Passenger Flows in CGE Models for Transport Project Evaluation*

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May 2002. Paper to be presented to the ERSA Congress 2002, August 2002, Dortmund

Abstract

Recently computable general equilibrium (CGE) methods are becoming more and more popular for estimating welfare effects of transport projects, when a differentiation by region or social group is required. This paper focuses on the spatial distributional dimension. Most spatial CGE applications, however, have up to now only taken the impact of goods transport costs into consideration. To a large extent, however, welfare effects are due to time and cost savings in passenger transport. This paper extends the CGE approach by including business and private passenger travel. It aims at an empirically operational model design deriving passenger flows from optimizing behaviour of firms and households. Equivalent variation measures for quantifying welfare impacts in monetary terms are derived. Another contribution of the paper is to discuss certain complications arising in the standard DIXIT-STIGLITZ approach of modeling monopolistic competition, if transport costs are additive rather than multiplicative.

1 Introduction

Though extensive research is already under way for assessing the infrastructural needs as well as costs and benefits of individual projects, very little is still known about the spatial distribution of the benefits. Traditional approaches to cost benefit and regional impact analysis are not really capable of taking account of the complex mechanisms by which transport cost changes affect the spatial

*Preliminary, comments welcome. Financial support of the EU Commission within 5th Framework RTD Programme, Thematic Programme "Promoting Competitive and Sustainable Growth", Key Action 2 "Sustainable Mobility and Intermodality", Objective 2.1: "Socio-Economic Scenarios for Mobility of People and Goods", Project IASON, is gratefully acknowledged. Responsibility for the content of this paper is strictly mine.

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allocation. This holds true already in a static framework, not to speak about the even more complex channels through which the transport system affects economic dynamics. The critical issue is to assign the benefits from using the transport links to regions. Assigning costs and benefits from construction and maintenance to regions is less of a problem, and traditional techniques like multiplier analysis are acceptable. Assessing the benefits from newly installed capacities and answering to the question where they accrue, however, is much more difficult. Four types of methods are used in practice.

The *first* is to assign benefits as measured by direct cost reductions or consumer surpluses gained on the links under study, to the place of investment itself. This method is applied in the official German manual for transport infrastructure evaluation [9], for example. Its shortcomings are so obvious, that a further discussion is not worth the effort.

The *second* method is to measure benefits by estimating rates of return on infrastructure investments in a production function approach, using cross section, time series, or panel data. An influential take-off of this literature was Aschauer [2], see [15] for a survey. Intricate econometric problems have to be solved for this type of analysis which are thoroughly discussed in an extensive literature. As far as the regional distribution of effects is concerned, however, the shortcomings of this approach are similar to those of the first one. While accessibility changes may affect many regions — possibly in a different way, depending on the pattern of interregional flows — this approach attributes all output effects exclusively to the region, where the respective investment is done.

The *third* method is to establish an interregional demand driven input-output model with trade coefficients depending on transportation costs (the EUNET model [13] is an example). Though this seems attractive because a lot of sectoral detail can be taken account of, it gives a theoretically unconvincing picture of the effects of changing transport costs, because the approach is based on the traditional fixed coefficients input-output model. Hence, the interrelation between price and quantity effects, that spread through the economy along forward and backward linkages, is not handled satisfactory.

The *fourth* method is to measure the impact of transport cost reductions by accessibility indicators telling how a region's generalized cost of reaching its markets and of traveling to a hypothetical set of destinations is affected by the cost reductions. In a second step accessibility changes are then related to regional economic indicators like GDP per capita or real growth of GDP, using cross section regression techniques (see the SASI model [17] or [16]).

The *fifth* more recent technique is to set up a multiregional computable general equilibrium (CGE), in which transport costs explicitly appear as firms' expenditures for transport and other kinds of business travel and as households' costs of private passenger travel. CGE models with a spatial dimension (SCGE) have recently been applied to transport project evaluation by several authors [20, 3, 6, 5, 7, 18] (see [4] for an introduction). These contributions have made considerable progress in comparison to the traditional approaches itemized above. They nevertheless still suffer from several limitations. Some models lack sectoral detail, they are confined to trade costs and disregard costs of passenger travel, or they take costs of business travel into consideration, but disregard transport costs for goods. This paper introduces some essential features of a new version of our presently running model called CGEurope. The new version is under development within a research project in the 5th framework program of the EU, called IASON, aiming at developing methods for a comprehensive evaluation of spatial impacts of transport initiatives. Transport initiatives include infrastructure investments as well as transport policies influencing transport expenditures by pricing policies, deregulation and others (see the IASON homepage [1] for the first progress reports).

Compared to the version of CGEurope already in use [6, 4, 3] the new version to be implemented in IASON is extended in the following respects (for details see the IASON progress report [8]):

- The current version has only two sectors (tradables an non-tradables), while the new one has more sectors, including special sectors producing transport services.
- The new version models the use of resources for transport in a more sophisticated way than the current one by including explicitly the just mentioned activities producing transport services. In the current version these resources simply come from using up certain amounts of the composite of tradable goods.
- The current version takes only transport costs in interregional trade into account, while the new one also includes business travel and private passenger travel. Business travel is a service produced by a special sector, while private passenger travel is a consumption good, for which households need a service of another special sector. Their expenditures for this service represent their out-of-pocket costs. In addition to that, they also have time costs, modeled as a disutility in the households's preferences.
- Finally, the transport network from which the cost measurement is derived will be much more refined, based on the networks developed within the SASI project.

