated by the indirect utility function $V_\rho(\mathbf{l})$, and an error term that renders a closed logit form, e.g. an extreme distributed error term $\varepsilon_\mathbf{l}$.

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[1]A complete list of variables and parameters are included in the appendix.

$$\tilde{V}_\rho(\mathbf{l}) = V_\rho(\mathbf{l}) + \varepsilon_\mathbf{l} \tag{2}$$

From the properties of $\varepsilon_\mathbf{l}$ it follows[2] that

$$\Pr(\mathbf{l} \mid \rho) = \frac{\exp(V_\rho(\mathbf{l}))}{\sum_{\mathbf{l}'} \exp(V_\rho(\mathbf{l}'))}$$

Given the total population $\overline{N}_\rho$, the optimal distribution of households becomes

$$N_\rho(\mathbf{l}) = \overline{N}_\rho \Pr(\mathbf{l} \mid \rho) \tag{3}$$

2.2.3 Specification of utility

The utility function of the households adopts a nested CES structure as shown in figure 2 below.

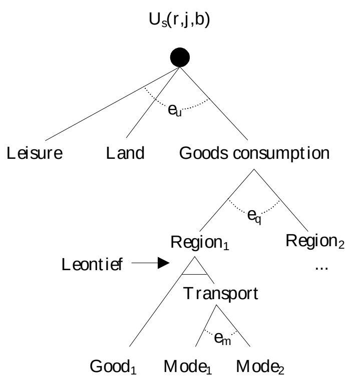

Figure 2: Household utility function.

At the upper level households consume leisure F, land A and composite goods Q at a constant elasticity of substitution e_u. The composite goods are differentiated according to place of origin with elasticity e_q (Armington nests). When households consume goods they are also assumed to consume a fixed proportion of transport T, e.g. the nest between consumption and goods and transport are Leontief. This is a reasonable assumption since going only half of the way on a shopping trip is meaningsless. With respect to transport mode, however, the model allow for substitution. Hence, if the relative competitiveness between modes becomes in favour of public transport there will be a shift away from private transport at rate equal to e_m. The direct utility function can be represented mathematically as

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[2]A somewhat similar approach, in which short- and long-term utility was decomposed in a probabilistic sense according to a nested logit formulation, was considered in Rich (2001).

$$U_\rho(\mathbf{l}) = \left[\mathbf{T}_{\rho,\mathbf{l}} \left(\beta_{\mathbf{l}}^{\rho,Q} Q_\rho(\mathbf{l})^{\frac{e_u - 1}{e_u}} + \beta_{\mathbf{l}}^{\rho,F} F(\mathbf{l})^{\frac{e_u - 1}{e_u}} + \beta_{\mathbf{l}}^{\rho,A} A_\rho(\mathbf{l})^{\frac{e_u - 1}{e_u}} \right) \right]^{\frac{e_u}{e_u - 1}} \qquad (4)$$

where $\mathbf{T}_{\rho,\mathbf{l}} = \theta_{\rho,r} + \lambda_{\rho,j}$ represents taste variation for sociogroup ρ due to unobserved utility at the location of residence and work and where $Q_\rho(\mathbf{l})$ are the consumption nest given by

$$Q_\rho(\mathbf{l}) = \left(\sum_d \beta_{\mathbf{l},d}^{\rho,Q} \left(Q_\rho(\mathbf{l},d) + \gamma \left(\sum_m \left(\beta_{\mathbf{l},d,m}^{\rho,T} T_\rho(\mathbf{l},d,m)^{\frac{e_m - 1}{e_m}} \right) \right)^{\frac{e_m}{e_m - 1}} \right)^{\frac{e_q - 1}{e_q}} \right)^{\frac{e_q}{e_q - 1}} \qquad (5)$$

Consumption in region d are given by $Q_\rho(\mathbf{l},d)$, whereas the amount of transport are a mode aggregate proportioned by γ. $F_\rho(\mathbf{l})$ and $A_\rho(\mathbf{l})$ measure demand for leisure and land whereas $\beta_{\mathbf{l},d}^{\rho,Q}$, $\beta_{\mathbf{l}}^{\rho,F}$, $\beta_{\mathbf{l}}^{\rho,A}$, and $\beta_{\mathbf{l},d,m}^{\rho,T}$ determine consumption shares. Normally we would assume elasticities of substitution to vary according to ρ, however, to keep notation somewhat simple this has been omitted. A note worth mentioning, regard the importance of $\beta_{\mathbf{l},d,m}^{\rho,T}$. Since $\beta_{\mathbf{l},d,m}^{\rho,T}$ represent the linkage between mode of transport and the car ownership there will be severe differences in these shares. However, $\beta_{\mathbf{l},d,m}^{\rho,T}$ as well a most other parameters represented in the demand side, will be backed by a solid data foundation from which they can be calibrated.

