The Welfare Effects of New Infrastructure: *An Economic Geography Approach to Evaluating New Dutch Railway Links*

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Abstract

We specify a spatial CGE model for the Netherlands based on the so-called New Economic Geography. The model distinghuises 14 sectors, two modes of transportation and over 500 municipalities. Key parameters are estimated by fitting predicted interregional trade flows to bi-regional input-output data. The model is then calibrated to a baseline scenario for 2020. From there, the transport grid is modified in line with several propositions for changes in rail infrastructure. The effects of these changes on employment and welfare are computed. We find that the most ambitious project leads to a redistribution of around 8.000 jobs from regions further out to regions along the line and especially at the end of it. The national net welfare effect is equivalent to a 250 million euro increase in GDP.

Keywords: Infrastructure Evaluation, Computable General Equilibrium, New Economic Geography

1 Introduction

In 2000, the Dutch government commissioned research into the effects of a major infrastructural project involving the construction of a rail link between Amsterdam and the north of the country. The region around Amsterdam is part of the Randstad region[1], which is the economic core in the West of the country: 42% of employment and more than 48% of GDP is produced on an area that contains no more than 15% of the country's surface. Quite the opposite, the North of the Netherlands[2] is considered an economically lagging region with 11% of GDP and 8% of employment on 27% of the country's area. Attempts to jump-start the northern economy with investment premiums, infrastructure and the forced relocation of government offices so far have not succeeded (cf. Oosterhaven 1996). The unfulfilled potential is aptly illustrated by relatively high unemployment rates and the return of the now privatised government companies to the West.

The construction of a high speed rail link between the West and the North is thought to remedy at least part of this problem. Arguments in favor of construction center around the indirect effects of such a link. Of these there are two main effects, external to the train's operator, that could benefit the country as a whole. The first concerns changes in commuting behavior. With a fast rail link, workers in the West could relocate to the North while keeping their current jobs. The incentive to move comes from the relatively low prices of northern real estate as housing construction in the West reaches its limit. Alternatively, potential emigrants from the North would no longer need to move to the West, but could instead decide to commute to it. The decrease in pressure on the Western housing market would be considered a national benefit. This housing migration effect is explored in a parallel paper by Elhorst and Oosterhaven (2002a).

The second main effect concerns the changes in the economic and location behavior of firms. Many companies that start in the North eventually move to the West, quoting their desire to be close to other companies (mostly those that deliver services, like advertising agencies and legal firms) and the wish to serve a larger market as a reason for leaving. This desire is strong enough to overcome the higher prices of property, the tighter labor market and greater congestion of the West. With a rail link in place, the price of these services to firms located in the North would be lower, and market access would be easier. These two factors could possibly shift the balance in favor of location outside the center. Such induced activity is

[1]The statistics pertain to the greater agglomeration of Amsterdam, the province of Utrecht and the province of South Holland, which includes The Hague and Rotterdam. GDP statistics come from RUG/CBS (1999), others from the 1998 LISA database.

[2]The North refers to the total of the provinces Friesland, Groningen and Drenthe. The GDP figure is misleadingly high as the natural gas exploitation in the North is statistically part of it, whereas this region hardly profits from it.

seen as the key to further economic development. A fast link would 'bring the [North] into the country's busy mainstream—and reduce pressure on the crowded Randstad' (The Economist, 2001).

In this paper, we will explore these last effects by means of the first Spatial Computable General Equilibrium (SCGE) model for the Netherlands. The model fits in the New Economic Geography line of research and builds on a concept introduced by Venables (1996). The basic structure resembles a similar model developed for the European Union by Bröcker (1999). The model is more detailed, however, introducing fourteen different sectors and their input-output linkages, and two modes of transportation (people and freight).

Besides these two main effects, two secondary effects may be estimated, *viz.* the effect of the shifts in economic activity, discussed here, on the location choice of workers (*i.e.* labour migration), and the effects of the total of housing and labour migration on consumption demand. These two secondary effects are modelled separately in such a way that the endogenous effects of one model serve as the exogenous inputs of the next model. They are discussed elsewhere (Elhorst *et al.* 2000).

The effects that are captured by the SCGE model in this paper lend themselves to an explanation in terms of forward and backward linkages (Hirschman, 1958). A reduction in transport costs generally leads to a lower price of products consumed far from their production site. This leads to an increase in demand for these products, which is an example of a backward linkage. This will lead to more exports in the regions of production and more imports in the regions of consumption. Because these cheaper imports can be used as intermediate inputs, local producers in turn can reduce *their* prices: this is an example of a forward linkage. Because we use IO tables and detailed information about the effect of the rail link on personal travel times, we can track effects through the economy and derive detailed welfare results.

An important part of the data used in the construction of this model is taken from the fourteen Dutch bi-regional input-output tables (RUG/CBS 1999, see also Eding *et al.* 1999) in which the economic ties between each Dutch province and the rest of the country appear in detail. Some of the model's parameters come directly from this publication; others are estimated by fitting trade flows predicted by the model to flows observed in these tables. Special care is taken with respect to the spatial structure of the model: we discern between the transport of goods and people and in the latter case discuss the role of public transport. Nontradeable goods are left outside the analysis, and we make room for services that are tied to locations, such as local government and education.

This paper continues as follows: in Section 2, we discuss the relevant economic theory and the specification of the model. Estimation of the parameters and calibration of the model is done in Section 3. Section 4 discusses the project alternatives and shows the results of simulations. Appendices give further details. Section 5 discusses the uncertainty of the results and points out the present modelling weaknesses. Section 6 concludes.

2 The Model

There exist several models that explain spatial patterns of production by increasing returns to scale and transport costs. In these models, agglomeration is caused by the desire to overcome transport costs when selling one's product or making purchases. This similar desire on the side of producers and consumers leads to a feedback loop, resulting in self-enforcing agglomeration. The precise form of this loop differs between models. An overview of the different types of models and their properties is given in Fujita *et al.* (1999).

We use a specification introduced by Venables (1996) where firms use both labor and intermediate goods in production. Workers are not allowed to relocate, but firms enter and leave the market according to profitability. For some parameter values, a situation where most activity is located in one single region is stable: the attraction for firms consists of the low price of intermediate goods and is self-enforcing.

We modify this model on several counts. Different sectors are introduced, leading to a richer set of possible outcomes (the effects of different sectors in these models are explored in Knaap, 2000). The labor market is simplified, so that it is in line with Dutch reality. Transport costs are differentiated according to what exactly is transported, goods or people; also, we account for the existence of non-tradeables and services that are tied to a location.

In the following sections, we use the convention that there are fourteen sectors indexed by s. The country can be divided in fourteen major regions (twelve provinces and two metropolitan areas) indexed by p, in forty smaller corop regions indexed by o or in 548 communities (*i.e.* municipalities) indexed by c. A full description, and the available data on each level, can be found in Appendix A.