The way how transport cost changes are modeled in this framework is obvious. After having calibrated the model, such that the data of a benchmark year are reproduced, transport costs or travel times are changed exogenously and the new equilibrium system is solved. The main indicator for the regional consequences one is looking at is the welfare change of regional households, as measured by the households' utility functions. Though an ordinal utility index as it stands has no operational meaning, it can be transformed to the so-called Hicks-measures of variation. They measure the welfare change in monetary terms (see [19, p. 161]).

CGEurope is confined to the regional welfare effects resulting from the use of the transport infrastructure. Effects from the construction phase, from financing and maintenance are not considered. We also do not include local traffic including commuting, even if it is commuting over longer distances crossing the borders of the regions in our system.

2 Non-formal description of the new CGEurope

CGEurope is a static non-monetary equilibrium model for a closed system of regions. The world is subdivided into a large number of regions.[1] Each region shelters a set of households owning a bundle of immobile production factors used by regional firms for producing in several sectors two kinds of goods, non-tradable local goods and tradables. Firms use factor services, local goods and tradables as inputs. In addition, they also use a special kind of input called business travel, which is produced by a special service sector. The unit costs of the service required by firms depend on the state of the transport infrastructure as well as on national segmentation of space. An extra cost is added for international trips, representing additional costs of communication, travel restrictions et cetera.

The firms in a region buy local goods from each other, while tradables are bought everywhere in the world, including the own region. Produced tradables are sold everywhere in the world, including the own region. Free entry drives profits to zero; hence, the firms' receipts for sold local goods and tradables equal their expenditures for factor services, intermediate local and tradable goods and business travel.

Goods trade is costly. For transferring goods from the origin to the destination, resources of two kinds are required, namely (1) information and service costs and (2) transportation costs for goods, including any kind of logistic costs. The former are assumed to come in the form of costs for passenger travel, that are another expenditure item of firms, paid to the business travel producer. The latter are paid to another special industry producing the goods transportation service. The cost amount of both kinds per unit of traded good is again a function of the state of infrastructure, and an extra cost is added for international flows.

Regional final demand, including investment and public sector demand, is modeled as expenditure of utility maximizing regional households, who spend their total disposable income in the respective period. Disposable income stems from returns on regional production factors, which, by assumption, are exclusively owned by regional households, and a net transfer payment from the rest of the world. This transfer income can be positive or negative, depending on whether the region has a trade deficit or surplus. Transfers are held constant in our simulations. Introducing fixed interregional income transfers is a simplified way to get rid of a detailed modeling of interregional factor income flows, and of all kinds of interregional flows of private and public funds. Households expend

[1] The current version has 805 regions, of which 800 cover Europe, including the Asian parts of Russia and Turkey. The new version has more, but the model version with full sectoral detail can only be implemented on a level, that is more aggregated with regard to regions (see [8] for details).

their income for local and tradable goods as well as for travel. The vector of travel demand is differentiated by destination. Households gain utility from a set of activities connected with travel (like tourism) and suffer from disutility for spending travel time. We exclude commuting and other kinds of local traffic like shopping et cetera. Implicitly, expenditures for these activities are included in consumption demand and are assumed not to be affected directly by the transport policies studied in comparative static simulations.

The factor supply is always fully employed due to the assumption of perfect price flexibility. We assume complete immobility of factors, which means that interregional factor movements as a reaction an changing transport costs is not included. The other extreme assumption would be perfect factor mobility; but this is not realistic. Immobility is taken as a first approximation for short term effects. The best choice would be mobility, but an imperfect one. There are ways of introducing such an assumption, but theoretically consistent approaches require forward looking dynamics, which are too complicated to be introduced into our model in the present stage of its development.

Firms representing production sectors are of two kinds, producers of local goods and producers of tradables. Each local good is a homogeneous good, though one equivalently may regard it as a given set of goods, such that the good's price is to be interpreted as the price of a composite local good. The market for tradables, however, is modeled in a fundamentally different way, following the by now popular Dixit-Stiglitz approach[2]. Tradables consist of a large number of close but imperfect substitutes. The set of goods is not fixed exogenously, but it is determined in the equilibrium solution and varies with changing exogenous variables. Different goods stem from producers in different regions. Therefore relative prices of tradables do play a role. Changes of exogenous variables make these relative prices change and induce substitution effects.

Households act as price taking utility maximizers. They have a nested-CES utility function representing substitution between goods and travel activities, between goods from different sectors, between different kinds of travel activities, between destinations for each kind of travel and between varieties for each kind of goods. Travel time disutility is subtracted from the households' utility function in an additive separable format.

Firms maximize profits. Local goods producers take prices for inputs as well as for local goods sold to households and other firms as given. The production functions are linear-homogeneous nested-CES functions. The lowest CES nest for intermediate inputs makes a composite out of the bundle of tradables. For the sake of simplicity it is assumed to be identical for all users and to be the same as the respective CES nest in the households' utility function. Input of business travel is also represented by a CES nest on the lowest level, making a composite good of business trips between the firm's location and all regions of the world, that are potential destinations of business trips. Due to linear-

[2]The idea is from [10]. It has been introduced into trade analysis by Ethier [11] and into economic geography by Krugman [12]. For a wide range of applications see [14].

homogeneity the price of a local good equals its unit cost obtained from cost minimization under given input prices.