The taste variation $\mathbf{T}_{\rho,\mathbf{l}}$ is included to account for two facts. Firstly, that unobservable utility component will exist. These are primarily related to the residential zone due to different types of amenities but can arguably be related to place of work as well. Secondly, that different household is likely to react differently on these unobservable attributes. Hence, they should vary according to ρ.

The corresponding budget constraint matches the shopping level with the budget. The disposal income left for shopping and shopping transport are given by (6)

$$(1 - \tau_w(r)) w(j) \bar{L}(\mathbf{l}) + r\bar{C}_\rho(\mathbf{l}) + G(r) - \tau_c(b) - 2k_d TC_\rho(\mathbf{l}) \quad (= M_\rho(\mathbf{l})) \qquad (6)$$

$\bar{L}(\mathbf{l})$ and $\bar{C}_\rho(\mathbf{l})$ measure maximum labour supply and capital endowment, whereas $G_\rho(r)$ represent lump-sum transfers. At the cost side, $\tau_c(b)$ represent fixed car costs whereas $2\bar{k}_d TC_\rho(\mathbf{l})$ are annual commuter costs related to $\mathbf{l}$ with $\bar{k}_d$ representing a fixed number of annual working days. $TC_\rho(\mathbf{l})$ involve mode choice because commuters will select commuter mode according to its competitiveness. That is,

$$TC_\rho(\mathbf{l}) = \sum_m \Pr(m \mid \mathbf{l}, \rho) TC_m(\mathbf{l}) \qquad (7)$$

Where $\Pr(m \mid \mathbf{l}, \rho) = \exp(k_{\rho,\mathbf{l},m} + TC_m(\mathbf{l})) / \sum_{m'} \exp(k_{\rho,\mathbf{l},m'} + TC_{m'}(\mathbf{l}))$ with $TC_m(\mathbf{l})$ equal to $p_m^t(r,j) D(r,j)(1+\tau_m)$. $p_m^t(r,j)$ is the transport producer price multiplied by taxation $(1+\tau_m)$ and distance $D(r,d)$. For public transport, the producer price will equal the marginal public transport price $p^t(r,d)$ (section 2.4.1), whereas, for private transport it will equal $p^p(r,d)$ (section 2.4.2). Demand for commuting by mode m are given by

$$T_m^c(\mathbf{l}) = \sum_{\rho} 2k_d \Pr(m \mid \mathbf{l}, \rho) N_\rho(\mathbf{l}) \qquad (8)$$

The other side of the budget in (6) represents what is consumed. That is

$$\left(M_\rho(\mathbf{l})=\right) \sum_d p^s(d) Q_\rho(\mathbf{l}, d) + \gamma \sum_m \left[D(r,d) p_m^t(r,d)(1+\tau_m)\right] T_\rho(\mathbf{l}, d, m) \qquad (9)$$

Here $p^s(d)$ are the producer price of commodities produced in sector S at place of production and $D(r,d)p_m^t(r,d)(1+\tau_m)$ the price of transportation similar to the transport cost of commuting. In (6), the net income can seem artificial in the sense that wage are earned on the basis of $\overline{L}(\mathbf{l})$, however, the hourly wage rate are adjusted accordingly. What it means, is that the marginal price of leisure and labour equal the adjusted wage rate $w(j)$. Furthermore, they are substitutes at rate e_u implying an elastic labour supply. Labour supply and leisure are linked as

$$F_\rho(\mathbf{l}) = \overline{L}(\mathbf{l}) - N_\rho(\mathbf{l})$$

From (4) Marshallian demand functions for $T_\rho(\mathbf{l}, d, m)$, $Q_\rho(\mathbf{l}, d)$, $F_\rho(\mathbf{l})$ and $L_\rho(\mathbf{l})$ can be derived using Roy's identity.

