Spoor B1:

Assessing transport investments - towards a multi-purpose tool.

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September 2008

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Assessing transport investments - towards a multi-purpose tool

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Abstract

This paper presents a multi-purpose tool to assess transport investments. The model can handle any combination of passenger and freight transport modes in a simplified network. It is calibrated to a given traffic forecast and can be used to assess the benefits and costs of combinations of strategic pricing behaviour and investment. The use of the model is illustrated with examples.

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We would like to acknowledge the Funding consortium and the Policy research Center Budgetary & Tax Policy, Government of Flanders (B) for financial support.

1 Introduction

This paper presents the MOLINO-II model. This is a multi-purpose model that allows to assess investments as well as strategic pricing behavior by operators in a simplified network. The network can contain different types of modes and can deal with freight and passenger transport simultaneously. Of course the model we present can not solve all questions. Its ambition is not to make a full benefit cost analysis starting from scratch but rather to perform an extra check or a more strategic appraisal of a project that has been evaluated using state of the art network models.

There is a huge fixed cost in constructing and maintaining state of the art macroscopic network models. The network models have often a high degree of detail in the representation of the network and contain detailed discrete choice representation of users' behavior. Our modelling approach differs from the traditional one in three respects. First, we only focus on a simplified network that is directly relevant for the investment. Second, we use aggregate models to represent behavior as they can be calibrated with a minimum of data. Third, we allow different types of strategic pricing behavior by network operators and governments. The latter feature is becoming increasingly important when all transport can be priced and the funding of investment relies more and more on user pricing.

The typical use of the model will be to assess long distance investments by government agencies, investors and infrastructure managers. One of the objectives is to be able to fulfill the requirements of benefit cost analysis as required by international institutions as there are the World Bank, European Investment Bank, European Commission etc.. A beta version of the model have been used to assess investment and pricing of a bridge, a new international freight railway, a rail and road tunnel as well as a HSR project.

We start the paper with an example to show how we represent the network and the supply. We describe the modelling of the users, operators and infrastructure managers as well as the objective functions of local and federal governments. Chapter 3 discusses data requirements, calibration, simulation use of the model and software. Chapter 4 gives illustrative computations of Nash equilibria in a simple parallel and serial network and a graphical representation of some real world investment problems that have been tackled with this model. In the conclusion we briefly discuss possible extensions of this model.

2 Model

2.1 Network representation and supply

The model we present is mainly used for investment analysis and this will guide the network definition. An investment project aims to improve the quality or speed on a given link or set of links that connect some origins and destinations. We start from the links that are improved, examine what type of trips is affected and add to the network definition the potential competing links that may be affected by the project.

Before we start with the formalization an example may clarify the concepts. Consider the upgrade of the Brenner Pass, one of the most important alp crossings connecting northern Europe, especially Germany, and Italy. As the fragile Alpine environment and the existing road infrastructure limit the possible growth of road transport, the new rail axis (denoted as T1 in figure 1, where T stands for rail link) from Berlin to Palermo (Italy) is planned in order to strengthen rail transport and to improve its modal split on the Brenner route. The improvement of the rail tunnel will affect the transport by road through the Brenner pass and so the road link R1 need to be included in the network description (where R stands for road). Beside the Brenner pass, there exists two other alpine crossings, being the Gothard tunnel which consists of a road and rail tunnel and the Lötschberg Base Tunnel (only rail). An improvement on the Brenner Pass will potentially also influence the traffic on these competing links, this means that also links R2, T2 and T3 must be included. In order to model the Brenner-Axis in MOLINO-II , a network with six nodes north of the Alps (Kassel, Köln, Mannheim, Nürnberg, München) and three nodes south of the Alps (Milano, Verona, Bologna) needs to be set up in order to catch the most important traffic flows crossing the Alps which could be affected by an improvement of the Brenner Pass. The nodes and the links between them were chosen according to their importance for the transalpine transport. Each node north of the Alps is linked to each node south of the Alps by a sequence of links. Such a sequence of links will be denoted as a path, e.g.; the origin node Mannheim is connected to the destination node Milan via the path [T4,T3,T6], or [R4,R2,R5]. In this way, 18 OD pairs linked by 20 road paths and 22 rail paths were constructed.