Tradable goods producers take only prices for inputs as given. They produce a raw output by a technology designed in the same way as for local goods producers. Instead of directly selling their output, however, they transform the homogeneous raw output into a final differentiated output. The respective technology is increasing returns, with a decreasing ratio of average to marginal input. Firms are free to compete in the market for a tradable good which already exists, or to sell a new one not yet in the market. The latter turns out to be always the better choice. Hence, each good is monopolistically supplied by only one firm, which is aware of the finite price elasticity of demand for the good. The firm therefore sets the price according to the rules of monopolistic mark-up pricing. This choice, of course, is only made if the firm at least breaks even with this strategy. If it comes out with a positive profit, however, new firms are attracted opening new markets, such that demand for each single good declines until profits are driven back to zero.

This is the well-known mechanism of CHAMBERLINian monopolistic competition determining the number of goods in the market as well as the quantity of each single good. Due to free entry the price of a tradable good just equals its average unit cost. It turns out that under the assumption of a constant price elasticity of demand for each variety of goods, output per variety is also constant, such that output variations come in the form of variations in the number of varieties, and real output is the endogenous measure of variety. In the main part of this paper we just assume all producers in a sector to face the same constant price elasticity of demand for their respective supplied brands. In the standard economic geography model with the so-called iceberg form of transportation costs this would be implied by the model, but in our case with transport costs being an additive component of the local price this holds only approximately. We discuss this complication below in section 3. The main part of the paper regards it as a nuisance, though, that would make hardly any difference in the numerical results.

Certainly, assuming local markets to be perfectly competitive lacks empirical plausibility. Local goods producers may in fact exert some monopoly power, local goods might be diversified, just like tradables, et cetera. The reason why this assumption is nevertheless preferred is that this is the simplest way to get rid of the local sectors which only play a secondary role in an analysis focusing on interregional trade. Another choice without major technical problems would be to assume monopolistic competition for the local sectors as well. This, however, is not recommended, because it introduces a size-of-region effect. Large regions in our system (like the Asian part of Russia, for example) would support a high diversity of local goods, generating an unrealistic low prices of composite local goods, given the factor price(s) and technology in the region.

Three features give the model its spatial dimension:

- the distinction of goods, factors, firms and households by location,
- the explicit incorporation of cost for trading goods (and services, regarded

as a special kind of goods) as well as costs for business travel, depending on geography as well as national segmentation of markets, and

- the explicit incorporation private passenger travel, with time costs and out-of-pocket costs depending on geography as well as on national segmentation of space.

2.1 The formal structure

2.2 Notation

Lower case Greek letters are parameters, upper case Greek letters are exogenous variables, calligraphic letters like $\mathcal{F}$ are functions. All others are endogenous. Subscripts $r, s \in \{1, \ldots, R\}$ denote regions, superscripts $i, j \in \{1, \ldots, I-3, b, g, h\}$ denote sectors. There are three special sectors at the end of the list, one producing a service called "business travel" (sector b), one producing a service called "goods transportation" (sector g), and one producing a service called "services for private passenger travel" (sector h). Superscripts $k \in \{1 \ldots, K\}$ denote factors. Vectors are bold faced, and always understood as column vectors. An apostroph $'$ denotes transposition of a vector.

- $\boldsymbol{A}_r$ — $(I \times I)$-matrix of intermediate input-coefficients with typical entry a_r^{ij} denoting the input of goods from sector i per unit of sector j's output. If i denotes a tradable, the respective input is meant to be the CES-composite made of all the varieties bought in region r as well as in all other regions. This composite is the same for firms using it as an input as for households consuming it, as already mentioned.
- $\boldsymbol{B}_r$ — $(K \times I)$-matrix of primary input-coefficients with typical entry b_r^{kj} denoting the input of factor k per unit of sector j's output.
- $\boldsymbol{X}_r$ — $(I \times 1)$-vector of regional outputs with typical entry X_r^i;
- $\boldsymbol{p}_r$ — the corresponding mill price vector with typical entry p_r^i.
- $\boldsymbol{D}_r$ — $(I \times 1)$-vector of regional demand for (composite) goods with typical entry D_r^i;
- $\boldsymbol{q}_r$ — the corresponding price vector with typical entry q_r^i.
- $\boldsymbol{F}_r$ — $(I \times 1)$-vector of regional final demand for (composite) goods.
- $\tilde{\boldsymbol{F}}_r$ — $((I-3) \times 1)$-vector of regional final demand for (composite) goods, with the three last elements (demand for transport services) deleted; $\tilde{\boldsymbol{F}}_r = (F_r^1, \ldots, F_r^{I-3})'$.
- $\boldsymbol{\Psi}_r$ — $(K \times 1)$-vector of regional factor supply with typical entry Ψ_r^k;
- $\boldsymbol{w}_r$ — the corresponding price vector with typical entry w_r^k.