$$T_\rho(\mathbf{l}, d, m) = \gamma Q_\rho(\mathbf{l}, d)\left(\beta_{\mathbf{l},d,m}^{\rho,T}\right)^{e_m} \left(\frac{\left[D(r,d) p_m^t(r,d)(1+\tau_m)\right]}{\tilde{p}_{mqu}^{\rho}(\mathbf{l}, d)}\right)^{-e_m} \qquad (10)$$

Where

$$Q_\rho(\mathbf{l}, d) = \left(\beta_{\mathbf{l},d}^{\rho,Q}\right)^{e_q} \left(\beta_{\mathbf{l}}^{\rho,Q}\right)^{e_u} \left(\mathbf{T}_{s,1}\right)^{e_u} \left(\frac{\tilde{p}_{mqu}^{\rho}(\mathbf{l}, d)}{\tilde{p}_{qu}^{\rho}(\mathbf{l})}\right)^{-e_q} \left(\frac{\tilde{p}_{qu}^{\rho}(\mathbf{l})}{\tilde{p}_{u}^{\rho}(\mathbf{l})}\right)^{-e_u} \frac{M_\rho(\mathbf{l})}{\tilde{p}_{u}^{\rho}(\mathbf{l})} \qquad (11)$$

$$F_\rho(\mathbf{l}) = \left(\beta_{\mathbf{l}}^{\rho,F}\right)^{e_u} \left(\mathbf{T}_{s,1}\right)^{e_u} \left(\frac{w(j)(1-\tau_w)}{\tilde{p}_{u}^{\rho}(\mathbf{l})}\right)^{-e_u} \frac{M_\rho(\mathbf{l})}{\tilde{p}_{u}^{\rho}(\mathbf{l})} \qquad (12)$$

$$A_\rho(\mathbf{l}) = \left(\beta_{\mathbf{l}}^{\rho,A}\right)^{e_u} \left(\mathbf{T}_{s,1}\right)^{e_u} \left(\frac{r_{A,\rho}(r)}{\tilde{p}_{u}^{\rho}(\mathbf{l})}\right)^{-e_u} \frac{M_\rho(\mathbf{l})}{\tilde{p}_{u}^{\rho}(\mathbf{l})} \qquad (13)$$

The respective prices indices $\tilde{p}_{mqu}^{\rho}(\mathbf{l}, d)$, $\tilde{p}_{qu}^{\rho}(\mathbf{l})$, and $\tilde{p}_{u}^{\rho}(\mathbf{l})$ are given by

$$\tilde{p}_{mqu}^{\rho}(\mathbf{l}, d) = \left(\sum_m \left(\beta_{\mathbf{l},d,m}^{\rho,T}\right)^{e_m} \left[D(r,d) p_m^t(r,d)(1+\tau_m)\right]^{e_m-1}\right)^{\frac{1}{1-e_m}} \qquad (14)$$

$$\tilde{p}_{qu}^{\rho}(\mathbf{l}) = \left(\sum_d \left(\beta_{\mathbf{l},d}^{\rho,Q}\right)^{e_q} \left(p^s(d) + \gamma \tilde{p}_{mqu}^{\rho}(\mathbf{l}, d)\right)(\mathbf{l}, d)^{e_q-1}\right)^{\frac{1}{1-e_q}} \qquad (15)$$

$$\tilde{p}_{u}^{\rho}(\mathbf{l}) = \left[\left(\mathbf{T}_{s,1}\right)^{e_u} \mathrm{f}_u(\mathbf{l})\right]^{\frac{1}{1-e_u}} \qquad (16)$$

where

$$\mathrm{f}_u(\mathbf{l}) = \left(\beta_{\mathbf{l}}^{\rho,Q}\right)^{e_u} \left(\tilde{p}_{qu}^{\rho}(\mathbf{l})\right)^{e_u-1} + \left(\beta_{\mathbf{l}}^{\rho,F}\right)^{e_u} \left(w(j)(1-\tau_w(r))\right)^{e_u-1}$$
$$+\left(\beta_{\mathbf{l}}^{\rho,A}\right)^{e_u} r_{\rho,A}(r)^{e_u-1}$$

