Road Pricing and Agglomeration Economies

A new methodology to estimate indirect effects with an application to the Netherlands

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Abstract

Infrastructure investment consumes a large part of the total government budget. Given the restriction on this government budget it is important to look into different ways to improve accessibility and national welfare. A congestion charging scheme may be a good way to improve the allocation of road usage over different user groups, thereby enhancing economic welfare. However, a congestion charge also increases the costs of travelling thereby possibly inducing strong agglomeration effects (Arnott, 2007).

The partial direct cost reduction (or benefits) of congestion charging, being those cost reductions that can be directly attributed to the users or owners of infrastructure, are relatively easy to determine. These welfare gains of direct cost reductions can be estimated using an infrastructure (traffic) demand curve. All other effects besides the direct cost reduction are commonly referred to as the indirect effects. These indirect effects, such as the effects due to agglomeration economies, are more difficult to determine. The New Economic Geography gives us however the theoretical framework to address these agglomeration effects via a spatial computable general equilibrium (SCGE) approach.

Agglomeration effects of *congestion charging* are difficult to assess using a SCGE approach. In a SCGE approach the government revenue due to the congestion charge should be redistributed to the population via additional government expenditure or tax cuts. This redistribution of the government revenue may be either agglomeration or dispersion augmenting. This effect may be very large, turning the analysis in a discussion of the indirect effects of *redistribution schemes* instead of a discussion of the indirect effects of the congestion charge.

In this paper we propose a methodology based on a multiplier derived from a SCGE model to estimate the agglomeration effects of congestion charging with an agglomeration neutral redistribution effect. In this way we *do* take the redistribution effect into account without

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letting it interfere with the effect of the congestion charge. This is important because we only want to evaluate the congestion charge independent of the chosen redistribution scheme.

In our application of the proposed methodology for the Netherlands it is found that agglomeration benefits are substantial and have in general the opposite sign as the relative cost change. The resulting overall indirect effect in a polycentric environment depends on whether the scheme is agglomeration or dispersion augmenting. The total indirect effect of all the congestion charging schemes we investigated where agglomeration augmenting and resulted therefore in additional benefits.

1. Introduction

Infrastructure investment consumes a large part of the total government budget. Given the restriction on this government budget it is important to look into different ways to improve accessibility and national welfare. A congestion charging scheme may be a good way to improve the allocation of road usage over different user groups, thereby enhancing economic welfare. However, a congestion charge also increases the costs of travelling thereby possibly inducing strong negative agglomeration effects (Arnott, 2007).

These agglomeration effects due to changes in transport and commuting costs play an important role in the New Economic Geography (NEG). An overview of the possible effects which occur due to external effects to the size of the market and increasing returns to scale is for instance given in Fujita et al. (1999) or Baldwin et al. (2003). These indirect effects are passed on to parties that are not directly affected by the project (Heyma and Oosterhaven, 2005) via external effects of infrastructure on the working of labor and product markets.

In the interest of providing acceptable guidance to policy makers on the likely impacts, it is important to capture full economic ramifications of the projects (Newbery, 1998). Indirect effects can however only be estimated using a full-fledged spatial computable general equilibrium model (SCGE). A difficulty lies in the fact that solving a spatial general equilibrium model is rather complex with extensive analytical and data requirements (Preston and Holvad, 2005; Thissen, 2005).

A second problem in the specific case of road pricing is inherent to the SCGE approach. In a SCGE approach the government revenue of the congestion has to be redistributed to the population. Otherwise money would leak out of the system causing the policy measure always to be negative. The effect of this redistribution can be large and can be either agglomeration or dispersion augmenting. This may turn the analysis in a discussion of the indirect effects of redistribution schemes instead of a discussion about the charging scheme. In other words, we would not be evaluating a transport policy measure but redistribution policy instead.

The methodology proposed in this paper is needed to estimate the welfare benefits of a congestion charge policy in the presence of agglomeration economies. In our empirical application for the Netherlands we first derive a multiplier that relates the spatial indirect effect to the direct effect. We therefore determine both the effect of a change in accessibility with agglomeration effects using a SCGE model and the effect of a change in accessibility without agglomeration effects using a neoclassical approach. We subsequently present the agglomeration multiplier, which is defined as the ratio of the effects of the model taking agglomeration forces into account with respect to the effects in a model without agglomeration economies. The agglomeration multiplier is region and relation specific.

We can subsequently estimate the agglomeration effects of a congestion scheme using the change in generalized costs. The redistribution of the charge does not affect our indirect effect because it is taken into account separately when we determine the direct effect. In this way we *can* take the redistribution effect into account *without* letting it interfere with the effect of the congestion charge.

In the next section, we present a theoretical framework and a description of the SCGE model (RAEM) employed in this study. Subsequently, we present and discuss the agglomeration multipliers and the indirect effects of congestion charging. The final section concludes the paper with discussions and policy implications.

2. A method to estimate welfare effects of road pricing in the presence of agglomeration economies

The here proposed methodology addresses the problem how to include agglomeration effects in the evaluation of road pricing policies such as congestion charging, without the disrupting effect of the redistribution of the receipts of the road pricing scheme. We will need a general equilibrium model to adequately address the agglomeration economies. However, we do not want to include the redistribution effects in the general equilibrium model. We therefore propose to treat the redistribution effect in a 'standard' partial approach determining the direct effects. Subsequently we will determine the indirect agglomeration effect separately. In this way we don't have to take the redistribution effect into account when determining the agglomeration effect for this effect has already been taken into account when determining the partial direct effect. The total effect will now be the sum of the direct and the indirect effect.

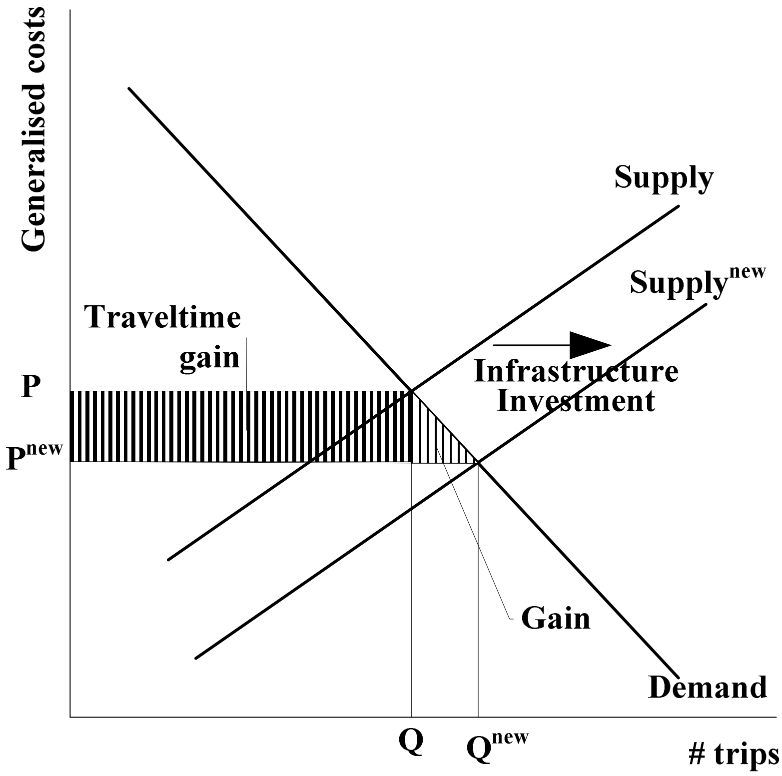
To explain the methodology in more detail we will first discuss the standard approach to determine the partial direct effect. Subsequently we will turn to the approach to determine the indirect agglomeration effect.

2.1 Determining the partial direct effect of road pricing

We can determine the partial direct effect of road pricing using only the demand curve for transport services. We illustrate this methodology by use of Figure 1 and Figure 2. In Figure 1 we present the generally used method to estimate the partial welfare effect of infrastructure investment while the slightly different case of road pricing policies is presented in Figure 2.