- t^i_{rs} tradables from sector i delivered from region r to region s.
- c^i_{rs} Cost for shipping one unit of i-goods from region r to region s, such that the local price for this unit in region s equals $p^i_r + c^i_{rs}$.
- σ^i Elasticity of substitution between varieties produced by sector i.
- Λ State of transport infrastructure.
- $\mathcal{F}^i_r(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)$ Unit cost function derived from cost minimization subject to the representative firm's technology; its value is the cost per unit of sector i's output.
- $\mathcal{B}_{rs}(\Lambda)$ Business travel distance from region r to region s, defined as the amount of the b-good (business travel service) per return trip from r to s; thus, $q^b_r \mathcal{B}_{rs}(\Lambda)$ is the cost per trip, because the service is assumed to be bought entirely in the region of origin.
- $\mathcal{H}_{rs}(\Lambda)$ Similarly for private passenger travel: private passenger travel distance from region r to region s, defined as the amount of the h-good (private passenger travel service) per return trip from r to s; thus, $q^h_r \mathcal{H}_{rs}(\Lambda)$ is the cost per trip.
- $\mathcal{D}_{rs}(\Lambda)$ Travel time for a private passenger return trip from region r to region s; for the sake of simplicity, one may assume, as an acceptable approximation, $\mathcal{H}_{rs}(\Lambda)$ and $\mathcal{D}_{rs}(\Lambda)$ both to be proportional to a common measure of time distance; then both are the same, up to a factor.
- $\mathcal{G}^i_{rs}(\Lambda)$ Goods transport distance from region r to region s determining the amount of the g-good (goods transport service) needed for shipping i-goods from r to s. The g-good stems entirely from region s, such that $q^g_s \mathcal{G}^i_{rs}(\Lambda)$ is the transportation cost argument in the function $\mathcal{T}^i$, specifying unit trade costs and explained next.
- $\mathcal{T}^i(q^g_s \mathcal{G}^i_{rs}(\Lambda), q^b_s \mathcal{B}_{rs}(\Lambda))$ Trade cost function, merging transportation cost and business travel cost to a composite trade cost per unit shipped.
- $\boldsymbol{y}_r$ $(R \times 1)$-vector of households' trips with typical entry y_{rs} denoting the number of return trips to region s taken by households living in region r.
- Y_r regional income.
- Υ_r Net income transfers from other regions to region r.

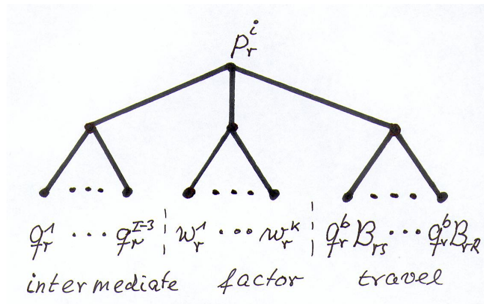

Figure 1: Firm's decision tree

- $\mathcal{C}_r(\boldsymbol{q}_r, Y_r, \Lambda)$ Household's demand function, assigning vectors of final goods demand and passenger travel demand to local prices, income and the state of the infrastructure determining, via functions $\mathcal{H}$ and $\mathcal{D}$, time costs and out-of-pocket costs for the trips. (When deriving $\mathcal{C}$, further variables and parameters will be introduced below in subsection 2.4.)

2.3 Firms

Each sector j in a region r is represented by a firm (or a set of identical firms) with linear-homogeneous technology represented by the unit-cost function $\mathcal{F}_r^j(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)$. Hence, by Shephard's lemma, the input coefficients for intermediate goods (a_{ij}) and production factors (b_{kj}) are

$$a_r^{ij} = \frac{\partial \mathcal{F}_r^j(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)}{\partial q_r^i}, \tag{1}$$

$$b_r^{kj} = \frac{\partial \mathcal{F}_r^j(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)}{\partial w_r^k}. \tag{2}$$

The unit-cost function is a nested constant elasticity of substitution (NCES) function, with a lower nest representing the choice between destinations for business travel. See figure 1 for an example, where the respective prices or unit-costs are assigned to the inputs. The unit-cost of a return trip from r to s is $q_r^b \mathcal{B}_{rs}(\Lambda)$. The partial derivative of the NCES function with respect to $q_r^b \mathcal{B}_{rs}(\Lambda)$ yields, by Shephard's lemma, the number of trips from r to s per unit of output. Demand for business travel service per unit of output is the total derivative with respect to q_r^b, which is of course the same as summing over all trips, each multiplied by the respective travel distance $\mathcal{B}_{rs}(\Lambda)$.

The firm's output is either directly sold as a local good under perfect competition, or it is regarded as a "raw output" transformed to a set of horizontally diversified brands of tradable goods. Each brand is supplied under monopolistic competition in the Dixit/Stiglitz style and produced by using up the firm's output in a double way, once for variable costs that are proportional to output,

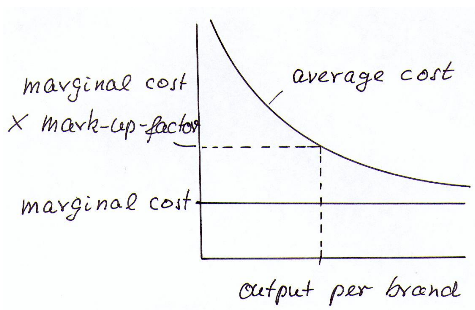

Figure 2: Output decision of firms under monopolistic competition

and once for fixed costs which are proportional to the number of supplied varieties. If the price is a fixed mark-up over marginal costs and profits are driven to zero by free market entry, then the output per brand is also fixed, and total output of diversified goods is proportional to the amount of raw output used for producing them (see figure 2). With an appropriate choice of units the factor of proportionality can be chosen to be unity, such that the raw output quantity is the same as the final diversified output, and the price is the unit cost. Hence,

$$p_r^i = \mathcal{F}_r^i(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda). \tag{3}$$

Up to now, the constant mark-up is an assumption, not a conclusion. In fact, if customers choose between varieties according to a CES function *and if* transport costs are multiplicative (like with the iceberg type of transport costs), then the constant mark-up follows from optimizing behaviour, while with additive transport costs mark-ups derived from optimizing behaviour would strictly speaking not be constant. We continue with assuming a constant mark-up factor until we come back to the point in section 3.