2.1 Production and Utility

2.1.1 Specification

Utility of a representative consumer i in province p is given by the following nested function:

$$U_{i,p} = \prod_{s=1}^{14} U_{i,sp}^{\theta_{sp}} \tag{1}$$

where:

$$U_{i,sp} = \left(\sum_{c=1}^{548} n_{cs} X_{i,cs}^{1-1/\sigma_s} \right)^{\frac{1}{1-1/\sigma_s}} . \tag{2}$$

with $X_{i,cs}$ the level of consumption by person i of a sector s-product from community c. As it turns out that all firms from a certain community in the same sector use the same price, the number $X_{i,cs}$ holds for all those firms. The number of firms in community c that are in sector s is given by n_{cs}. As seen above, utility is computed in two stages: first, in (2), sub-utility within each sector is computed by aggregating purchases from all communities of origin. This aggregation is done by a CES function, indicating that the firms within a sector operate under monopolistic competition (Dixit and Stiglitz, 1977). The size of the different $X_{i,cs}$'s depends on the price of the product and the sector-specific elasticity σ_s. Sectorial utilities $U_{i,sp}$ are combined using the Cobb-Douglas function in (1). This specification implies that each sector receives a fixed share of the consumers' budget.

As appears from this specification, we allow for different utility functions in different parts of the country: each major region p has its own set of utility parameters Θ_p. While it is unclear if regional peculiarities of this kind are a stable phenomenon, this specification allows us to take parameters Θ_p directly from the bi-regional IO tables: they are simply the share of the consumer budget devoted to each sector. Assuming that each region described in the IO tables has its own preferences is a convenient shortcut that nonetheless has its price: a higher share of the budget devoted to a certain sector could also indicate a lower price of those products in a certain region, possibly due to transport costs. While recognizing this problem, we employ the specification in (1) to capture as much regional variation as possible.[3]

On the production side, we assume that a firm j, in sector s and major region p, faces the following double nested production function:

$$Y_{j,ps} = c_{ps} L_{j,ps}^{\alpha_{ps}} Q_{j,ps}^{1-\alpha_{ps}} \tag{3}$$

$$Q_{j,ps} = c'_{ps} \prod_{s'=1}^{14} Q_{j,s',s}^{\gamma_{p,s',s}} \tag{4}$$

$$Q_{j,s,s'} = \left(\sum_{c=1}^{548} n_{cs} X_{j,c,s,s'}^{1-1/\sigma_s} \right)^{\frac{1}{1-1/\sigma_s}} . \tag{5}$$

The production of any firm is thus a Cobb-Douglas aggregate of labor L_j and all intermediate goods Q_j used. The parameter $1-\alpha_{ps}$ in (3) is the share of intermediate products used in production. It varies per sector and per

[3] The variance of θ_{sp} over p around the average θ_s was typically around 5% of the θ_s.

major region p, and is derived from the bi-regional IO tables. The sector-region specific constants c_{ps} and c'_{ps} allow us to use a simple form for the cost function later on. Derivations of these constants are in appendix B.1. The aggregate intermediate good on its turn is an aggregate of the goods and services from all fourteen sectors, as shown in (4). Once again the aggregation is of the Cobb-Douglas variety, with the parameters $\gamma_{p,s',s}$ taken directly from the IO tables.

On the sectorial level, we assume monopolistic competition in (**??**). So, while the input share of a certain sector may be a constant $\gamma_{p,s',s}$, the actual producer that is chosen to supply the input is dependent on the price. This is a very appealing assumption, as in reality parameters like $\gamma_{p,s',s}$ are often dictated by technical constraints, but within these constraints the producer is free to shop around for the cheapest supplier. The Dixit-Stiglitz (1977) specification of $Q_{j,s,s'}$ is identical to that of sectorial sub-utility in formula (2).

In this specification, it is essential that producers and consumers share the same elasticity of substitution σ_s. This way, the demand curve from both parties is identical and the optimal price for the supplier is the same, regardless of the type of customer. It also implies that we can use the same price index for both producers and consumers. Different values of σ_s would make the model much more complicated and are not considered here.

2.1.2 Solution

The standard monopolistic competition results hold in this model, leading to familiar, if somewhat elaborate, expressions for demand and supply. Consumers and producers both exercise demand. If we look at a consumer in community c in major region p with income w, her demand for a certain product from producer j in sector s', located in community c' will be:

$$D\left(p_{j,c',c,s'}\right) = w \cdot \theta_{s',p} \cdot \frac{p_{j,c',s',c}^{-\sigma_{s'}}}{G_{s',c}^{1-\sigma_{s'}}} \tag{6}$$

with the price index defined by:

$$G_{s',c} = \left(\sum_{c''=1}^{548} n_{c'',s'} \cdot p_{j,c'',s',c}^{1-\sigma_{s'}} \right)^{\frac{1}{1-\sigma_{s'}}}. \tag{7}$$

Similarly, a producer in sector s in community c in major region p, who spends wL on labor, will demand from producer j in sector s' in community c' the following:

$$D\left(p_{j,c',s',c}\right) = wL \cdot \frac{1-\alpha_{p,s}}{\alpha_{p,s}} \cdot \gamma_{p,s',s} \cdot \frac{p_{j,c',s',c}^{-\sigma_{s'}}}{G_{s',c}^{1-\sigma_{s'}}}. \tag{8}$$

Notice that, as usually in monopolistic competition models, a positive quantity is demanded from *each* producer, no matter how high the price (and no matter how far away). This may cause a problem later on as many products in real life are not suitable for transport over long distances . We will return to this problem in Section 3.2.1.

2.2 The Labor Market

One of things that sets this model apart from that in Venables (1996) is the specification of the labor market. Usually a completely inelastic labor supply is assumed, where a given amount of labor is always employed and the wage is computed as the closing variable of the model. Wage differences there lead to marginal cost changes and to price differences between regions, which is an important step in the model's final results.

We feel that such a competitive wage-setting environment does not accurately reflect the situation in the Netherlands. Wages are negotiated on a national level and are hardly different between regions. This has several repercussions: first, there are no incentives to migrate between regions in order to receive a higher nominal wage. Second, local labor markets do not always clear. Unemployment is prevalent in those regions where excess labor supply exists. The unemployed nonetheless are able to exert demand, in the same way as the employed workers, but through unemployment benefits.

Therefore, we model the labor market as quantity-oriented and demand-controlled. We assume that the wage is equal throughout the country and set it equal to unity. Any shocks in labor demand are absorbed by hiring or firing workers, implicitly assuming that there are no effective constraints on labor supply: each community has a sufficiently large pool of unemployed to use in times of increased labor demand. The consequences of deviations from this assumption are investigated separately in Elhorst and Oosterhaven (2002b).

To avoid modelling a complete government sector with all its complexities, the effect of income taxes and unemployment benefits is modelled in a simple, convenient way: all incomes are taxed at a rate of 100% and then redistributed to all inhabitants. This implies that the consumer income in any community is proportional to the number of inhabitants. Because the labor supply decision and its expenditure effects are modelled exogeneously outside the SCGE (Elhorst *et al.* 1999), this rather unorthodox taxation scheme does not have and should not have an impact on the supply of labor.