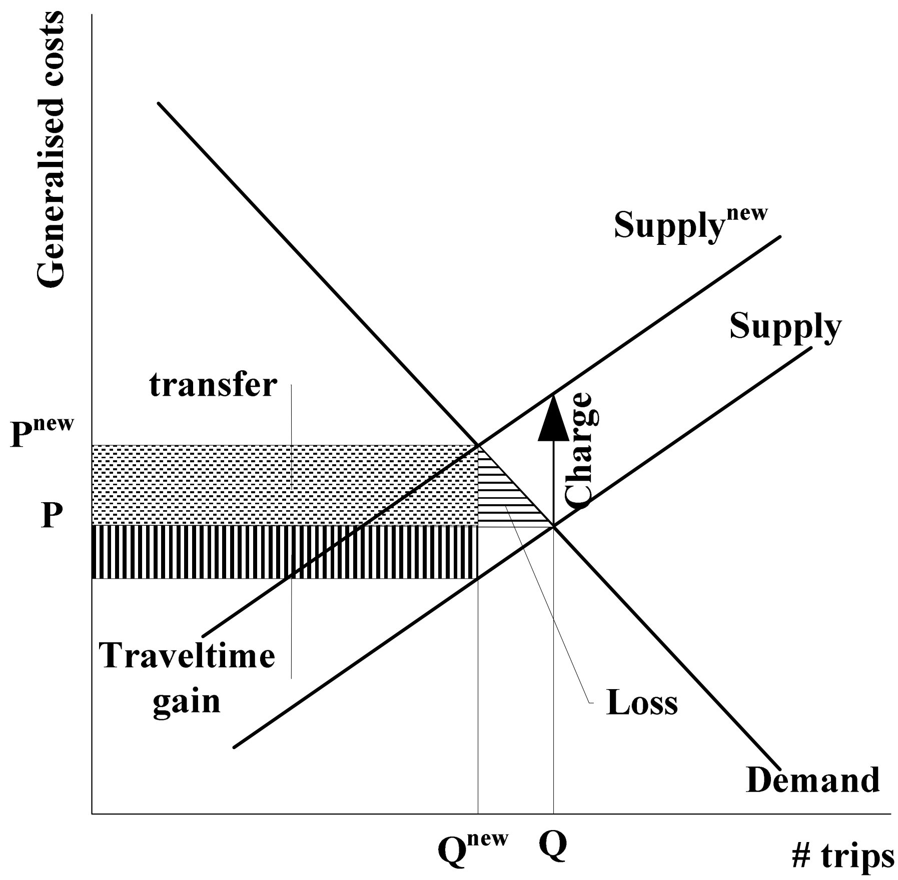
In Figure 1 we see the downward sloping demand curve and the upward sloping supply curve for transport services. On the y-axis we have the price of the transport services while the number of trips is on the x-axis. The equilibrium amount of trips is Q at price P. New infrastructure investment will lead to an outward shift of the supply curve. As a consequence there will be more trips at a lower price because there will be less congestion and there is a travel time gain for those who were using the transport services. There is also an additional welfare gain. This gain is the welfare derived from the transport services by the new users. This is presented by the triangle in Figure 1. The welfare gain, or the partial direct benefit, is presented by the rectangular shape (travel time gain) and triangular shape (gain of new users) in Figure 1.

Figure 1: The partial direct benefits of infrastructure investment



In Figure 2 we present the direct benefit when road pricing policies are implemented. We start in the same equilibrium with price *P* and quantity *Q*. Subsequently a charge is levied for road usages. This will increase the price of road usage and is therefore represented by a upward shift of the supply curve. We will arrive at a new equilibrium at price P^{new} and number of trips equal to Q^{new}. We can see in the Figure 2 that there is a welfare presented by the triangle which represents the loss due to less consumption of trips. The people who still use the road have to pay a charge. This charge is however given back by the government by, for instance, a reduction of income taxes or VAT. Thus this is not a welfare gain but only a redistribution of wealth. However, because less people use the road there is an additional welfare gain, represented by the rectangle in Figure 2, which represents the travel time gain due to less congestion. Thus, the total partial direct benefit is the positive travel time gain and the negative loss due to a fewer number of trips.

Figure 2: The partial direct benefits of road pricing



2.2 Determining the indirect agglomeration effect

The change in generalized costs and the associated change in behavior of the users of transport services are the causes of the agglomeration effect. In case of the analyses of the effect of new transport infrastructure as presented in Figure 1, we would estimate the indirect effect by changing the generalized cost of transport services in a general equilibrium model and calculate the change in welfare. This is explained in more detail in section 5. However, this will give us the total benefit and we calculate the indirect benefit by subtracting the direct benefit. The costs of the infrastructure project are commonly subtracted from the welfare gains in a cost-benefit analysis and can therefore be left out of the analysis.

The indirect benefits can be estimated in almost the same way in the case of road pricing. However, the estimate based on the change in generalized costs would not give us the total effect anymore. This can be easily derived from Figure 2. We see in Figure 2 that the generalized costs go up while there is a welfare gain due to the travel time gains. The reason is that the charge and redistribution should be taken into account. This can therefore only be simulated correctly with a general equilibrium model when the receipts of the road pricing are redistributed to the population. However, the spatial impact of the redistribution scheme will interfere with the indirect effect and therefore it will no longer be obvious whether the road pricing policy is evaluated or the redistribution scheme. We therefore propose a different approach.

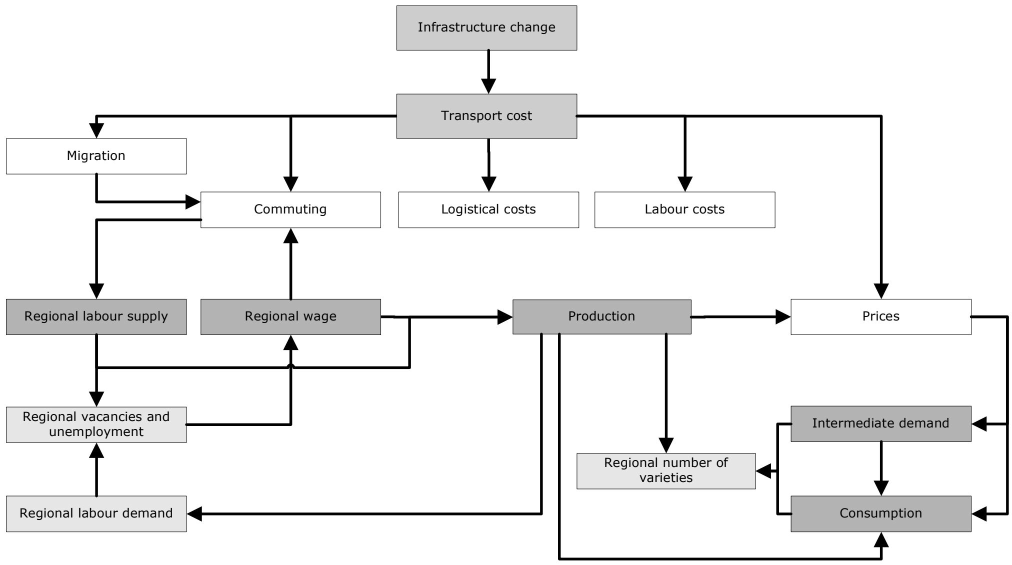
We will start by determining the indirect effect of a change in the generalized costs on every possible link in the model. We do this by model simulations and linearising the outcomes. In this way we get multipliers that represent the total benefits over the change in the generalized costs. We get the indirect effect related to the change in generalized costs by subtracting one from this multiplier. Multiplying the change in generalized costs due to road pricing with the multiplier (minus one) gives us the indirect effect of roadpricing due to agglomeration economies. The total welfare effect is now simply equal to the sum of both the direct and indirect effects. The redistribution effect is now included in the direct effect and has not interfered with the indirect agglomeration effect. In this way we can evaluate road pricing policies in the presence of agglomeration economies without the disrupting effect of the redistribution policy that is associated with the road pricing policies.