2.4 Households

Households in region r own the stock of factors Ψ_r, that is assumed to be fully employed due to price flexibility and perfect competition on the factor market. Up to now, we neither deal with unemployment nor with interregional factor mobility. Households' income then equals

$$Y_r = \boldsymbol{\Psi}_r' \boldsymbol{w}_r + \Upsilon_r, \tag{4}$$

where Υ_r denotes an exogenous net income transfer, summing to zero over all regions of the closed world. In a real model like this, where only relative prices are determined and the price level is arbitrary, fixing an exogenous variable in nominal terms makes no sense, of course. In our comparative static simulations, we therefore fix the price level by holding constant a global consumer price index. Hence, implicitly Υ_r is fixed in real terms. Υ_r is introduced for allowing for regional (and, hence, also national) balance of trade deficits or surpluses.

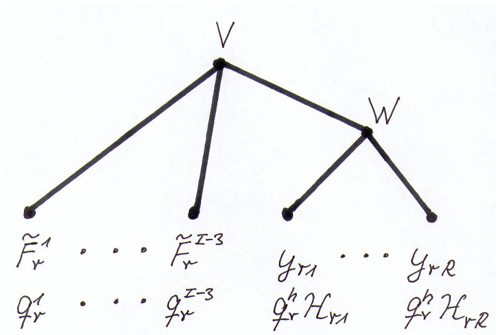

Figure 3: Household's decision tree

It represents transfers through the public budget, factor payments and capital flows, which are all taken as exogenous here for keeping things tractable. In fact, endogeneous public transfers require a public sector submodel, which we want to avoid, and endogenous capital flows would even require a dynamic model with forward looking agents and all that, which is out of our reach.

There is no public sector and no explicit investment decision in our model. Therefore, households' demand represents all final demand, including public consumption as well as public and private investment. Households spend their income for consuming goods/services and for traveling. Their budget constraint is

$$Y_r = \tilde{\boldsymbol{F}}'_r \tilde{\boldsymbol{q}}_r + q_r^h \sum_s (y_{rs}\mathcal{H}_{rs}(\Lambda))$$

with $\tilde{\boldsymbol{q}}_r = (q_r^1, \ldots, q_r^{I-3})'$. Traveling contributes to the households' utility, but also imposes a burden on them in the form of travel time. We incorporate that in the most simple manner by assuming homothetic preferences of the form

$$\mathcal{U}_r(\tilde{\boldsymbol{F}}_r, \boldsymbol{y}_r, \Lambda) = \mathcal{V}_r(\tilde{\boldsymbol{F}}_r, \boldsymbol{y}_r) - \gamma \sum_s (y_{rs}\mathcal{D}_{rs}(\Lambda)),$$

with a linear-homogeneous function $\mathcal{V}$. That is utility is additive separable in subutility from consuming goods and travel and in disutility of travel time.

A tractable solution can be obtained, when $\mathcal{V}$ is specified as an NCES form, with an upper nest defining the choice between consumption goods $i \in \{1, \ldots, I-3\}$ and a composite travel good, and a lower nest defining the choice between travel destinations (see figure 3). For ease of notation, write C_i for F_r^i and Q_i for q_i^r, $i \in \{1, \ldots, I-3\}$, and write y_s for y_{rs}, P_s for $q_r^h\mathcal{H}_{rs}(\Lambda)$ and T_s for $\mathcal{D}_{rs}(\Lambda)$, $s \in \{1, \ldots, R\}$. Hence, $\boldsymbol{C} = (C_1, \ldots, C_{I-3})$ now denotes the goods consumption vector, $\boldsymbol{Q} = (Q_1, \ldots, Q_{I-3})$ the corresponding price vector, $\boldsymbol{y} = (y_1, \ldots, y_R)$ denotes the travel consumption vector, $\boldsymbol{P} = (P_1, \ldots, P_R)$ the corresponding price vector and $\boldsymbol{T} = (T_1, \ldots, T_R)$ the corresponding travel times vector.

Then we get $\mathcal{U}(\boldsymbol{C}, \boldsymbol{Y}) = V - \gamma \boldsymbol{T}'\boldsymbol{y}$, with

$$V = \left(\sum_i \alpha_i^{\frac{1}{\epsilon}} C_i^{\frac{\epsilon-1}{\epsilon}} + W^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}}, \tag{5}$$

$$W = \left(\sum_s \beta_s^{\frac{1}{\mu}} y_s^{\frac{\mu-1}{\mu}} \right)^{\frac{\mu}{\mu-1}}. \tag{6}$$