2.3 Transport Costs and Prices

2.3.1 Specification

It is customary in SCGE models of this kind to let transport costs take the form of a leakage: a certain fraction of the transported product is lost along the way, and the size of the fraction is determined by the distance travelled. By incurring transport costs in the product itself, there is no need to explicitly model a transport sector and prices can easily be adjusted for distance. We modify Samuelson's (1952) *iceberg* approach a little to account for the fact that there are two types of transport, and the new infrastructure will change only one of those types. Transport of goods is assumed to be unaffected by the new rail links, as it takes place mostly by truck, ship or pipeline. Passenger transport, on the other hand, is definitely affected by the new link.

We compute transport costs as follows: in general, transport causes a markup on the price of a product, depending on the distance d that is travelled:

$$f\left(d\right) = 1 + \nu d^{\omega}. \tag{9}$$

Depending on the sector s to which the product belongs, a share π_s is goods transport and a share $1 - \pi_s$ uses passenger transport. The total transport markup thus is equal to:

$$\begin{aligned} \tau_s\left(d_g, d_p\right) &= \left[f_g\left(d_g\right)\right]^{\pi_s} \cdot \left[f_p\left(d_p\right)\right]^{1-\pi_s} && (10) \\ &= \left[1 + \nu_g \cdot d_g^{\omega_g}\right]^{\pi_s} \cdot \left[1 + \nu_p \cdot d_p^{\omega_p}\right]^{1-\pi_s} && (11) \end{aligned}$$

Distance for goods transport d_g has been measured in kilometers. The distance for passenger transport d_p is measured in minutes and is computed as an average between public transport time and driving time (see Appendix A.2). The parameters ν_i and ω_i are estimated in Section 3. The parameters π_s have been obtained exogenously and are specified in Appendix A.3.

2.3.2 Solution

The marginal costs MC for firm j in sector s, community c and region p are equal to:

$$MC_{j,s,c,p} = w^{\alpha_{ps}} \cdot \tilde{G}_{cs}^{1-\alpha_{ps}} \tag{12}$$

where the price index of intermediate goods $\tilde{G}_{cs}$ is defined as:

$$\tilde{G}_{sc} = \prod_{s'=1}^{14} G_{s',c}^{\gamma_{p,s',s}} \tag{13}$$

with the price index for sector s in community c, $G_{s,c}$, defined above in (7).

The optimal price for the above firm is, as usual in marginal costs, a markup times the marginal costs:

$$p_{j,s,c,p} = \frac{\sigma_s}{\sigma_s - 1} MC_{j,s,c,p} \tag{14}$$

This gives the price $p_{j,s,c,p}$ which holds in community c in which the firm operates. The price in another community c' is found using the specification of transport costs in (10):

$$p_{j,c,c',s} = \tau_s \left(d_{g,c,c'},\, d_{p,c,c'} \right) \cdot p_{j,s,c} \tag{15}$$

where $d_{c,c'}$ is the distance between the two communities per transport mode.

2.3.3 Computation

The actual computation of the price that a company charges for its product in a given community is fairly complicated. As follows from (12), each price is a function of the local, *i.c.* national wage (which is one, by definition) and the local price index of intermediate goods. This last price index depends on the price of nearly every other available good in the country, as well as on the transport costs for all these goods. In turn, these prices each depend on all other prices and applicable transport costs. The equations that describe the pricing decisions, *i.e.* (7) and (11)-(13), cannot be solved analytically. In practice, a numerical procedure is used where all prices are set to one and the system is allowed to iterate until convergence. This presupposes knowledge of the parameters ν_i, ω_i and σ_s, which have been estimated as described in Section 3. It also presupposes knowledge of the number of firms $n_{c,s}$ in each sector in each community. It may be proven that this number is proportional to the product of α_{ps} and $L^{total}_{c,s}$ (see appendix B.2). The latter is the amount of labor that is used by the sector in that community, both are a known variables.

3 Estimation and Calibration

3.1 Procedure and Data

In the previous section, we specified the first and only Dutch SCGE model and pointed out where the data came from and how we found most the model's parameters directly from the IO tables. That is, except for eighteen unknown parameters that will be estimated in this section. We will call this set of parameters Γ, and they are:

- the fourteen elasticities of substitution σ_s, each particular to a specific sector, and

- the parameters of the two transport cost functions, ν_i and ω_i ($i = g,\, p$).

These parameters are estimated in the following way: for any given set of values for the unknown parameters Γ, the model is used to compute the demand that is exercised by each region upon every producer in the country. Adding a subset of these producers in an appropriate way, any flow of trade in the country can be computed.

For instance, the demand from inhabitants of province $\widetilde{p}$ for products from sector s that are produced *outside* their own province can be computed to replicate the import flow of sector-s products that is listed in the bi-regional IO table for province $\widetilde{p}$. This involves the adding up of many small demands from one municipality inside $\widetilde{p}$ with regard to products from sector-s firms in all municipalities outside $\widetilde{p}$, *i.e.*

$$\sum_{j \in s} \sum_{c' \notin \widetilde{p}} \sum_{c \in \widetilde{p}} D(p_{j,c',c,s}) \tag{16}$$

The demand function $D(\cdot)$ in (16) is either private demand (6) or intermediate demand (8). All of these functions are known in principle, given Γ. To compute the amount of money allocated to sector-s goods in each community, the prices for all goods have to be established. and the prices and transport costs have to be used to divide this budget between producers in all 548 communities. Hence, the computation is intensive. The software implementation of the model takes care of this tedious task.

The number of trade flows from the IO tables that may be used is, in principle, equal to $(14 \times 4 \times 14 \times (14+1) =)\, 11,760$, since there are fourteen bi-regional tables, each with four sets of flows: flows *from* inside and outside the region *to* inside and outside the region. Each set consists of a fourteen by fourteen matrix with flows of intermediate goods and fourteen flows of final goods.[4] We will estimate the parameters by trying different sets of Γ and finding the one that minimizes the sum of squared differences between the predicted (log-)flows of goods and the (log-)flows in the IO tables. The logarithms are used so that the larger flows do not dominate the estimation.

For several reasons, we do not use all the available data, both discarding some flows and summing to aggregates. First, the data regarding flows *from* outside a region *to* outside a region are discarded. The reason for this is that the quality of the data is thought to be poor; it is constructed as a residual-category by subtracting known flows from a total. This also creates a redundancy in the data, as the same totals are used twice. Second, we aggregate the rest of a data because of two reasons: first of all, computational restrictions limit the number of data points that can be digested in a reasonable time. Secondly, many flows are insignificant and measured

[4] To make matters confusing, there are fourteen regions and fourteen sectors.

with a large error. By adding small flows, we hope to average out some of the errors.

So, we sum observations across the sub-rows of the IO tables until we are left with $(14 \times 3 \times 14 =)$ 588 datapoints. Thus, for each of 14 regions, for each of the 14 sectors, we use the intra-regional sales to (both intermediate and final) customers inside the own region, the exports to customers outside theown region in the rest of the country, and the imports from producers outside the own region in the rest of the country. These 588 datapoints are then matched with those predicted by the model.