3. The SCGE model

The SCGE model "RAEM" that is used in the analysis[1] fits in with the new economic geography theory (NEG) and builds on models developed by Venables (1996) and Oosterhaven et al. (2001). Markets operate under conditions of monopolistic competition, with perfect competition as a special case. The choice between monopolistic and perfect competition is based on data on production and trade in the Netherlands and is not made a priori. The estimated degree of competition on the different product markets determines the agglomeration strength of the respective sectors, in other words the degree to which a particular sector benefits from having other firms in its neighbourhood. The equations referred to in the text below are given in Appendix A.

Figure 3: The effect of infrastructure changes in the model

[1] RAEM is a Dutch abbreviation for Spatial General Equilibrium Model



Although most recent models used in policy analysis resort to simplifying the theoretical models to make them analytically tractable (see Baldwin et al. (2003) for an overview), RAEM does not use these empirical shortcuts and is therefore a theoretically sound and complete model, built in the tradition of general equilibrium models. The main reason for not using simplifications that would simplify the development of the model and analysis using it is the effect that these could have on policy evaluation.

Figure 3 gives an overview of the model from the perspective of infrastructure policies. In this figure, changes in transport costs trickle down through the economy, affecting regional (as well as national) economic development. Transport costs affect the labour market via commuting and the possibility of migration (the housing effect and cost-of-living effect), they affect prices directly and affect logistical costs and labour costs (e.g. with respect to salesmen) that influence the production process. The interaction between regional labour supply and demand and wages results in both national and regional changes in vacancies and unemployment. Changes in regional production affect intermediate demand, consumption and variety through the variety effect, the market-access effect and the market-crowding effect.

3.1 General Structure of the Model

The model uses a multi-sector approach, identifying fourteen sectors in the standard SBI '93 classification. In line with the theoretical framework in the NEG literature, a number of varieties are produced in each sector identified. All these varieties are imperfect substitutes. The model identifies 40 regions in the Dutch COROP classification. Transport costs link the regional goods markets.

A substantial proportion of the indirect effects of transport infrastructure on the regional economy occur because of agglomeration effects. If a firm is able to choose between several varieties of imports, it can increase productivity by having a more roundabout production process. At the same time the utility to consumers increases if they have more variety to choose from, producing strong agglomeration effects in regions. If products become more expensive owing to increased transport costs, access to variety decreases: thus productivity declines exponentially with a decline in the scale of operating.

The labour market is based on the Pissarides (2000) approach, incorporating search theory. The unemployed search for jobs in the various regions with a typical search intensity, while firms look for employees and set a number of vacancies. Given the probability of a match, an unemployed person is hired. In the long run, equilibrium labour supply is such that utility is equal for workers among regions, taking local differences such as those in house prices into account. The medium-term version of the model limits migration between regions and therefore leaves open the possibility of regional utility differences.

3.1.1 Production and Agglomeration

Monopolistic competition is modelled using a nested production function, as in Venables (1996). The first step is to determine what the sectoral demand for goods will be, using a standard Cobb-Douglas production function (0.1). The second step is to specify regional demand, using a standard Dixit-Stiglitz CES approach (0.4).

As regards regional demand for goods, it is assumed that the intermediate market operates under conditions of monopolistic competition where the products from different suppliers in the various regions are not perfect substitutes, based on a standard Dixit-Stiglitz regional CES aggregation

$$Q_j = \left(\sum_i n_i Q_{ij}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

where n_i is the number of varieties in region i, Q_{ij} are the intermediate deliveries from region i to region j, and σ is the elasticity of substitution between varieties. Sector indices are omitted.

Increased diversity of inputs allows producers to use a more ‘roundabout’ production process and lowers unit costs at given input prices, inherent to this CES aggregation. This equation allows for agglomeration effects on product markets in NEG models with vertical linkages.

The standard result with monopolistic competition equilibrium is that the number of varieties equals the nominal production divided by the fixed costs times the substitution elasticity. The substitution elasticity between varieties therefore determines the number of varieties produced in each region, and it is the parameter that determines the strength of agglomeration effects.

3.1.2 Utility and consumption

Although consumption is sometimes modelled analogously to production, it is not considered particularly realistic to have constant nominal shares in consumption. We have therefore opted for the LES (Linear Expenditure System) as a more realistic upper tier (0.6). The lower tier of our Utility function is analogue to the CES function above discussed. Total income in a region is (0.7) spent entirely on consumption, of course. The allocation of income to goods by sector is determined by consumer preferences, which are based on the Stone-Geary utility function (0.14).

Thus love of variety is also assumed. Owing to lack of data, regional substitution elasticity is assumed to be equal for both consumption and intermediate products. The regional spatial demand function (0.7) and the consumer price of the basket of goods aggregated over the regions (0.4) is therefore equal for both intermediate demand and consumption.

3.1.3 The Labour Market

The regional labour market is based on Pissarides' (2000) search theory, whereby the unemployed search for jobs in the various regions with a region-specific search intensity, while firms look for employees and set a number of vacancies based on the cost of a vacancy and the expected gain from and probability of finding an employee (0.12). The labour market is closed by this condition, which means that the return to a vacancy equals the cost of a vacancy. Given the probability of a match, an unemployed person is hired. This search behaviour determines the resulting commuting matrix (0.9). A short or medium-term version of the model sets limits on migration between regions and leaves open the possibility of regional utility differences.

In the short term we may be satisfied with a model without migration, but in the long run this is inappropriate, as it implies permanent utility differences among regions. If we take amenities such as environmental factors and house prices into account, we would expect labour to migrate towards regions with a higher utility level. In the final equilibrium, the labour supply is such that utility is equal for workers among regions, taking local differences such as those in house prices into account.

In the equation (0.13) we postulate that the utility of a worker in a region is a multiplicative function of the utility derived from consumption and that derived from living in a region (housing and living environment factors). The utility of amenities is based on the amount of housing available in a region (the number of workers divided by the exogenous housing stock) and region-specific quality factors of the available housing. Housing can be safely assumed to be a 'normal' good, in other words we assume that there are decreasing returns to housing. We use the most straightforward decreasing returns function, the logarithmic function (0.15). In the long run, equilibrium utility is equal between the regions. The model only determines the relative utility level: in other words, the national utility level has to be set for the base solution.

3.1.4 Transport

Our model identifies three types of transport costs, the cost of commuting (as described in the section on the labour market), the transport cost (of transporting goods from the factory to the shop), and the shopping cost, which comprises the search cost of finding the best variety and the cost of bringing the goods home from the shop, or bringing the consumer to the place of consumption. Most models based on monopolistic competition consider the transport of goods from the factory to the shop. While shopping costs may be negligible in the case of a lot of industrial goods, they are definitely not negligible in the case of services, however: for example a hairdresser's with low transport costs and high shopping costs. All three types of transport cost are exogenous to the model and are determined using different models (Smart and Smart-G, TNO).

In all previous studies known to us the transport costs of goods are modelled using iceberg transport costs, but it is quite easy to show that this produces results that are misleading and simply wrong in a multi-sector context, for the following two reasons:

- Transport is produced with the production function of the good transported. This clearly gives wrong results in service sectors and mining sectors.
- The transport costs are a mark-up over the price of the good to the firm transporting the goods, hence a change in mark-up due to a change in transport costs may produce real production effects on the firm via elasticity of demand. In other words, given the effect of declining transport costs, the firm's sectoral production may also decline, owing to its reduced transport production.