Finally, based on a standard result, the indirect utility function in (2) can be expressed as

$$V_\rho(\mathbf{l}) = \frac{M_\rho(\mathbf{l})}{\tilde{p}_u^\rho(\mathbf{l})} \qquad (17)$$

2.3 Production sectors

2.3.1 Sector S

The producer of local goods and services, sector S, produces a single composite good at producer price $p^s(r)$. The level of production $Y_s(r)$ is assumed to be proportional to the regional population, in the sense that the regional population determines what is demanded locally. This construction is largely inspired by Lorry and implies

$$Y_s(r) = a\sum_{j,b} N(r,j,b) \qquad (18)$$

Whereas the level of production is determined outside the sector, the production technology can be flexible allowing for substitution effects between factor inputs. The departure point, however, will be simple as shown in figure (local) below.

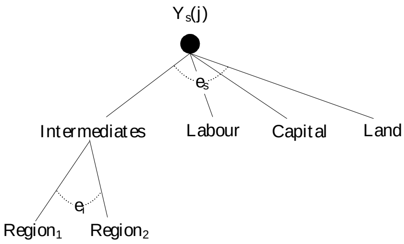

Figure 3: Production of local goods and services.

Intermediates are introduced as Armington nests implying that manufactured goods from different regions are imperfect substitutes. Formally, the production function can be written

$$Y_s(r) = \left(\beta_r^{s,\mathbf{I}}\mathbf{I}_s(r)^{\frac{e_s-1}{e_s}} + \beta_r^{s,\mathbf{L}}\mathbf{L}_s(r)^{\frac{e_s-1}{e_s}} + \beta_r^{s,\mathbf{C}}\mathbf{C}_s(r)^{\frac{e_s-1}{e_s}} + \beta_r^{s,\mathbf{A}}\mathbf{A}_s(r)^{\frac{e_s-1}{e_s}}\right)^{\frac{e_s}{e_s-1}} \qquad (19)$$

with the Armington nests for intermediates given by $\mathbf{I}_s(r) = \left(\sum_{r'}\beta_{r,r'}^{s,\mathbf{I}}\mathbf{I}_s(r,r')^{\frac{e_i-1}{e_i}}\right)^{\frac{e_i}{e_i-1}}$. Factors are written in bold-uppercase to distinguish these from household demands with $\mathbf{L}_s$ representing labour, $\mathbf{C}_s$ capital, $\mathbf{A}_s$ land, and $\mathbf{I}_s$ intermediates.

The producer price are given by

$$p^s(r) = \left[\left(\beta_r^{s,\mathbf{I}}\right)^{e_s}\tilde{p}_{\mathbf{I}}^s(r)^{1-e_s} + \left(\beta_r^{s,\mathbf{L}}\right)^{e_s} w(r)^{1-e_s} + \left(\beta_r^{s,\mathbf{A}}\right)^{e_s} r_s(r) + \left(\beta_r^{s,\mathbf{C}}\right)^{e_s} r\right]^{\frac{1}{1-e_s}} \qquad (20)$$

Where the aggregate price for intermediates $p_{\mathbf{I}}^{\{s\}}(r)$ is given by

$$\tilde{p}_{\mathbf{I}}^s(r) = \left[\sum_{r'}\left(\beta_{r,r'}^{\mathbf{I}}\right)^{e_i} p_{\mathbf{I}}^s(r,r')^{1-e_i}\right]^{\frac{1}{1-e_i}} \qquad (21)$$

$p^{\mathbf{I}}(r,r')$ is the price at destination including freight transport costs and taxation. That is

$$p_{\mathbf{I}}^s(r,r') = p^m(r') + p^f(r,r')f_h + \tau_f D(r,r') \qquad (22)$$

$p^m(r')$ is the producer price of manufactured goods at the origin of production (see section 2.5) and $p^f(r,r')$ the price of freight transport multiplied by a handling factor f_h.