3.2 Problems with the estimation

3.2.1 Transportability

Within the model described so far, the consumption decision is based on prices, which in turn are the influenced by transport costs. Thus, a strong preference for local goods can only be explained by very high transport costs. As it turns out, for some sectors the preference for local goods proved so strong that it would imply incredibly high costs of transport. For example, in our measured year consumers in the province of Utrecht spent 749 mln euro on education. Almost 92% of these expenditures were made *within* the own region, which produces only 9% of the country's educational output. Clearly, if price was the only issue, transport costs would be immense. There seems to be something in the nature of education that makes in less suited for trade.

So far the model described has no non-tradeables. To allow for these, sector-specific parameters ae introduced that measure *transportability*. Derived from the regional commodity trade balances (RUG/CBS 1999), these parameters indicate the degree to which output can only be produced on the spot, because it is over-the-counter or personal. These parameters are exogenous to the model and given in appendix A.3. We account for transportability by dividing expenditures on a sector's product into expenditures on non-tradeables and expenditures on tradeables using the new parameters. The demand for non-transportables, by definition, is satisfied by supply from the own region, whereas the demand for tradeables is divided over the whole country using the above framework. The approach is alike that of Bröcker (1999), who assumes a general 2:3 ratio of tradeables to non-tradeables, whereas our parameters are sector-specific.

3.2.2 Identification

Bröcker (1999) found that the estimation of the parameter set Γ suffers from the problem that the parameters may not be separately identifiable. He proves for a slightly different transport cost function, which nonetheless resembles (9), that parameters are not identified at all. The problem is quite intuitive: increasing the costs of transport or increasing the price elasticity of demand σ has exactly the same effect: more local goods will be consumed, either because imported goods become more expensive or because the (cheaper) local goods can be more easily substituted for (more expensive) imported goods. This leads Bröcker to use extra data about the importance of transport costs in final good prices in his estimations.

We have found that our model suffers from the same problem, in the sense that the search for optimal parameters seems to take place in a lower dimensional subspace of the parameter space. Nonetheless, a unique optimum was found. The parameters at this optimum, which is discussed below, are in a similar range as other estimations of this kind (Bröcker 1999, and Hanson 1998, for instance).

3.3 Estimation results

The parameters that minimize the sum of squared errors are shown in Table 1. The graph in Figure 1 shows the goodness of fit of the estimation. The (log)flows of trade as predicted by the model are on the horizontal axis, the actual (log)flows are on the vertical axis. The diagonal is the $45°$ line - a point on this line means that the prediction is exactly on the mark.

Parameter	Estimate	Parameter	Estimate	Parameter	Estimate
σ_1	11.1	σ_8	23.6	ν_g	0.006
σ_2	8.3	σ_9	8.2	ω_g	0.770
σ_3	12.5	σ_{10}	13.7	ν_p	0.010
σ_4	16.4	σ_{11}	14.2	ω_p	0.593
σ_5	24.0	σ_{12}	12.2		
σ_6	15.1	σ_{13}	12.5		
σ_7	29.8	σ_{14}	18.7		

Table 1: Parameters Γ as obtained from a non-linear least squares procedure

So far, we have used the wage as a numeraire. This means that all values inside the model, including the predicted flows of trade, are denoted in terms of w. During the estimation, when we compare the predicted trade flows with actual numbers in millions of guilders, we must convert our internal figures. This is done by multiplying them by a factor so that, on average, the prediction of the trade flows is correct. This procedure is equivalent to estimating an intercept in Figure 1. This factor, or the intercept, in turn is an indication for the actual value of our numeraire, the wage level w. We find an intercept of -2.55 which indicates an average wage of $35,350$ euro. This is surprisingly close to the actual figure, which is $35,950$ euro for our measured year.

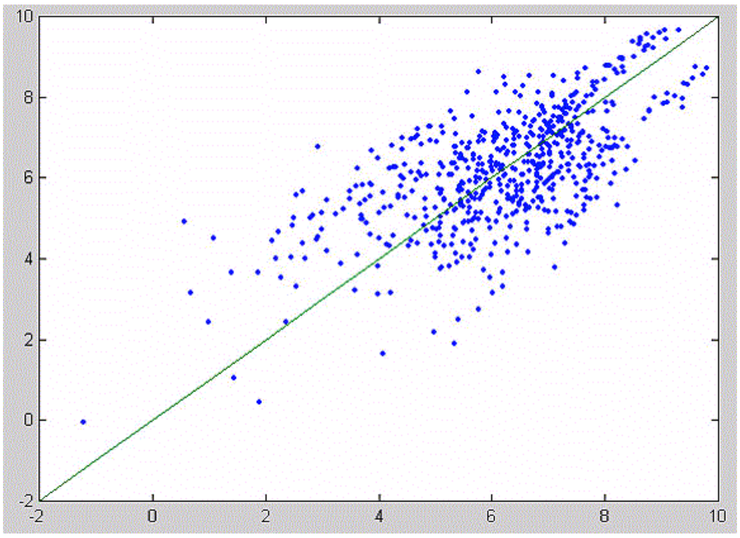

Figure 1: Actual (horizontal) versus predicted (vertical) log trade flows.

With the numbers in Table 1, we can do some back-of-an-envelope calculations about the effect of distance on demand. With a typical elasticity $\sigma = 12$ we can compute at which distance half of wholesale is lost because of transport costs. For this distance $d_{1/2}$, there must hold that:

$$1/2 = \left(1 + \nu_i \cdot d_{1/2}^{\omega_i}\right)^{-11}, i \in \{g, p\}. \tag{17}$$

Using this formula, we compute that a customer who would buy 1 euro's worth when the supplier would live next door, buys exactly 50 cents' worth from the same supplier when the distance between them is 21 kilometers and all hauling involved is goods transport. Similarly, if all transport is of the passenger kind (*i.e.* the supplier must meet the customer in person) the potential purchase is halved every 22 minutes.

3.4 Calibration and simulation

We now have the complete set of parameters, estimated using data from the 1990s. The aim of the model is to evaluate the impact of certain infrastructural changes in 2020. To be able to do this, the model is calibrated to a dataset that describes the situation in 2020 if none of the proposed projects is carried out. This dataset consists of the travel-times between all Dutch communities based on the projected state of public transport in 2020 (NEI/HCG 2000) and the projected number of jobs in each community in each sector in 2020 (TNO/RUG/VU/TUD 2000). We call this set the null-alternative; it is constructed exogenous to the model and based on economic scenarios from CPB (1997) and known plans to upgrade infrastructure. More information about the different scenarios is in Appendix A.2.4.