We therefore use a different approach to modelling transport costs. In RAEM, transport costs are a mark-up over the price in a competitive transport market where there is one price for transport. This price is set as the numerair in the model. Thus by setting the mark-up of transport costs over the price, we immediately set the real transport production. We can now determine the total transport used in the model: this equals the total nominal value of transported goods times the mark-up (0.17). We also assume that the demand for transport goods is spread over the country regionally, based on the historical situation (0.18), as there is little empirical evidence of any relationship between transport production and the location of either transport production or transport consumption. Transport is produced using a production function comparable to the other sectors in the model.

RAEM distinguishes between shopping costs and transport costs, shopping costs typically being non-monetary costs,[2] i.e. they are produced and consumed by the household, *not* by the transport sector. These shopping costs affect regional demand for certain goods, however, so they are included in the mark-up over the price of goods with respect to spatial demand, but omitted with respect to material balances.

3.1.5 The government

The role of the government in the model is merely redistributive. It raises income tax to pay for unemployment benefit, which is set at a percentage of the average wage in the Netherlands. Assuming that the government balances its budget, we also know the income tax rate (0.21).

3.2 Interpreting the Model: Main Interactions

The product markets and the labour market are the crucial markets when it comes to the role of transport infrastructure in the economy. The product markets are affected by changes in transport infrastructure via regional trade, and the labour market via workers' commuting behaviour.

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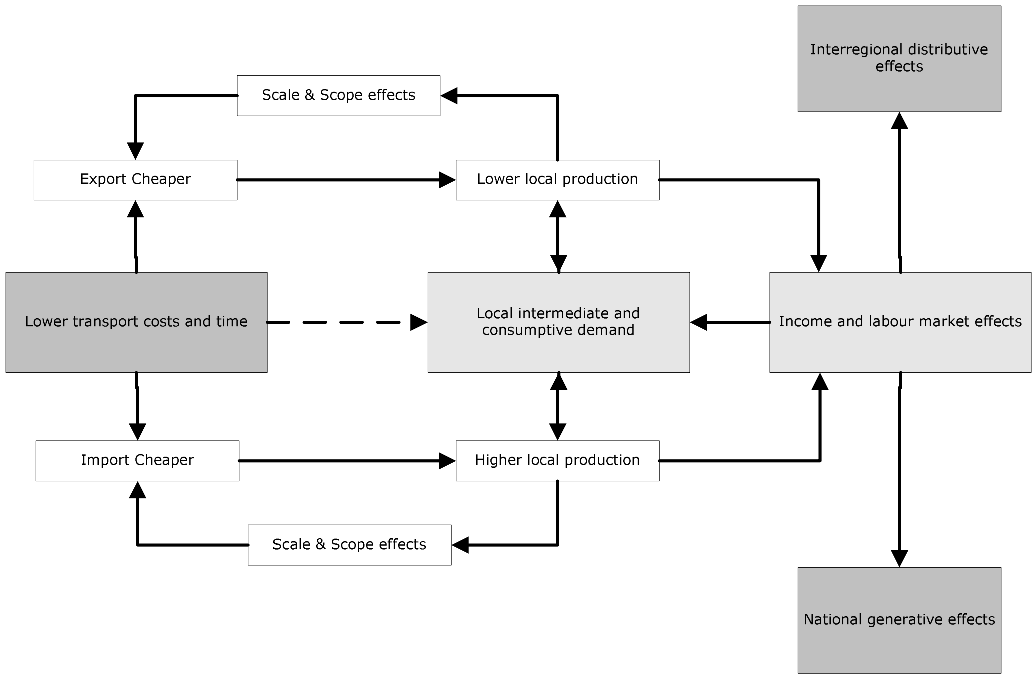
[2] For the sake of convenience we assume that the shopping costs of the firm are also internal to the firm. In the case of firms cf. in particular the search costs and travel costs involved in making business deals.

3.2.1 Interregional Trade and Agglomeration Effects

Product markets play a crucial role in the effect of changes in the economic space on regional economic development. Product markets are affected by changes in transport infrastructure via regional trade and the labour market. The way product markets are affected by changes in transport infrastructure will be given below as an example how agglomeration effects influence spatial economic developments. The effects of a change in transport costs on product markets in a NEG model with monopolistic competition and pecuniary effects such as agglomeration economies are graphically presented in Figure 4. In this flow diagram the other markets, such as the labour market, are taken Ceteris Paribus. A change in transport costs changes the competitive position of different regions. Firms in a region where transport costs decrease due to a new road will see their products become more competitive (cheaper) on other regional markets, but see also product varieties from other regions become more competitive on the local market. Thus, on the local market the firm faces increased competition that will lead to a competitive disadvantage for local industry and may lead to a decline of productivity in the local region due to scale and scope effects. This decline of local productivity causes the relative price of imports to decrease even more which enhances this negative effect for the region (pecuniary externality). On other regional markets the firm faces the opposite effect. Here the firms' products become cheaper causing demand and production to rise with positive scale and scope effects and thereby enhancing the firm's competitive advantage over firms from other regions. Which of the two effects will be dominant depends on the relative dependency of a region to trade and the size of the local market.

Figure 4: effects of changes in transport costs on product markets[3]

[3] This figure is adapted from Oosterhaven and Rietveld (2005).



Consumers see their access to different markets and more varieties increase. As long as the above mentioned potential negative production effect is not too large, it is expected that they gain from the reduction in transport costs. Thus, here we see how a change in transport costs may cause changes in demand and production via scale and scope effects that will lead to both national generative and interregional distributive results. Moreover it was shown that this might lead to cumulative processes via pecuniary externalities that result in far stronger effects than those in models without agglomeration effects.

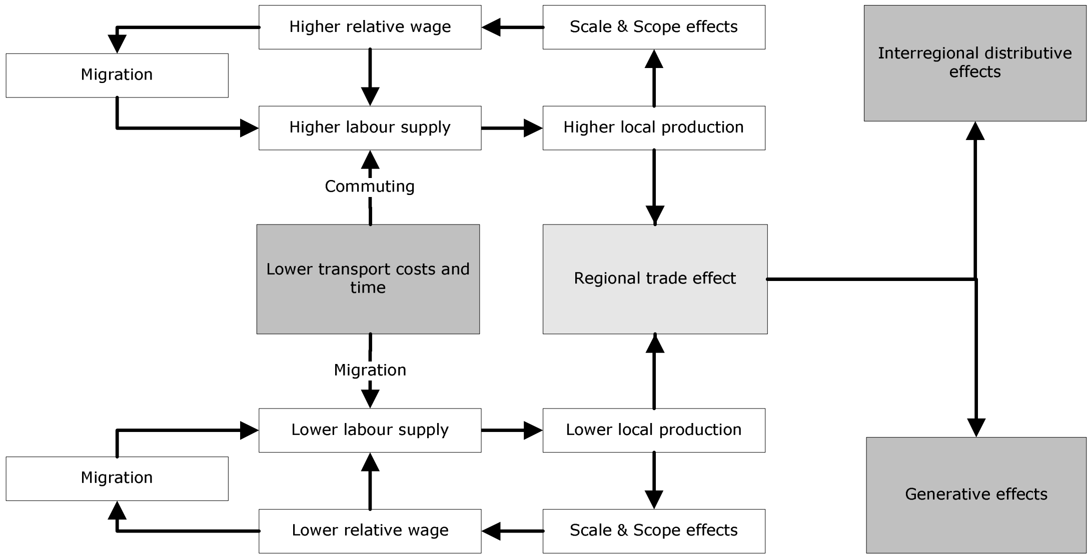
3.2.2 Matching and Efficiency on the labour market

A sudden increase in transport costs will have strong repercussions on the economy via the regional labour market. Pissarides' (2000) approach to modelling the labour market assumes that the unemployed search for jobs in the various regions with a typical search intensity, while firms look for employees and set a number of vacancies. Given the probability of a match, an unemployed person is hired. This search behaviour determines the resulting commuting matrix. The model incorporates unemployment in different regions due to mismatch between searching employees and employers. The labour supply is determined by the long-term equality of the utility of workers among regions, taking local differences such as those in house prices into account. This price of space, determined by the housing stock and the number of people in a region, gives us the equilibrium solution.[4]

How a decrease in transport costs affects the economy is graphically depicted in Figure 5, where product markets are taken ceteris paribus. Transport costs affect the economy by influencing economic behaviour with regard to migration and commuting.