Furthermore, a transport distance tax τ_f multiplied by distance $D(r,r')$ is added. Factor requirements are derived in the usual way

$$\mathbf{L}_s(r)=\left(\beta_r^{s,\mathbf{L}}\right)^{e_s}\left(\frac{w(r)}{p^s(r)}\right)^{-e_s}\frac{y_s(r)}{p^s(r)}$$

$$\mathbf{C}_s(r)=\left(\beta_r^{s,\mathbf{C}}\right)^{e_s}\left(\frac{r}{p^s(r)}\right)^{-e_s}\frac{y_s(r)}{p^s(r)} \qquad (23)$$

$$\mathbf{A}_s(r)=\left(\beta_r^{s,\mathbf{A}}\right)^{e_s}\left(\frac{r_s(r)}{p^s(r)}\right)^{-e_s}\frac{y_s(r)}{p^s(r)}$$

$$\mathbf{I}_s(r,r')=\left(\beta_r^{s,\mathbf{I}}\right)^{e_s}\left(\beta_{r,r'}^{\mathbf{I}}\right)^{e_i}\left(\frac{p_{\mathbf{I}}^s(r,r')}{p_{\mathbf{I}}^s(r)}\right)^{-e_i}\left(\frac{p_{\mathbf{I}}^s(r)}{p^s(r)}\right)^{-e_s}\frac{y_s(j)}{p^s(r)} \qquad (24)$$

2.3.2 Manufacturing

The manufacturing sector uses a similar production technology as the sector for local goods and services. The main difference is that the level of production $Y_m(r)$ as well as the production technology is assumed exogenously to the model. This implies the flow of intermediates (between regions) in the sector to be fixed as well as factor requirements $\mathbf{L}_m(r)$, $\mathbf{C}_m(r)$, $\mathbf{A}_m(r)$ and $\mathbf{I}_m(r)$ and the producer price $p^m(r)$.

However, in addition to the fixed freight flow pattern between manufacturing units, there is an endogenous flow pattern from the manufacturing sector to the service sector, which are taken into account in a separate freight sector described below.

2.4 Transport sectors

2.4.1 Public Transport

The public transport sector produces a transport service $Y_t(r,r')$ at a producer price equal to $p^t(r,r')$. Only labour $\mathbf{L}_t(r)$ and capital $\mathbf{C}_t(r)$ are used at substitution rate e_t.

$$Y_t(r,r')=\left(\beta_{r,r'}^{t,\mathbf{L}}\mathbf{L}_t(r,r')^{\frac{e_t-1}{e_t}}+\beta_{r,r'}^{t,\mathbf{C}}\mathbf{C}_t(r,r')^{\frac{e_t-1}{e_t}}\right)^{\frac{e_t}{e_t-1}} \qquad (25)$$

For transport service (r,r') we assume the origin r, to be place of production. E.g. employment and capital are required in region r. The producer price are given by

$$p^t(r,r')=\left[\left(\beta_{r,r'}^{t,\mathbf{L}}\right)^{e_t}w(r)^{1-e_t}+\left(\beta_{r,r'}^{t,\mathbf{C}}\right)^{e_t}r\right]^{\frac{1}{1-e_t}} \qquad (26)$$

with factor requirements given by

$$\mathbf{L}_t(r,r')=\left(\beta_{r,r'}^{t,\mathbf{L}}\right)^{e_t}\left(\frac{w(j)}{p^t(r,r')}\right)^{-e_t}\frac{y_t(r,r')}{p^t(r,r')}$$

$$\mathbf{C}_t(r,r')=\left(\beta_{r,r'}^{t,\mathbf{C}}\right)^{e_t}\left(\frac{r}{p^t(r,r')}\right)^{-e_t}\frac{y_t(r,r')}{p^t(r,r')} \qquad (27)$$

3.4.2 Private transport

Whereas public transport is represented in a separate sector, this is not the case with private transport. The production level and the resources required in terms of time and money are handled internally in the households. Hence, households face a fixed marginal producer price $p_{\mathbf{l}}^{p}(r,r')$, which depend on $\mathbf{l}$ and the car ownership status in particular. Consequently, the final output of private transport is determined endogenously in the model by aggregation over households.

The amount of private transport in a given scenario will depend on mode choice substitution effects as well as the overall location pattern.