Given the parameters, the amount of labor used in each sector in each community, and the matrix of transport times we can compute supply and demand for each sector in each community in 2020, in the null scenario. Unfortunately, given that the data in the null-scenario come from outside our model, there is nothing that guarantees the equality of supply and demand in each sector, in each municipality. To start out with a balanced model we must somehow equate the two. Therefore it is assumed that the difference between supply in demand for each sector in each community is the result of factors outside our model, *e.g.* natural resources, and that the error is additive. That is, average productivity varies across regions, but marginal productivity is equal.

One of the interesting figures concerning the implementation of a certain project will be the change in the number of jobs that ensues. This number can now be computed using the SCGE model in the following way:

- The change in transport costs gives a change in demand for each sector in each municipality.
- Supply must meet demand; from the change in demand we infer an equal change in supply.
- Using (3), we can translate this change in supply into a change in the amount of labor needed.

The use of extra labor in turn triggers new demand effects that make their way through the economy. The number of jobs gained or lost in each municipality is computed using the model. This is the methodology by which we proceed to simulate the different options for a high-speed rail link.

4 Simulation Results

4.1 The scenarios, some remarks

We evaluate six scenarios that are alternatives to the null-scenario to which we have calibrated our model above. The only difference between these scenarios and the null-scenario is in the matrix with travel-times. In each scenario, a different infrastructural project is implemented and the changes in travel-time between all communities are computed. These computations are done outside our model by NEI/HCG (2000). Details are in Appendix A.2.4.

When we run our simulations, there are two more factors which we must take into account. First of all, while this study is concerned with the Netherlands as a closed country, we feel uncomfortable letting all the extra demand generated by the changes in the economy be absorbed by domestic producers. That is why we only let 50% of the extra demand come to bear on the Dutch market, letting the other half leak out of the country. As it turns out, this measure is does not have a large impact because the *extra* demand is very small; it is the distribution of demand that changes the most.

Secondly, we take account of a third sector-specific exogenous characteristic, *exogenous ties*. With this parameter, we incorporate the fact that for some companies, the choice of location and level of activity is wholly independent of prices, as they are tied to their location and their customers are tied to them. This may be because of localized natural resources or because of a fixed local clientièle, as in the case of municipal governments. The parameter gives the share of companies for which changes in price (as a result of changes in transport costs) does not alter their scale of operation, except for sector-wide changes in demand. For instance, a municipal government which is 100% tied to its location and customers, does not sell any more or less because of changes in transport costs. However, if the changes lead to a smaller demand for *all* government services this does affect all municipal governments equally. More on this parameter can be found in Appendix A.3.

4.2 Endogenous number of varieties

During the first attempts to simulate a new equilibrium with the model we encountered a severe problem . This problem is the result of our specification of the labor market, which was detailed in Section 2.2. There, we assumed that there exists an infinite supply of labor at each location at the present wage. This assumption followed from the fact that the wage is not thought to be a regionally differentiated variable in the Netherlands. However, as it turns out, the model becomes unstable because of this assumption. The instability works as follows: if at a certain location demand is increased, the number of jobs and hence the number of firms goes up (see formula (25) in the Appendix). With the new firms, new varieties are introduced which lead to a new increase in demand and a new increase in the number of jobs. Because of the infinite supply of labor at unit cost, this process becomes explosive. Table 2 shows the dynamics of such a run. We evaluate the MZB scenario, and for two cities we give the change in the number of jobs after each iteration of the model. While Almere, situated along the new line, grows explosively the more peripheral city of Eindhoven looses all its emploment.

To stop the model from exploding the way it does in Table 2, we leave

Iteration	1	2	3	4	5	6	7
Almere	$2,063$	$3,757$	$5,417$	$7,305$	$9,691$	$12,931$	$17,448$
Eindhoven	-5	-43	-105	-188	-293	-423	-591

Table 2: Change in employment when the number of firms varies endogenously.

the number of firms fixed during simulation runs. This means that our analysis only picks up the short run effects that relate to the redistribution of demand as a result of the new prices, and to the fact that less product is wasted in transport. Effects that come about because of an change in the number of varieties at certain locations are no longer part of the analysis.

4.3 Outcomes

We evaluate the six proposed rail projects and compare them to the reference case in which only planned improvements to infrastructure are made. The rail variants are specified in Appendix A.2.4. For each, we compute a new equilibrium of supply and demand, given the changed costs of transport. Each equilibrium is evaluated in two ways (cf. Richardson, 1979):

1. To indicate the *interregional distribution* effects, Figure 2 shows the changes in the number of jobs for the 40 corop regions (NUTS-2). These changes are summarised quantitatively in Table 3 for each of four aggregate regions: the two regions that are supposed to benefit most, the West and the North, the Flevoland region through which all the lines go, and the rest of the country.

2. To indicate the *national efficiency* effect, Table 4 shows the national output effect and the national average change in consumer welfare. This last effect is computed as the amount of income needed to generate the increase in utility that is actually achieved in the model.

First, we discuss the interregional re-distribution of jobs over the Netherlands. As expected: regions at the end of the line (the Randstad and the North) profit at the cost of the rest of the country. Both regions experience an increase in demand (from each other) and a decrease in the price of intermediate goods, leading to higher order effects. Clearly the effect of speed is decisive, but the trajectory of the variant plays a role too. The Hanzeline variants HIC and HHS only increase the speed along an almost unchanged trajectory. Hence, especially the economic core area (the Randstad) hardly profits from this improvement, whereas it profits clearly more from the four other variants that involve new trajectories to the North. If the schedule calls for frequent stops along the way (as in MZM) or follows the old trajectory (as in HIC and HHS), the middle province of Flevoland also shares in the gains. The rest of the country always experiences a relative deterioration in its competitive position, especially with respect to the economically largest market in the West of the country.

	HIC	HHS	ZIC	ZHS	MZB	MZM
Northern Netherlands	650	1800	900	2000	3500	3100
Randstad region	250	400	1200	1800	2150	2500
Province of Flevoland	350	600	400	900	2100	2450
Rest of Netherlands	−1250	−2900	−2500	−4700	−7800	−8100

Table 3: Changes in regional numbers of jobs per rail variants in 2020

The aggregate outcomes in Table 3 hide a substantial redistribution of jobs at lower spatial levels of aggregation. The underlying material at the level of 14 sectors and 548 municipalities, of course, shows the largest differences. From this last material, for instance, it can be deduced that the bulk of the employment effect in the North relates to the services sector in the city of Groningen, where the new line would terminate. This is not too surprising as only business travel times improve, while Groningen is by far the largest (service) city in the North and also enjoys the largest %-gain in travel time to the largest sub-market of the Netherlands, that is the Randstad. Other sub-regions in the North, such as those to the east and south of the city of Groningen, in fact, show negative employment effects as their relative competitive position deteriorates compared to northern cities closer to the new infrastructure (see also Figure 2).

Besides these interregional re-distributive effects, there are also important national efficiency effects, shown in Table 4. This is a little surprising, as an increase in the number of firms is not yet allowed. There is a minimal decrease in national employment (not shown), because labour becomes relatively more expensive compared to intermediate inputs. Total output, however, increases as savings in transport costs lead to lower prices and more demand. Most of the lower prices are passed on to consumers who also enjoy their own direct transport cost savings, which result in an overall reduction of consumer prices (CPI). The assumption that we made about the redistribution of income implies that in the model this is even literally true for everyone, even those living in the regions that loose jobs and output.