[4] This deviates from the standard Krugman (1980) monopolistic competition model, where there are many possible equilibria.

Figure 5: Effects of changes in transport costs on labour markets



Lower transport costs will also have an effect on migration, hence on the labour market and the regional economy. Here too, however, is the direction of the effect not clear beforehand. Two opposite effects can occur, depending on the size (or economic mass) of the region. If we are in the middle of a agglomeration with strong economic activity we can expect people to migrate there because the higher transport costs make commuting to it less attractive. If we have a region with little economic activity we can expect people to migrate out of it because commuting costs increase for people living there. Fig. 2 assumes that the effect of immigration into the region is dominant. Again the effect is heightened by increases in production and associated scale and scope effects.

Special attention should be paid to possible efficiency and matching effects on the labour market. As mentioned before is the spatial labour market based on employers searching for employees in a certain area. At the same time employees are searching for a job in a certain area. Given commuting distances and search intensities there is a probability for a match, and in that case a vacancy will be filled.

This equilibrating process on the labour market does not guarantee an increase in welfare if commuting distances become shorter. There are two reasons for this. The first reason is that people may be tempted to increase their time looking for a job in the wrong regions, i.e. regions that have no strong agglomeration effects. This may result in labour and production shifting out of the agglomeration and thereby causing a decline in production. In this case there may be an increase in the mismatch on the labour market.

The second reason is that shorter commuting distances on only longer distances may cause a shift from jobs close by to jobs far away. However, productivity of the country may not significantly change. This is caused by the fact that the *relative* commuting time determines the spatial pattern where people work. In case long distance commuting time becomes smaller vis-à-vis short run commuting time, employees will relatively increase their search time looking for a job far away. This will occur whether or not productivity and wages increase in the far away location. However, welfare decreases if there is only a shift from short distance to long distance commuting without a change in productivity, as the only change is an increase in commuting costs.

4. A total benefits multiplier

In a world without space, agglomeration effects or cross-hauling we can estimate the welfare effects using the demand function of infrastructure services. These so-called direct effects are all the partial benefits of infrastructure improvement for the owners or users of transport services.[5] These benefits exactly equal the change in the area under the demand curve for transport infrastructure. This makes them relatively easy to determine.

However, in a world with agglomeration effects this is no longer the case. The effects spill over to other regions and sectors and this is not taken into account when only looking at the users of transport infrastructure. These indirect effects can only be appropriately addressed with an economy wide spatial economic model such as RAEM. The size of these indirect effects can be determined by relating them to the direct effects. That is what we do in this section. We present the spatial under- or overestimation of the benefits of changes in accessibility by relating total benefits calculated with the RAEM model to the direct benefits calculated by use of the demand curve only. We call this ratio of total to direct benefits the total benefits multiplier. This multiplier gives us an indication for the location and the size of agglomeration effects.

Basically the method is straightforward. We analyse the potential of all possible regional connections determining the point elasticity of a 2.5 percent improvement in the travel time between regions. We distinguish among 40 regions in the Netherlands, and we therefore determine 1600 welfare effects of a 2.5 percent change in commuting time and/or transport costs between regions. These welfare effects are based on income equivalents.[6] The model takes explicitly migration into account, which is driven by regional welfare differences. In equilibrium we have therefore always-equal utility levels over the agents from different regions.

In the Figure 6 we present a subset of the most important interregional multipliers with respect to change in the generalised costs of commuting for the 1600 possible relations between all regions. Figure 6 discusses the effects if only commuting is addressed. It is immediately obvious from Figure 6 that the commuting costs within the region have far stronger effects with respect to economies of agglomeration than the commuting costs between regions. The main reason for this was explained before: decreasing intraregional commuting costs keep employees within the agglomerations. Interregional commuting costs lead to more employees working further away without a substantial change in the productivity level. Especially if the commuting costs out of agglomerations decrease there will be negative

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[5] Also external effects are included, but we leave the out here as they are not relevant for the discussion.

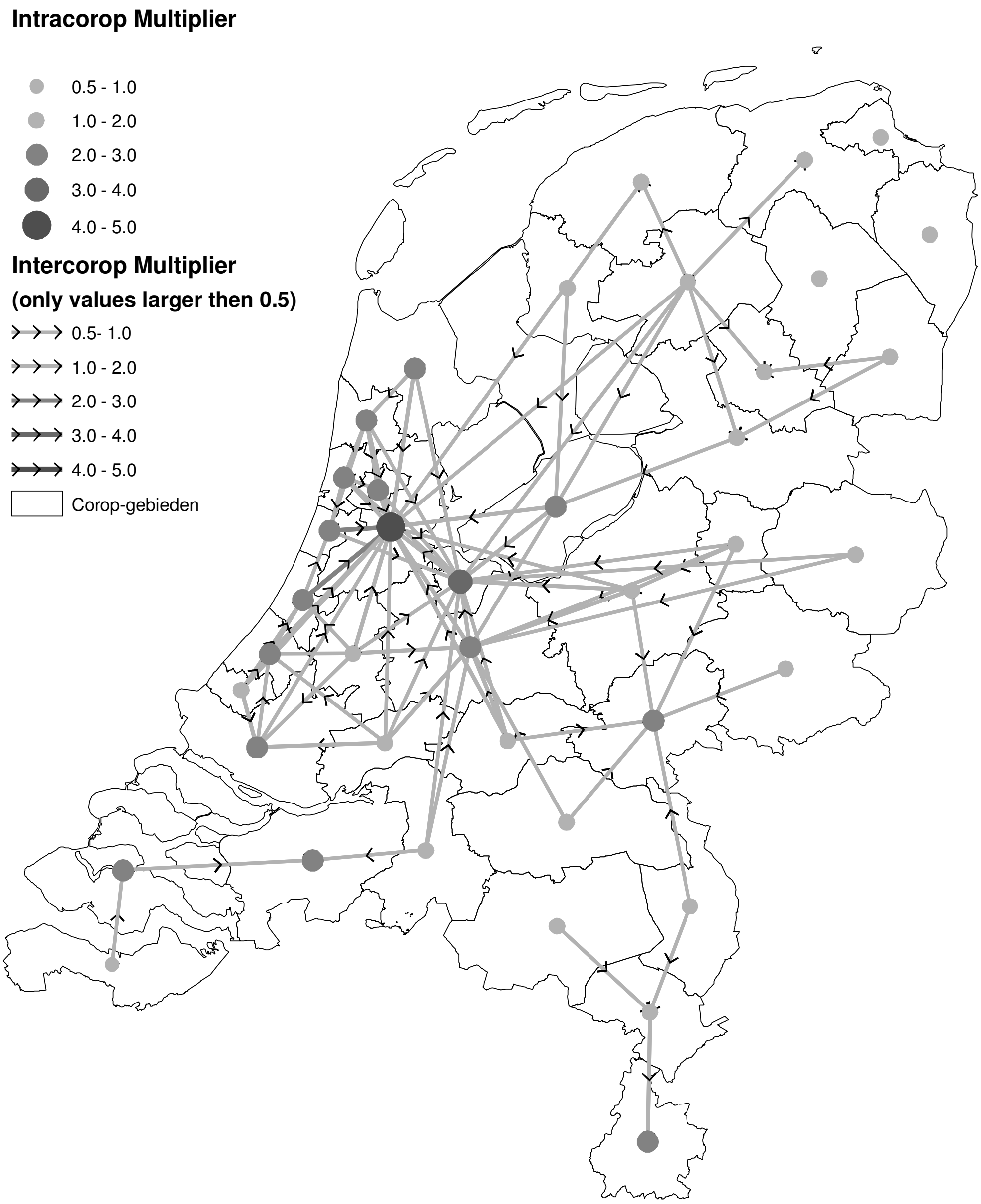
[6] Income equivalents are determined as the extra income that is needed to achieve the new welfare level given prices in the base-run.

welfare effects. Decreasing commuting costs towards agglomerations will induce economies of agglomeration and will cause a positive effect on growth.