ϵ and μ are elasticities of substitution, α and β are position (also called shift or share) parameters. The first order conditions lead to

$$C_i = V\alpha_i(\ell Q_i)^{-\epsilon}, \tag{7}$$

$$y_s = W(V/W)^{\mu/\epsilon}\beta_s(\ell P_s + \gamma T_s)^{-\mu}, \tag{8}$$

with Lagrangean multiplyer ℓ to be chosen such that the budget constraint $Y = \boldsymbol{Q}'\boldsymbol{C} + \boldsymbol{P}'\boldsymbol{y}$ holds. This is a non-linear system in $I - 3 + R + 1$ unknowns. But fortunately, it can be reduced to one equation in the unknown ℓ, from which everything else is obtained in closed form. This equation is

$$\sum_i \alpha_i(\ell Q_i)^{1-\epsilon} + S^{1-\epsilon} = 1, \tag{9}$$

with

$$S := \left(\sum_s \beta_s(\ell P_s + \gamma T_s)^{1-\mu} \right)^{\frac{1}{1-\mu}}.$$

After having solved this for ℓ (what, due to monotonicity, is easy), demand is obtained as

$$C_i = \tilde{C}_i \frac{Y}{\boldsymbol{Q}'\tilde{\boldsymbol{C}} + \boldsymbol{P}'\tilde{\boldsymbol{y}}}, \tag{10}$$

$$y_s = \tilde{y}_s \frac{Y}{\boldsymbol{Q}'\tilde{\boldsymbol{C}} + \boldsymbol{P}'\tilde{\boldsymbol{y}}}, \tag{11}$$

with

$$\tilde{C}_i = \alpha_i(\ell Q_i)^{-\epsilon}, \tag{12}$$

$$\tilde{y}_s = \beta_s S^{\mu-\epsilon}(\ell P_s + \gamma T_s)^{-\mu}. \tag{13}$$

For derivating this result, insert y_s from (8) back into (6) to obtain $W = S^{-\mu}V^{\mu/\epsilon}W^{(\epsilon-\mu)/\epsilon}$. Solving for W yields $W = VS^{-\epsilon}$. Inserting this back into (8) gives

$$y_s = V\beta_s S^{\mu-\epsilon}(\ell P_s + \gamma T_s)^{-\mu}.$$

From this and (7) one obtains (10) to (13) by eliminating V with the budget constraint. Finally, inserting $W = VS^{-\epsilon}$ and C_i from (7) into (5) and dividing the whole equation by V yields (9).

In the summary of the equations given in the appendix for the readers convenience, we denote the demand function resulting from these equations by $\mathcal{C}_r(\boldsymbol{q}_r, Y_r, \Lambda)$, for short. This is a well defined vector valued function assigning the demand for goods and for travel, $\begin{pmatrix} \tilde{\boldsymbol{F}}_r \\ \boldsymbol{y}_r \end{pmatrix}$, to the vector of local prices (including the price q_r^h for the private passenger travel service), to income and to the state of infrastructure, which determines travel costs and travel times via functions $\mathcal{H}$ and $\mathcal{D}$.

The main results of comparative static simulations we are interested in are welfare effects from changing Λ. These are measured by households' utility changes, expressed in monetary terms, using Hicks' concept of equivalent variation. This is simple with homothetic preferences: the relative equivalent variation (that is the equivalent variation as a percentage of the reference income) just equals the percentage change of the linear-homogeneous utility index $U = V - \gamma \boldsymbol{T}'\boldsymbol{y}$. From the last paragraph we obtain

$$V = \frac{Y}{\boldsymbol{Q}'\tilde{\boldsymbol{C}} + \boldsymbol{P}'\tilde{\boldsymbol{y}}}. \tag{14}$$

We have to calculate U for the reference as well as the counterfactual to be evaluated, in order to know the relative (and by multiplying with the reference income also the absolute) equivalent variation.

2.5 Interregional trade

We assume tradables consumed or used as intermediate inputs in the destination region to be a composite good, composed of brands from all over the world (including the own region itself) according to a symmetrical CES index with substitution elasticity σ^i for sector i. Let p_r^i denote the mill price for i-goods from r and c_{rs}^i the transaction cost per unit of good shipped from r to s, such that $p_r^i + c_{rs}^i$ is the local price in s. Then applying the standard formulae for CES functions yields the composite price q_s^i (that is the minimal unit cost per composite tradable) and the trade flows t_{rs}^i from r to s:

$$q_s^i = \begin{cases} \left(\sum_r \psi^i X_r^i (p_r^i + c_{rs}^i)^{1-\sigma^i}\right)^{\frac{1}{1-\sigma^i}} & \text{if } i \text{ is tradable,} \\ p_s^i & \text{else,} \end{cases} \tag{15}$$

$$t_{rs}^i = \begin{cases} \psi^i X_r^i \left(\frac{q_s^i}{p_r^i + c_{rs}^i}\right)^{\sigma^i} D_s^i & \text{if } i \text{ is tradable,} \\ \left\{ \begin{array}{ll} D_s^i & \text{for } r = s \\ 0 & \text{else} \end{array} \right\} & \text{else,} \end{cases} \tag{16}$$

We have included the non-tradable case in the equations for convenience of exposition. D_s^i denotes total use of the composite good in destination region s,

$$\boldsymbol{D}_s = \boldsymbol{A}_s \boldsymbol{X}_s + \boldsymbol{F}_s. \tag{17}$$

$\boldsymbol{A}_r$ is the input-coefficient matrix with typical entry a_r^{ij} given in equation (1).