3.4.3 Freight Transport

The freight transport sector produce a unified transport output $Y_f(r,r')$ at a producer price $p^f(r,r')$. The sector is assumed to use only labour and capital at substitution rate e_f . E.g. the production technology is similar to that of public transport.

$$Y_f(r,r') = \left(\beta_{r,r'}^{f,\mathbf{L}} \mathbf{L}_f(r,r')^{\frac{e_f-1}{e_f}} + \beta_{r,r'}^{f,\mathbf{C}} \mathbf{C}_f(r,r')^{\frac{e_f-1}{e_f}} \right)^{\frac{e_f}{e_f-1}} \tag{28}$$

As for public transport, the place of production is assumed to be the origin region. The producer price are given by

$$p^f(r,r') = \left[\left(\beta_{r,r'}^{f,\mathbf{L}}\right)^{e_f} w(r)^{1-e_f} + \left(\beta_{r,r'}^{f,\mathbf{C}}\right)^{e_f} r \right]^{\frac{1}{1-e_f}} \tag{29}$$

With factor requirements given by

$$\begin{aligned} \mathbf{L}_f(r,r') &= \left(\beta_{r,r'}^{f,\mathbf{L}}\right)^{e_s} \left(\frac{w(j)}{p^f(r,r')} \right)^{-e_f} \frac{y_f(r,r')}{p^f(r,r')} \\ \mathbf{C}_f(r,r') &= \left(\beta_{r,r'}^{f,\mathbf{C}}\right)^{e_f} \left(\frac{r}{p^f(r,r')} \right)^{-e_f} \frac{y_f(r,r')}{p^f(r,r')} \end{aligned} \tag{30}$$

4 Equilibrium conditions

In the market equilibrium conditions demand equal supply on each of the markets represented in the model. The labour market clearing are represented by (31)

$$\sum_{r,b} N(r,j,b) = \sum_{r'} \left(\mathbf{L}_f(j,r') + \mathbf{L}_t(j,r') \right) + \mathbf{L}_s(j) + \overline{\mathbf{L}}_m(j) \quad \forall j \in R \tag{31}$$

The capital market by (32)

$$\sum_{j,b} \overline{K}_s(r,j,b) = \sum_{r'} \left(\mathbf{C}_f(r,r') + \mathbf{C}_t(r,r') \right) + \mathbf{C}_s(r) + \overline{\mathbf{C}}_m(r) \quad \forall r \in R \tag{32}$$

The land market by (33-35)

$$\mathbf{A}(r) = \mathbf{A}_r(r) + \mathbf{A}_m(r) + \mathbf{A}_s(r) + \sum_{\rho} \mathbf{A}_{\rho}(r) \tag{33}$$

with (34) and (35) representing additional capacity constraints for residential location and the use of land in sector S .

$$\mathbf{A}_{\rho}^{\min}(r) \leq \mathbf{A}_{\rho}(r) \leq \mathbf{A}_{\rho}^{\max}(r) \tag{34}$$

$$\mathbf{A}_{s}^{\min}(r) \leq \mathbf{A}_{s}(r) \leq \mathbf{A}_{s}^{\max}(r) \tag{35}$$

The transport equilibrium equation in (36) equals the level of the public transport with what is actually consumed by households in their commuting and shopping transport.

$$Y_t(r,'r) = \sum_{\substack{b,\rho \\ m=public}} T_m^c(\mathbf{l})\, p_m^t(r,r') + \sum_{\substack{b,\rho \\ m=public}} T_\rho(\mathbf{l},r',m)\, p_m^t(r,r') \tag{36}$$

The commodity market equilibrium in (37) require production to be equal to consumption

$$Y_s(d) = \sum_{\rho,\mathbf{l}} N_\rho(\mathbf{l}) Q_\rho(\mathbf{l},d)\, p^s(d) \tag{37}$$

The use of intermediates in sector S should equal production level in sector M. Since the production level of sector M are fixed, the use of intermediates simply equal total production $Y_m(r)$ multiplied by $(1-\mu_r)$ where μ_r is a fixed export share out of the region.

$$(1-\mu_r) Y_m(r) = \sum_{r'} \mathbf{I}_s(r',r) \tag{38}$$

The freight transport output should equal intermediate transport between sector S and M, as well as the fixed flow of intermediates between manufacturing units $\mathbf{I}_m(r,r')$. Hence

$$Y_f(r,r') = p^f(r,r') D(r,r')(1+\tau_f)[\mathbf{I}_s(r,r') + \mathbf{I}_m(r,r')] \tag{39}$$