In Figure 6 we can also clearly identify the labour market agglomerations by the direction of the arrows. After all, only decreasing commuting costs towards agglomerations generate economies of agglomeration. The labour market agglomerations in the Randstad are therefore Amsterdam, Utrecht, en Rotterdam. The lesser agglomerations Arnhem-Nijmegen (in the east), Maastricht (in the south) and Breda (in the south-west) can also be distinguished.

Including goods transport in the analyses completely changes the picture. Trade profits much more from a decrease in long distance transport costs. The reason is that on longer distances the difference between the regions are larger and trade and specialisation becomes more profitable. This specialisation becomes even more profitable due to the agglomeration economies in the core. It is immediately clear form Figure 6 that Amsterdam is the main centre of gravitation of the Dutch economy. However, there is also a second reason that the effects in Amsterdam are stronger than in other regions. Amsterdam is also the region with the highest congestion and much friction on the housing market, which limits in migration. Reducing these constraints by reducing the commuting and transport costs will have more effect than in other regions.

Fig. 6: The total benefit multiplier for commuting



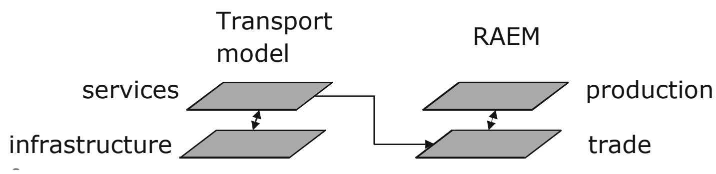
The above discussed difference in the spatial indirect effect between product and labour markets is striking if we compare the freight and commute multipliers. With respect to commuting the intra region multiplier is strongly positive while the inter region multiplier is weak and mostly smaller than 1. The freight multipliers are just the opposite; large between regions and small within regions. The reason is that lower freight costs between different regions stimulates agglomeration effects via trade, while lower commuting costs within regions stimulate agglomerations via migration and less (wasteful) commuting.

5. Congestion charging and agglomeration effects

Estimating the economic effect of congestion charging is complex research that demands both spatial economics analyses as well as transport and traffic analyses. The economic processes of economies of agglomeration often occur on a relatively high spatial aggregation level. Transport and traffic analysis, however, takes place on a transport network where processes on a far lower level of spatial aggregation are important. Moreover, both types of analyses are commonly based on complex models that are numerically difficult to solve. Integrating both analyses is therefore not a realistic option.

The aggregation of the RAEM model that captures the economic effects mentioned above is, however, too high to estimate transport costs including the complete transport infrastructure and logistics network. We therefore need two models: a transport model that uses trade flows as an input to estimate transport costs given the congestion charging, and a RAEM model to estimate trade flows and production levels given transport costs. The transport model used was Smart (TNO). Figure 7 graphically depicts the interaction between the two models.

Fig. 7: The interaction between transport models and RAEM



To overcome these problems, we conducted an analysis in two steps. First, the RAEM model was employed to estimate the agglomeration multipliers presented previously. Second, we used a transport model to estimate generalised costs for car commuters and freight traffic before and after the implementation of congestion charge. The charge was levied only during the peak hours and on roads of which more than 80% of their capacity were being used. Based on the agglomeration multipliers, changes in generalised costs obtained from the transport model were subsequently used to estimate the relative size of agglomeration economies as a result of the congestion charging scheme.

5.1 Changes in generalised costs, direct benefits and indirect benefits

As shown in Figure 8, the congestion charge increases generalised costs of car commuters considerably. This is partly because the journey to work is a mandatory trip and shifting the departure time to off-peak period is not always a viable option. It is clear from the figure that charges are mainly imposed on trips undertaken within the Randstad due to the relatively high level of traffic congestion in this area. We find that the commuting costs within the region increase to a much larger extent than the costs between regions. This reflects the fact that commuting trips within the region still outnumbers those between regions. The generalised costs increases are most apparent for the four major labour market agglomerations in the

Randstad mentioned previously. An increase in generalized costs is also observed for the in-coming links towards these agglomerations. In contrast, the charging scheme reduces the generalized costs of freight transport for both within and between regions. The main reason is that the value of time of freight transport is substantially higher than that of commuters. While some commuters switch to other transport modes because they value their travel time savings lower than the generalized costs post-charging, freight traffic remains on the road and benefits from the travel time reductions as a result of the charging scheme. A decrease in generalized costs is most apparent for Rotterdam, Amsterdam and Eindhoven, where logistics and port activities are concentrated. The magnitude of a change in generalized costs for freight traffic was found to be very small because the cost increase due to the congestion charge was more or less compensated by the value of the travel time gains. This implied that the indirect benefits for freight traffic were also negligible for they are caused by a change in the generalized costs. However, because many of the change in generalized costs were either slightly negative or slightly positive and cannot be considered significantly different from zero, no conclusions can be drawn from them. We will therefore not discuss the results with respect to freight traffic.[7]

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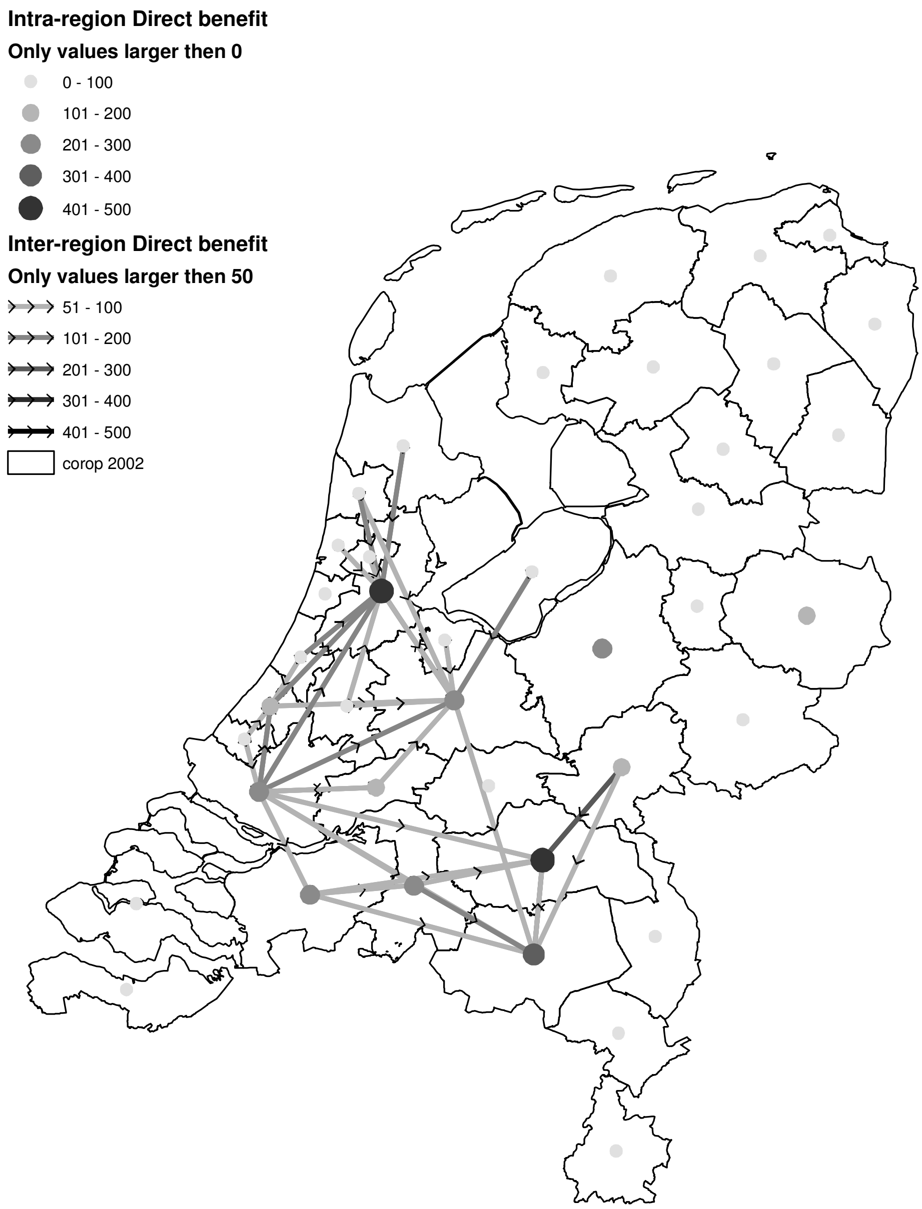
[7] A discussion of the change in generalized costs for freight traffic can be found in the policy research report Hilbers et al. (2007).