It has been demonstrated in the empirical literature that interregional transaction costs for goods do not merely consist in transportation costs, but also communication costs. Trade in goods, and even more so trade in services is tied to exchange of information. It is also well documented that even in the age of the internet face-to-face contacts are still indispensable in exchanging information that is not sufficiently standardized to be transmitted by telecommunication. Hence, we assume the costs c^i_{rs} to consist partly of transportation costs and partly of costs for business travel between the source and the destination,

$$c^i_{rs} = \mathcal{T}^i(q^g_s \mathcal{G}^i_{rs}(\Lambda), q^b_s \mathcal{B}_{rs}(\Lambda)),$$

with cost composition according to a CES index. We use a LEONITIEF technology here (that is we set the elasticity of substitution between transport and business travel equal to zero), but in general substitutability is also allowed.

2.6 Equilibrium

What is still missing for closing the system is a complete description of the final demand vector $\boldsymbol{F}_r$. As explained in subsection 2.4, coordinates 1 to $I-3$ of this vector, denoting final demand for goods from all sectors except the three special sectors producing travel and transportation services, are derived from households' utility maximization under the budget constraint. We must add final demand for these three sectors. Demand for the business travel service required in interregional trade is

$$F^b_s = \sum_{i,r} t^i_{rs} \frac{\partial \mathcal{T}^i(q^g_s \mathcal{G}^i_{rs}(\Lambda), q^b_s \mathcal{B}_{rs}(\Lambda))}{\partial q^b_s}. \tag{18}$$

Note that there is also intermediate demand for business travel as explained above in section 2.3. Similarly, demand for the goods transportation service is

$$F^g_s = \sum_{i,r} t^i_{rs} \frac{\partial \mathcal{T}^i(q^g_s \mathcal{G}^i_{rs}(\Lambda), q^b_s \mathcal{B}_{rs}(\Lambda))}{\partial q^g_s}. \tag{19}$$

Finally, demand for private passenger travel is

$$F^h_s = \sum_s \mathcal{H}_{rs}(\Lambda) y_{rs}. \tag{20}$$

Now we have equations for each endogenous variable except factor prices $\boldsymbol{w}_r$. They are determined by the requirement of factor market clearing

$$\boldsymbol{\Psi}_r = \boldsymbol{B}_r \boldsymbol{X}_r, \tag{21}$$

with $\boldsymbol{X}_r$ obtained from the requirement of goods market clearing,

$$X^i_r = \sum_s t^i_{rs}. \tag{22}$$

3 A Nuisance

We have introduced additive transport costs above, such that the local price of a good in the destination region s is the mill price p_r^i plus the transport cost per unit, c_{rs}^i. So far we have neglected the unpleasant fact that this generates certain technical difficulties in the standard Dixit/Stiglitz model, namely that producers are not facing constant price elasticities of demand anymore, even though the elasticity in the demand region still is the parameter σ^i (when the number of brands is large and the choice between brands is described by a CES index).

Omitting the industry index for the sake of notational simplicity, we obtain for the price elasticity of demand in region r

$$e_r = \sigma \sum_s \frac{t_{rs}}{Z_r} \frac{p_r}{p_r + c_{rs}},$$

with $Z_r = \sum_s t_{rs}$ denoting the sales of tradables in r. Let κ and π denote the marginal and fixed cost of tradables, both measured in terms of raw output needed for producing the final output of diversified tradables. Then, by the Amoroso-Robinson condition and the zero-profit condition, we have

$$X_r = \frac{e_r}{e_r - 1} \kappa Z_r = \kappa Z_r + n_r \pi,$$

where n_r denotes the number of brands. Solving for n_r yields

$$n_r = \frac{X_r}{\pi e_r}.$$

Hence, now both, the ratio of tradable sales to raw output and the ratio of the number of brands to raw output vary between regions as a function of e_r, and also vary with varying transport costs or varying prices.

If this is taken serious, our equations must be modified at several points, thus becoming considerably more complicated. The following applies, if i is tradable. We set $\kappa^i = 1$ in the following by the appropriate choice of units. Note that above we have implicitly chosen units such that $\kappa^i \times \text{mark-up-factor}^i = 1$.

1. Equation (3) now becomes

$$p_r^i = \frac{e_r^i}{e_r^i - 1} \mathcal{F}_r^i(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda).$$

2. Equations (15) and (16) become

$$\begin{aligned} q_s^i &= \left(\sum_r \psi^i \frac{X_r^i}{e_r^i} (p_r^i + c_{rs}^i)^{1-\sigma^i} \right)^{\frac{1}{1-\sigma^i}}, \\ t_{rs}^i &= \psi^i \frac{X_r^i}{e_r^i} \left(\frac{q_s^i}{p_r^i + c_{rs}^i} \right)^{\sigma^i} D_s^i. \end{aligned}$$

3. Finally, goods market equilibrium (equation (22)) now becomes

$$X_r^i = \frac{e_r^i}{e_r^i - 1} \sum_s t_{rs}^i,$$

because X measures raw output, while trade flows t are measured in terms of tradable goods.

This complicates the solution considerably, because it introduces an additional unknown e_r^i of the same dimension as prices and quantities. This is avoided by specifications like the iceberg form of transport costs or value related multiplicative costs as in [3] and explains why the trade research community fell in love with icebergs. Still, it would be possible also to handle the more complicated case, in particular as the impact of varying elasticities is likely to be small. Hence, one could solve the model in a first run by setting $e_r^i = \sigma^i$, and then iteratively correct e_r^i. Up to now, our plan is to dispense with the correction run and just stick to the assumption that producers act as if they were facing a constant elasticity, which does not vary over space.