	HIC	HHS	ZIC	ZHS	MZB	MZM
Δ output (in %)	0.004	0.010	0.004	0.010	0.016	0.016
Δ CPI (in %)	−0.02	−0.06	−0.02	−0.05	−0.09	−0.09
eqv. Δ Y (in million euro)	64	156	56	153	262	251

Table 4: Changes in national output, prices and consumer welfare per rail variant in 2020

Besides lower prices, consumers also enjoy a greater variety of available consumption goods. In fact, people along the fastest variants (MZB and MZM) will be able to go to the opera in Amsterdam and return the same evening, something that is hardly possible today. Because of the explicit utility function, the SCGE approach is able to translate the utility gain in the equivalent income increase that would have been necessary to reach the same change in utility (welfare).[5] In the case of the Transrapid these gains amount to 250-260 million euro yearly, which has to be compared with an investment cost of 5-7 billion euro.

Finally, there is the interesting phenomenon that the increase in output is much, much smaller than the decrease in the CPI. Part of this difference is explained by the peculiar implications of using iceberg type transport costs. Reducing iceberg transport costs implies that the suppliers need to produce less to satisfy the same level of demand on the part of these customers. Hence, consumption is able to increase more than production. This unwarranted result went unnoticed in the literature until now. When a macro SCGE is used, this property does not pose a serious problem as the macro economic output is inclusive of transportation output that does (implicitly) reduce. In a multi-sectoral SCGE, however, this iceberg type transport costs imply a serious mis-specification as they lead to an underestimation of the output effects in the non-transport sectors, especially in those sectors for which transport cost reduce most, whereas the opposite should be the case.

5 Evaluation

The study in this paper is part of a larger effort to gauge the most important effects of the infrastructural projects that are currently being proposed. The design of this effort is such that each sub-problem is analyzed in such a way that the effects from other sub-studies are deliberately left out. Then, all effects can be added up in the end without the risk of double-counting (Elhorst *et al*, 2000). It is therefore that we have not discussed such matters as migration by workers, international repercussions and the environmental impact of the projects. This sub-study has been limited to the economic redistribution of jobs and the consumer welfare increase that is to be expected after each of the projects.

In the course of this study, a large model has been constructed from the ground up, in a limited time. Shortcuts had to be taken, leading to some matters not getting the attention that they probably deserve. The exogenous sector-specific parameters in Appendix A.3 were picked by experts after consulting data on the subject, but not estimated rigorously. Due to

[5] The estimates are based on the 1995 GDP of 290 billion euro (CBS, Statline 2000).

the non-linear character of the model, it is hard to quantify the effects that errors in these parameters can have.

Secondly, the concept of an endogenous number of firms had to be abandoned after the model turned out to be unstable. This leads to a definite underestimation of the effects of a new link: any effects that we find with a fixed number of firms are sure to be larger when the full variety-effect is taken into account.

Thirdly, as indicated above, the use of *iceberg* transport costs is theoretically convenient and empirically acceptable in the case of a one-sector economy. In a multi-sector economy, it may lead to strange results: an underestimation of the impacts in precisely those sectors that are most sensitive to the reduction of transport costs at hand.

6 Conclusion

We have constructed a spatial CGE model for 548 Dutch communities with 14 sectors, based on New Economic Geography principles. Our model can best be compared to the one in Bröcker (1999) and Venables and Gasiorek (1996) and uses intermediate products as in Venables (1996). We calibrate the model to a base scenario for the year 2020 and use it to evaluate six infrastructural projects on which the Dutch government is about to decide.

We have chosen to model a demand-constrained labor market as if there is an infinite supply of labor available at a fixed wage. This leads to an instability in our model as the number of firms is derived from the amount of labor used. This problem is mitigated by assuming that the number of firms remains constant after a project has been implemented. Because of this, our outcomes only give an estimate of the short run effects.

The most ambitious plan leads to a shift of about 8,000 jobs. These jobs are gained in the North and the West of the country, because of direct demand effects (both region's products are cheaper for the other) and indirect effects: because of cheaper intermediate inputs prices go down. Both lead to a decrease in the consumer price index. The welfare increase that is the result of this decrease in prices is equivalent to one obtained after raising GNP about 250 million euro.

Finally, the construction of this model can be seen as the first step toward the construction of a larger spatial CGE model of the Netherlands, which can be used to help with infrastructural decisions in the future.

References

AND (2000), *Reistijden en afstandenmatrix Nederland 1998*, CD-ROM, AND Data solutions, Rotterdam.

Bröcker, J., 1999, *Trans-European Effects of "Trans-European Networks": A Spatial CGE Analysis*, Mimeo, Technical University of Dresden, Dresden

CPB, 1997, *Economie en fysieke omgeving, Beleidsopgaven en oplossingsrichtingen, 1995–2020*, Centraal Planbureau, Den Haag

Dixit, A.K. and J.E. Stiglitz, 1977, "Monopolistic Competition and Optimum Product Diversity," *American Economic Review* **67** (3), pp. 297-308

The Economist, 2001, *The flight of the train*, **359** (8217) April 12, pp. 28–29.

Eding, G.J., J. Oosterhaven, B. de Vet and H. Nijmeijer, 1999, "Constructing Regional Supply and Use Tables," in: G.J.D.Hewings, M. Sonis and Y. Kimura (eds.), *Understanding and Interpreting Economic Structure*, Springer Verlag, Berlin, pp. 237-63

Elhorst, J.P., T. Knaap, J. Oosterhaven, W.E. Romp, T.M.Stelder and E. Gerritsen, 2000, *Ruimtelijk Economische Effecten van Zes Zuiderzeelijn Varianten*, Mimeo, REG-publication 22, University of Groningen, NL

Elhorst, J.P. and J. Oosterhaven, 2002a, *Effects of Transport Improvements on Commuting and Residential Choice*, Mimeo, University of Groningen, NL

Elhorst, J.P. and J. Oosterhaven, 2002b, Arbeidsmarkteffecten van nieuwe verkeersinfrastructuur, *Tijdschrift Vervoerswetenschap* **38** (1), pp. 55-60

Fujita, M., P.R. Krugman and A.J. Venables, 1999, *The Spatial Economy*, The MIT Press, Cambridge, MA.