Fig. 8: Changes in generalized costs: commuting (unit: 10,000s EUR)

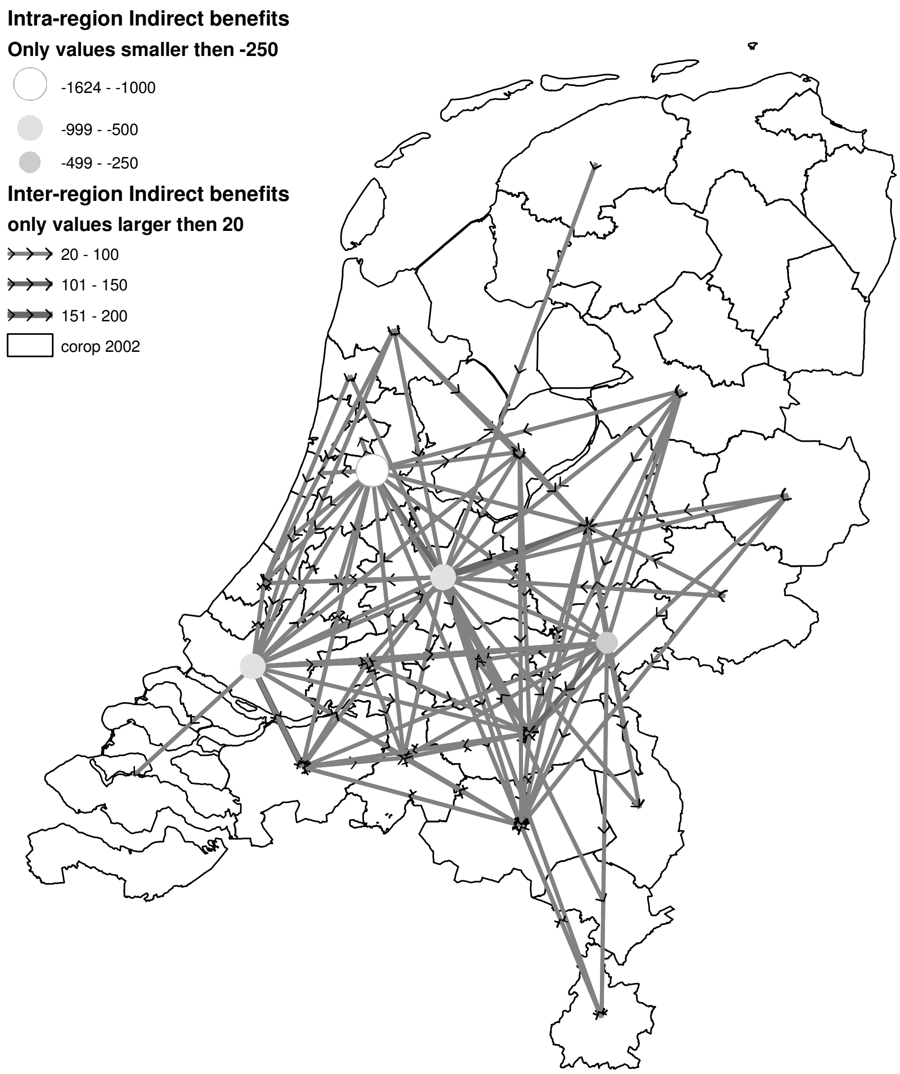
Changes in generalised costs, however, do not directly provide insight into the extent to which a congestion charging scheme contributes to the total economic benefits, which is the sum of direct and indirect economic benefits. Direct benefits in this study refer to the monetary values of travel time savings of travellers and the losses from those who do not longer travel on that route; they are presented with respect to commuting in Figure 9. With regard to commuting, the spatial distribution of direct benefits is somewhat similar to that observed for the changes in generalised costs. We see that the main agglomerations benefit the most from the charging scheme. The benefits are also observed on incoming links towards the aforementioned areas. Following the commuting pattern, direct benefits within the region are found to be much higher than those between regions.

Fig. 9: Direct benefits: commuting (unit: 10,000 EUR)



Concerning indirect benefits, Figure 10 clearly reveals that the charging scheme does bring about additional indirect benefits. However, in contrast with the results of direct benefits, the charging scheme does not always lead to positive indirect effects. We observe negative indirect effects for commuting within the region, while the opposite is true for that between regions. The explanation is that the sign of the indirect effects depends on the extent to which a change in generalised costs leads to an increase in productivity. An increase in generalised costs within the labour market agglomerations such as Amsterdam tends to reduce the job matching and efficiency in the labour market, as discussed earlier. This situation thwarts economies of agglomeration and reduces the productivity level of the region. With regard to the interregional commuting, an increase in generalised costs discourages employees to commute out of the agglomerations because the relative commuting costs increase in the direction out of agglomerations. This relative increase in the costs is due to the travel time gains that are only made when traveling on busy roads toward the agglomeration and not on the empty roads out of the agglomeration. At the same time it also encourages employees residing further away to migrate to the agglomerations because the general costs of commuting increase. These two complementary effects lead to an increase in the productivity level in the agglomeration. This finding suggests that the agglomeration effects can be substantial if congestion charging is targeted towards improving access to current economic agglomerations.

Fig. 10: Indirect effects of congestion charging: commuting (unit: 10,000s EUR)



5.2 Discussion of the agglomeration effects

The direct effects, those that can be directly attributed to the owners and users of infrastructure, are straightforward. Congestion charging gives the most benefit where there is a congestion problem and there is much traffic. The benefits for freight are limited as there is relatively far less freight traffic in congested areas.

The change in generalised costs for commute and freight traffic shows a completely different picture. Freight traffic profits the most due to its high value of time and the travel time gains from congestion charging. As a consequence generalised costs for freight traffic decrease slightly. The commuters, however, are confronted by increasing generalised costs as the travel time gains are less than the monetary congestion charge.

Table 1: Total direct and indirect effects of a congestion charge (million euro's)

	Freight	**Commute**
Direct welfare effect travel time gain	104	141
Direct welfare effect quantity change	0	-6
Totaal direct welfare effect	**104**	**135**
Indirect intra-region welfare effect	-2	-44
Indirect intra-region welfare effect	3	85
Total indirect welfare effect	**1**	**41**

The decreasing costs for freight result in positive agglomeration benefits between regions and negative agglomeration benefits within the regions. These effects are however limited effect as the changes in costs are also limited.