4 Conclusion

This paper shows how CGE models for transport project evaluation can be extended to incorporate, beyond mere transport costs, also costs of passenger travel in a way consistent with microeconomic foundations of agents' behaviour. The transport system, represented by the infrastructure symbol Λ in the above exposition, influences the equilibrium in three ways,

- by determining the costs of goods transportation,
- by determining the costs of business travel, which is a direct production input as well as a component of trade costs,
- and by determining the out-of-pocket costs as well as the time costs of private households' passenger travel.

Our next step is to calibrate the model, which means to specify all parameters and exogenous variables such that benchmark data are reproduced by the model's equilibrium solution. The main problem in this respect is that data for setting up a complete multiregional social accounting matrix do not exist. Most data, particularly the national account data, only exist on the national level, if they exist at all. Calibration is therefore based on the assumption that technologies and preferences do not vary over regions within each nation, such that national information is sufficient for calibrating the respective parameters. Formulating calibration equations with the limited data base and designing algorithms for solving them is another, and rather tedious piece of work, the description of which is beyond the scope of this paper.

The most important results for project assessment generated by comparative static analyses using CGEurope are the monetary measures of regional welfare effects of the evaluated transport initiatives. They measure utility gains of regional households and translate them to monetary amounts by the concept of equivalent variation (EV). One must not confuse these numbers with income changes. EV covers not just utility changes due to income changes. Utility changes are generated by

- changes of factor prices, generating income changes (given constant factor stocks),
- changes of goods prices,
- changes of consumption goods diversity (reflected by changes of the composite goods prices q_s^i in our case), and
- changes of passenger travel times per unit of travel.

Other results which might be useful in an assessment outside the strict framework of cost-benefit analysis are:

- changes in passenger travel by origin and destination;
- changes in interregional trade by sector, region of origin and region of destination, in nominal and real terms; it is worth mentioning that, unlike engineering models of travel flows, CG**E**urope measures real flows not in tons, but as values in constant benchmark prices (like the real GDP, for example);
- output changes, again in real and nominal terms;
- nominal and real income changes;
- factor price changes.

Estimates of real output and flow changes may also help in estimating environmental effects and adding monetarized environmental costs and benefits to the cost-benefit analysis results. These are not covered by the welfare measure generated in CG**E**urope.

Finally, note that CG**E**urope, according to present plans, does neither predict employment effects nor migration effects. Employment is held constant; labor demand adjusts to the fixed level of employment by flexible wages. The spatial distribution of the population is held fixed as well in the comparative static simulations.

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Appendix

For the reader's convenience, we repeat here the equations jointly defining the equilibrium in the order as they appear in the main text.

$$
\begin{aligned}
a_r^{ij} &= \frac{\partial \mathcal{F}_r^j(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)}{\partial q_r^i} \\
b_r^{kj} &= \frac{\partial \mathcal{F}_r^j(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda)}{\partial w_r^k}, \\
p_r^i &= \mathcal{F}_r^i(\boldsymbol{q}_r, \boldsymbol{w}_r, \Lambda), \\
Y_r &= \boldsymbol{\Psi}_r' \boldsymbol{w}_r + \Upsilon_r, \\
\begin{pmatrix} \tilde{\boldsymbol{F}}_r \\ \boldsymbol{y}_r \end{pmatrix} &= \mathcal{C}_r(\boldsymbol{q}_r, Y_r, \Lambda), \\
q_s^i &= \begin{cases} \left(\sum_r \psi^i X_r^i (p_r^i + c_{rs}^i)^{1-\sigma^i} \right)^{\frac{1}{1-\sigma^i}} & \text{if } i \text{ is tradable,} \\ p_s^i & \text{else,} \end{cases} \\
t_{rs}^i &= \begin{cases} \psi^i X_r^i \left(\frac{q_s^i}{p_r^i + c_{rs}^i} \right)^{\sigma^i} D_s^i & \text{if } i \text{ is tradable,} \\ \left\{ \begin{array}{ll} D_s^i & \text{for } r = s \\ 0 & \text{else} \end{array} \right\} & \text{else,} \end{cases} \\
\boldsymbol{D}_s &= \boldsymbol{A}_s \boldsymbol{X}_s + \boldsymbol{F}_s, \\
c_{rs}^i &= \mathcal{T}^i(q_s^g \mathcal{G}_{rs}^i(\Lambda), q_s^b \mathcal{B}_{rs}(\Lambda)), \\
F_s^b &= \sum_{i,r} t_{rs}^i \frac{\partial \mathcal{T}^i(q_s^g \mathcal{G}_{rs}^i(\Lambda), q_s^b \mathcal{B}_{rs}(\Lambda))}{\partial q_s^b}, \\
F_s^g &= \sum_{i,r} t_{rs}^i \frac{\partial \mathcal{T}^i(q_s^g \mathcal{G}_{rs}^i(\Lambda), q_s^b \mathcal{B}_{rs}(\Lambda))}{\partial q_s^g}, \\
F_s^h &= \sum_s \mathcal{H}_{rs}(\Lambda) y_{rs}, \\
\boldsymbol{\Psi}_r &= \boldsymbol{B}_r \boldsymbol{X}_r, \\
X_r^i &= \sum_s t_{rs}^i.
\end{aligned}
$$