Hanson, G.H., 1998, *Market Potential, Increasing Returns, and Geographic Concentration*, NBER working paper # 6429, Cambridge, MA

Hirschman, A., 1958, *The Strategy of Economic Development*, Yale University Press, New Haven, CT

Knaap, T., 2000, *Generalizations in a Model of Economic Geography*, *mimeo*, University of Groningen, NL

NEI/HCG, 2000, *Vervoerswaarde Studie Zuiderzeelijn*, commisioned by the Ministerie van Verkeer & Waterstaat, Nederlands Economisch Instituut, Rotterdam

Oosterhaven, J., 1996, "Dutch regional policy gets spatial," *Regional Studies* **30** (5), pp. 527–32

Richardson, H.W., 1979, "Aggregate efficiency and interregional equity," in: H. Folmer & J. Oosterhaven (eds.), *Spatial Inequalities and Regional Development*, Martinus Nijhoff, Kluwer, Dordrecht, pp. 161-184

RUG/CBS, 1999, *Regionale Samenhang in Nederland, Bi-regionale input-output tabellen en aanbod- en gebruiktabellen voor de 12 provincies en de twee mainport regio's.* Rijksuniversiteit Groningen/Centraal Bureau voor de Statistiek, REG-publication 20, University of Groningen, NL

Samuelson, P.A., 1952, "The transfer problem and transport costs: The terms of trade when impediments are absent," *Economic Journal* **62** (246), pp. 278-304

TNO/RUG/VU/TUD, 2000, *Indirecte Effecten Zuiderzeelijn, Hoofdrapport,* commisioned by the Ministerie van Verkeer & Waterstaat, TNO Inro, University of Groningen, Free University Amsterdam, Technical University Dresden, Delft.

Venables, A.J., 1996, "Equilibrium locations of vertically linked industries," *International Economic Review* **37** (2), pp. 341-359

Venables, A.J. and M.Gasiorek, 1996, *Evaluating Regional Infrastructure: A Computable Equilibrium Approach*, Mimeo, London School of Economics, UK

A Data and Conventions

A.1 Division of the Economy

In the Dutch economy, we identify 14 sectors that are indexed by the variable s and are specified in Table 6.

Geographically, we divide the country into 14 major regions. The basis of this division are the twelve Dutch provinces. Ten of these are directly used, wheras South-Holland and North-Holland are each split into two regions: greater Amsterdam including the area around the North Sea Canal and the rest of North-Holland, and on the other hand greater Rotterdam with its Ports and the rest of South-Holland.

Each major region in turn consists of one or more corop regions (NUTS-2 regions). There are 40 corop regions; the NUTS-2 division was originally intended to mark the size of local labor markets. Each corop region, finally, is divided into a number of municipalities. The model uses the 1998 situation regarding the municipal borders, leading to a total of 548 municipalities. The largest community is Amsterdam with 718,151 inhabitants, the smallest is the island of Schiermonnikoog with 1,003 inhabitants.

A.2 Available Data

A.2.1 IO Tables

Our most important source of data are the bi-regional input-output tables compiled in RUG/CBS (1999). Any reference to 'the IO tables' in this paper concerns this publication. The tables are available for all twelve provinces and for greater Amsterdam and greater Rotterddam. Of each of these regions we know the intra-regional 14x14 IO-table as well as the two 14x14 (imports and exports) trade matrices with regard to the rest of the Netherlands. From these tables, we derive not only the IO-structure on the regional level, but also flows of trade between the fourteen regions which help us estimate the model's parameters.

A.2.2 Community level data

We use the LISA (1998) database which gives, among other things, the amount of labor employed in each sector and total population in each community in 1998. From the 548x14 employment matrix, we derive production per sector per community and the number of firms per sector per community.

A.2.3 Distances

We discern two types of distance in the model. For goods transport, distance is measured in kilometers. We have computed the distance by car between all the possible pairs of communities using a CD ROM with travel information (AND, 1999). This distance is used for goods transport in all the rail variants, indicating that nothing changes with regard to freight. For passenger travel, we measure the distance between all communities in minutes. These distances are an average between the travel time by car (AND, 1999) and by public transport (NEI/HCG 2000). The latter matrix is the one that changes between the rail variants. The weighing is done with the actual *modal split* shares (NEI/HCG 2000). For each rail variant there is a modal split matrix for 28 areas, which takes into account the substitution effect that follows the construction of new infrastructure. This matrix is extrapolated to the 548x548 community pairs.

A.2.4 Scenarios and rail variants

We use one baseline scenario for our calibration of the year 2020. This scenario gives the number of jobs in each sector in each community in 2020 and the number of inhabitants in each municipality in the same year. It is compiled by TNO (*et al.*, 2000) and is based on the 'European Cooperation' scenario (CPB 1997) and a separate regional projection model used at TNO.

The 2020 scenario is used as a test on our model, calibrating it on the 1990s data en checking whether the 2020 scenario leads to an economy in equilibrium at the municipal level. We find that the baseline scenario leads to a severe disequilibrium. When investigated more closely, it turns out that the problems arise because of developments incorporated in the scenario that cannot possibly be predicted by our model, such as the structural shift from manufacturing industries towards service industries.

There are six proposed variants for a higher speed rail connection between Schiphol Airport and the City of Groningen. They are summarized in Table 5 (see Elhorst *et al*, 2000, for a more detailed description).

Rail Variant	Description	Groningen - Schiphol
REF	The null alternative. This includes the Hanzelijn between Lelystad and Zwolle, which is yet to be constructed.	118
HIC	Hanzelijn + IC. The only difference with REF is that trains will go at a higher speed.	102
HHS	Hanzelijn - high speed. A high-speed train replaces the intercity service on the HIC scenario, calling at the larger stations only.	71
ZIC	Zuiderzeelijn IC. New track is constructed between Lelystad and Drachten, leading to a straight link between the North and the West. The track is serviced with intercity trains.	89
ZHS	Zuiderzeelijn - high speed. A high-speed train replaces the intercity service on the ZIC scenario, calling at the larger stations.	65
MZB	Magnetic track. A new technology is used to create super-high speed trains which travel from Groningen to Amsterdam in a straight line. All trains call at all major stations.	59
MZM	Magnetic track - metro schedule. As MZB, but with a schedule that has non-stop trains between only a few terminals.	45

Table 5: Six rail proposals with total travel time in minutes in 2020

A.3 Other Coefficients

For each sector, there are three coefficients set exogenously. These are given in Table 6.

First, the share of goods transport per sector π_s has been determined by outside experts using figures about transport costs from the available data on different sectors.

Second, the tradeability of goods indicates the percentage of the output of a sector that can reasonably be expected to be available to customers outside the major region of production. For personal services like the proverbial haircut, tradeability is extremely low. Sector-wide figures are derived from IO data and sectorial indicators.

Third, the degree to which a sector is locationally tied to its present community is set by outside experts. Exogenous ties result when a firm does not consider the prices in its location decision. On the supply side, this happens when a firm uses specialized local inputs like natural resources or specialized imobile labor, or a facility like a port. On the demand side, ties come about because of localized outputs, such as those of the local government sector.