The increasing costs for commuters are causing very strong agglomeration effects. Especially the increase in costs within the regions cause strong negative agglomeration effects. These are compensated by many positive effects between regions. The overall effect is still strongly positive. The total direct and indirect (agglomeration) welfare effects are presented in Tabel 1.

The most important result of the analysis is that (agglomeration) indirect benefits and direct benefits of congestion charging often have an opposite sign. The reason is that there are positive direct benefits with congestion charging while at the same time generalised costs go up. This was also mentioned by Arnott (2007). What we show in this paper, is that the national implication in a polycentric setting is more complex. Positive and negative indirect effects may cancel out. The indirect agglomeration effect of congestion charging may be either positive or negative depending on whether it is causing agglomeration or dispersion at the national level.

6. Conclusions

In this paper we propose a methodology based on a multiplier derived from a SCGE model to estimate the agglomeration effects of congestion charging. In this way we can take the redistribution effect into account without letting it interfere with the effect of the congestion charge. The agglomeration benefits are found to be significant and often have the opposite sign as the direct benefits. The resulting overall indirect effect in a polycentric environment depends on the degree of national agglomeration that results from the charging scheme.

The most important result of the analysis is that (agglomeration) indirect benefits and direct benefits of congestion charging often have an opposite sign. This was also mentioned by Arnot (2007). What we show in this paper, is that the national implication in a polycentric setting is more complex. Positive and negative indirect effects may cancel out. The indirect agglomeration effect of congestion charging may be either positive or negative depending on whether it is leading to agglomeration or dispersion on the national level.

The policy implications are that it is important to assess whether a proposed road pricing scheme will result in more national agglomeration or dispersion. In a polycentric setting this implies the weighing of spatially different agglomeration effects. In those cases where congestion charging leads to dispersion other measures such as infrastructure investment might be more appropriate because road pricing may lead to negative agglomeration effects.

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7. APPENDIX: THE MATHEMATICAL RAEM MODEL

Production, income, consumption and spatial demand. Below are the equations describing the Cobb-Douglas production function, nominal labour demand, nominal demand for intermediate goods, the regional price index, total income, the Linear Expenditure System (LES), spatial demand and goods market equilibrium.

(0.1) $$y_{i,s} = A_{i,s} l_{i,s}^{\alpha_{i,s}} \prod_r q_{i,r,s}^{\beta_{i,r,s}}; \quad \sum_r \beta_{i,r,s} + \alpha_{i,s} = 1, \, r \neq transport$$

(0.2) $$w_{i,s} l_{i,s} = \alpha_{i,s} p_{i,s} y_{i,s}$$

(0.3) $$p_{i,s}^d q_{i,s,r} = \beta_{i,r,s} p_{i,s} y_{i,s}; \quad r \neq transport$$

(0.4) $$p_{j,r}^d = \left(\sum_i p_{i,j,r}^{t\;\,1-\sigma_r} \right)^{\frac{1}{1-\sigma_r}}; \quad r \neq transport$$

(0.5) $$TI_i = ben \sum_i un_i + (1-t) \sum_j f_{i,j} \frac{\sum_s l_{j,s} w_{j,s}}{\sum_s l_{j,s}}$$

(0.6) $$c_{j,r} = \theta_{j,r} + \frac{\phi_{j,r}}{p_{j,r}^d} \left(TI_j - \sum_r p_{j,r}^d \theta_{j,r} \right); \quad r \neq transport$$

(0.7) $$d_{i,j,r}^t = \left(\frac{p_{j,r}^d}{p_{i,j,r}^t} \right)^{\sigma_r} \left(c_{j,r} + \sum_s q_{j,s,r} \right)$$

(0.8) $$y_{i,s} = \sum_j d_{i,j,s}^t$$

The labour market and migration. Here are the equations describing the Beveridge curve, definitions of total labour supplied and demanded, labour market equilibrium, long-term equilibrium with respect to utility (clears migration), consumer utility (we use the LES thus based on the Stone-Geary utility function), utility of amenities and the migration adding-up constraint.

(0.9) $$f_{i,j} = a_i b_j un_i^{\lambda} v_j^{1-\lambda} e^{\varphi_{i,i} - \eta(tp_{i,j})}$$

(0.10) $$\sum_i f_{i,j} = \sum_s l_{s,j}$$

(0.11) $$\sum_j f_{i,j} = o_i - un_i$$

(0.12) $$w_{s,j} = \sum_i un_i \frac{f_{i,j}}{o_i - un_i}$$

(0.13) $u = u_i^c u_i^l$

(0.14) $u_j^c = \sum_r \phi_{j,r} \ln\left(c_{j,r} - \theta_{j,r}\right); \quad r \neq transport$

(0.15) $u_i^l = \ln\left(\kappa_i \frac{Lm_i}{o_i}\right)$

(0.16) $\bar{o} = \sum_i o_i$

Transport. The equations below define total transport costs, the location of transport production, and the sector price at the destination.

(0.17) $T = \sum_{i,j,r} tr_{i,j,r} p_{i,r} d_{i,j,r}^t; \quad r \neq transport$

(0.18) $y_{i,r} = \zeta_i T; \quad r = transport$

(0.19) $p_{i,j,s}^t = \left(1 + tr_{i,j,s} + tw_{i,j,s}\right) p_{i,s}$

The Government. The government pays unemployment benefit to the unemployed, which is financed out of income tax. This is described in the following two equations.

(0.20) $ben = ww \frac{\sum_{i,s} \alpha_{i,s} p_{i,s} y_{i,s}}{\bar{o} - \sum_i un_i}$

(0.21) $t = ww \frac{\sum_i un_i}{\bar{o} - \sum_i un_i}$

Table 1: List of Parameters

symbol	Explanation
$A_{i,s}$, $\alpha_{i,s}$ and $\beta_{i,r,s}$	Cobb-Douglas scale and share in region *i* and sector *s*
$\theta_{j,r}$ and $\phi_{j,r}$	LES floor level of consumption and marginal budget share in region *i* and sector *r*
φ_{ii} and η	Constant and sensitivity parameter for commuting
Lm_i	Housing stock indicator in region *i*
κ_i	Regional amenities factor
ζ_i	Spatial distribution of transport production
σ_s	Substitution elasticity in sector *s*
$tr_{i,j,s}$	Transport cost mark-up of a sector *s* good produced in *i* and consumed in *j*
$tw_{i,j,s}$	Shopping cost mark-up of a sector *s* good produced in *i* and consumed in *j*
$tp_{i,j}$	Commuting costs from region *i* to region *j*

Table 2: List of Variables

symbol	Explanation
$y_{i,s}$	Production in region *i* and sector *s*
$l_{i,s}$	Labour demand in region *i* and sector *s*
$q_{i,s,r}$	Intermediate demand for sector *s* goods in demanding region *i* and demanding sector *r*
$w_{i,s}$	Wage rate in region *i* and sector *s*
$p_{i,r}$	Producer price of sector *r* goods in region *i*
$p^d_{j,r}$	Dixit-Stiglitz Sector *r* price index in region *r*
$p^t_{i,j,r}$	Price at destination *j* of a sector good *r* from region *i*
$c_{j,r}$	Consumption of sector goods *r* in region *s*
TI_j	Total income in region *j*
$d^t_{i,j,r}$	Trade in sector *r* goods from region *i* to region *j*
$f_{i,j}$	Commuting matrix from region *i* to region *j*
un_i	Unemployed in region *i*
v_j	Vacancies in region *j*
o_i	Labour supply in living region *i*
$\bar{o}$	Exogenous total labour supply
u	Utility
u^c_j	Utility derived from consumption in region *j*
u^l_i	Utility derived from amenities (including housing price) in region *i*
T	Total transport production and nominal demand
ben	National unemployment benefit
t	Income tax rate

APPENDIX B: COROP REGIONS IN THE NETHERLANDS