The public sector collects taxes, which are redistributed back to the households. The total tax payment per region is the equal to the lump sum transfer $G(r)$.

$$\begin{aligned} G(r) = \sum_{j,b,\rho} N_\rho(\mathbf{l}) \Bigg(& \tau_w(r) w(j) + \tau_c(b) + 2k_d \sum_m \tau_m D(r,j)\, p_m^t(r,j) \\ & + \sum_{d,m} \tau_m p_m^t(r,d) T_\rho(\mathbf{l},d,m) \Bigg) + p^f(r,r') D(r,r') \tau_f [\mathbf{I}_s(r,r') + \mathbf{I}_m(r,r')] \end{aligned} \tag{40}$$

Where no value-added tax has been introduced. Finally, the Leontief technology in consumption of commodities and transport implies

$$\gamma = Q_\rho(\mathbf{l},d) / \sum_m \beta_{\mathbf{l},d,m}^{\rho,T} T_\rho(\mathbf{l},d,m) \tag{41}$$

5 Conclusion

In the paper, a prototype of a SCGE model for dealing with passenger transport flows has been introduced. The model is intended for economic comparative static analysis of mainly passenger transport infrastructure improvements. Examples of relevant projects are the location of new subway stations, evaluation of alternative metro lines or transport corridors. However, the model might be used more generally to analyse all sorts of changes to a given transport system. Potential applications are road pricing scenarios, taxation scenarios related to car ownership as well as the evaluation of structural changes in route planning for bus operators.

The integration between transport and the SCGE approach is needed in order to answer some of the criticism of traditional passenger transport models. Since the geography is explicitly represented we have the possibility of analysing not only efficiency but also equity. That is, who gains and who loose? Secondly, we get a better and easier derivation of consumer surplus measures, because double counting are avoided and indirect effects can be included.

However, a high spatial resolution level, which is often required in transport planning, is rarely supported in the data foundation of especially supply quantities. As a result, limitations need to be imposed on especially intermediate commodity flows as well as on the production of manufacturing goods. As a result, the present paper intentionally adopted a minimalistic approach to minimise problems related to data and calibration. Firstly, on the supply side, we suggest a design that corresponds to Lorry (1964). Hence, we distinguish between a manufacturing sector and a local service sector. The first are assumed exogenous, whereas the production level of the latter are determined endogenously in interaction with households. Furthermore, the production technology is assumed to be simple in the use of intermediates. The service sector conveys a single intermediate into a composite good using land, labour, and capital. Intermediates are used under Armington conditions. Finally, households are assumed to optimise behaviour in a two stage process. Firstly, they optimisation short-term activities, whereas in a second step they optimise strategically. As a consequence, the model will incorporate migration in a dynamic interaction with the infrastructure and the supply side.

5.1 Future directions

The model is to be calibrated on data from the Copenhagen region. The data foundation already exist in terms of a detailed land--use database, a large passenger transport survey, a freight transport survey, as well as a regionalised social accounting matrix at the municipality level. The line of action include;

- Construction of a consistent base year social accounting matrix, compiled from the various sources of information.
- A strategy for calibrating model parameters.
- A model closure.

References

Armington, P.S., 1969. A Theory of Demand for Products Distinguished by Place of Production, International Monetary Fund Staff Papers, 16, 159-78.

Bröcker, J., 1998. Operational Spatial Computable General Equilibrium Modelling, Annals of Regional Science, 32(3) 367-387.

Bröcker, J., 1999. Trans European effects of "Trans European Networks": Results from a spatial CGE analysis, Mimeo, Technical University, Dresden.

Bröcker, J., 2002. Passenger flows in CGE models for transport project evaluation, Paper presented at 42th ERSA Congress, Dortmund.

Ivanova, O., 2003. A Spatial Equilibrium Model with explicit representation of transport networks, Paper presented at the 5th Norfa Workshop, Haugesund.

Lowry, I.S., 1964. A Model of a Metropolis, S.Monica CA, Rand Corporation.

Rich, J.H., 2001. Two aspects of location modelling: Short-term versus long-term demand and the case of two-worker households. In Hensher D., editor, Travel Research Behaviour - The leading Edge, chapter 24, pp. 397-409. Pergamo, 2001.