Sector	Share of goods in total transport	Tradeability of outputs	Locational boundedness
1 Agriculture	0.90	1.00	0.80
2 Mining	0.90	1.00	1.00
3 Manufacturing	0.70	1.00	0.10
4 Public Utilities	1.00	0.50	0.30
5 Construction	0.70	0.70	0.20
6 Trade & Repairs	0.30	0.50	0.30
7 Hotels, Restaurants & Bars	1.00	0.50	0.50
8 Transport & Communication	0.70	0.75	0.30
9 Finance & Insurance	0.00	0.70	0.30
10 Other services & Real estate	0.00	0.55	0.30
11 Government	0.10	0.45	1.00
12 Education	0.00	0.55	0.80
13 Health services	0.10	0.45	0.80
14 Culture & Recreation	0.10	0.55	0.50

Table 6: Exogenously set coefficients per sector

B Derivations

B.1 Cost and Production functions

When two factors are combined in the Cobb-Douglas production function $X^\alpha Y^{1-\alpha}$ and total costs $X \cdot p_X + Y \cdot p_Y$ are minimized, marginal costs are, up to a constant factor, equal to:

$$p_X^\alpha \cdot p_Y^{1-\alpha}. \tag{18}$$

Putting the multiplicative constant in front of the production function, the marginal costs are exactly equal to (18). For this reason, c_{ps} and c'_{ps} are used.

It is not hard to prove that they must be equal to:

$$c_{ps} = (1 - \alpha_{ps})^{\alpha_{ps}-1} \cdot (\alpha_{ps})^{-\alpha_{ps}} \tag{19}$$

and:

$$c'_{ps} = \prod_{s'=1}^{14} \gamma_{p,s,s'}^{-\gamma_{p,s,s'}}. \tag{20}$$

B.2 The number of firms

We want to proof that the number of firms of a certain sector s in a community c in province p is proportional to the amount of labor consumed by that sector in that community multiplied by that sector's local labor requirement α_{ps}. Exit and entry are free so that each firm makes zero profits. It follows that each firm operates on a scale where gross profits $Y \cdot MC / (\sigma_s - 1)$ are equal to a fixed startup cost F_s, which may differ per sector. From the equation for marginal costs, this implies that the optimal scale of firm j in sector s and region p is equal to:

$$Y^*_{j,ps} = (\sigma_s - 1) \cdot F_s \cdot G_{c,s}^{a_s - 1} \tag{21}$$

From production function (3) we derive the production of a firm as a function of the amount of labor used. It turns out that this is:

$$\begin{aligned} Y_{j,ps} &= c_{ps} \cdot L_j \cdot \left(\frac{w}{G_{c,s}}\right)^{1-\alpha_{ps}} \cdot \left(\frac{1-\alpha_{ps}}{\alpha_{ps}}\right)^{1-\alpha_{ps}} && (22)\\ &= \alpha_{ps} \cdot L_j \cdot G_{c,s}^{\alpha_{ps}-1} && (23) \end{aligned}$$

where we use $w = 1$ and the definition of c_{ps}. Equating (21) and (23) we find that a firm operating at optimal scale uses a fixed amount of labor, equal to:

$$L^* = \frac{\sigma_s - 1}{\alpha_{ps}} F_s. \tag{24}$$

Because the amount of labor consumed in community c by sector s, $L_{c,s}^{total}$, is equal to:

$$L_{c,s}^{total} = n_{cs} \cdot L^* \tag{25}$$

we find that the number of firms n_{cs} varies proportionally to the product of $L_{c,s}^{total}$ and α_{ps}.

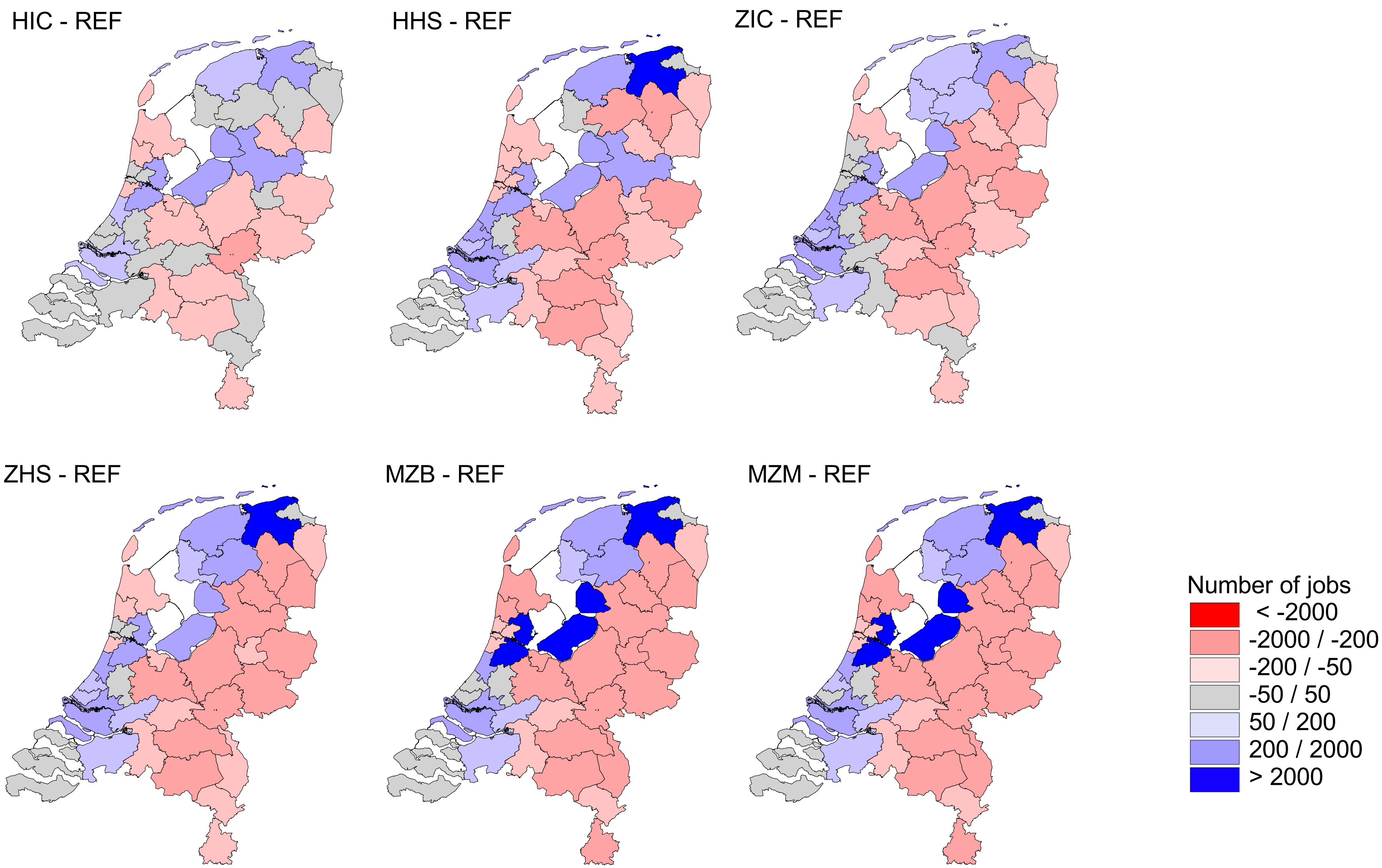

Figure 2: Employment effects per rail variant.