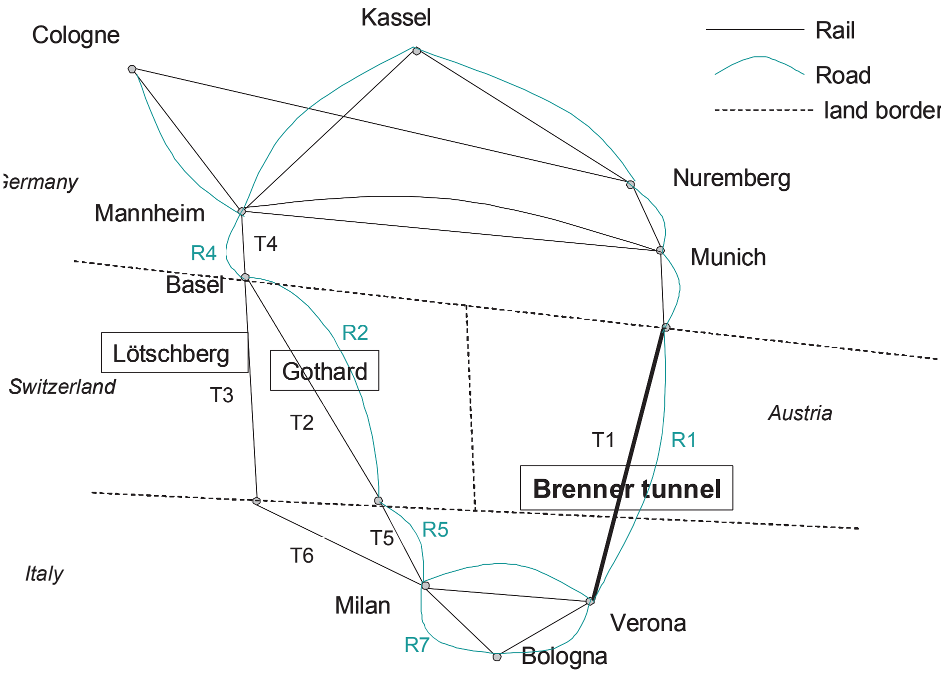

Figure 1: An example of a network in MOLINO II

To describe the model more formally we need following notation and concepts: $d = \{O, D\}$ denotes the set of Origin – Destination pairs, $L = \{1, .., l, \ldots L)$ the set of links and $P = \{1, \ldots, r, \ldots .R)$ the set of paths. Moreover, $\{r; l\}$ stands for paths r which l is part of, $\{d; l\}$ stands for the OD pairs where there is at least one path of which l is part of, $l \in r$ stands for the links l that are part of the path r and $l \in d$ stands for the links l that are part of a path r which connects the origin and destination node of d.

The model uses a horizon of T periods of one year $t = 1, , t, \ldots T$, and each representative day has m subperiods, to simplify one distinguishes between peak and off peak subperiods. Between each origin and destination, different types of users can travel; we distinguish between $k = 1, \ldots K$ classes of users. Classes of users can represent different types of freight transport (container, bulk etc.), different types of motives of passenger transport and/or different levels of income. The behavior of every class is given by a representative individual or shipper. The total volume of transport of a representative user of type k travelling between OD pair d, on a given link l (or a path r) during the subperiod m in year t is represented by $X_{ml}^{dk}(t)$ (or $X_{mr}^{dk}(t)$).

For every link l and every year t we define a length $d_l(t)$, a capacity $s_l(t)$, the maximum speed $v_{lk}^{\max}(t)$, resource costs per user type $rc_l^k(t)$, local government taxes $\tau_{ml,\text{loc}}^k(t)$ and central government taxes $\tau_{ml,\text{cen}}^k(t)$ as well as tolls $\hat{\tau}_{ml}^k(t)$.

Tolls and taxes can differ among subperiods and user types.

The generalized price for a trip for a user of type k using path r during period m, is the sum of a monetary term $T_{ml}^{k}(t)$ plus the time cost, $tt_{ml}^{dk}(t)$:

$$p_{mr}^{dk}(t) = \sum_{l \in r} \left[T_{ml}^{k}(t) + tt_{ml}^{dk}(t) \right] \quad (1)$$

The time cost for link l expresses the time needed for a user of type k to make a trip on the link, given the volume of the different users and the available capacity:

$$tt_{ml}^{dk}(t) = \frac{d_l(t)}{v_{lk}^{\max}(t)} \left[1 + A_l(t) \left(\frac{\sum\limits_{k,\{d;l\},\{r;l\}} \mu_{ml}^{k} X_{mr}^{dk}(t)}{s_l(t)} \right)^{B_l(t)} \right] \quad (2)$$

Where μ_{ml}^{k} is the relative contribution to congestion of user class k on link l and $A_l(t)$ and $B_l(t)$ are parameters defining the appropriate speed-flow relation for link l. As can be seen the congestion on a link is the result of the use made of the link by different types of users and for all OD's that have paths that use that link.

2.2 User behavior

For both passenger and freight transport we opt for an aggregate representation of behavior. Disaggregate choice behavior is clearly superior if a representative sample is available for simulation. Our experience is that this sample is often not available if one wants to go for a quick check of an investment project. We distinguish between passenger transport and freight transport.

2.2.1 Passenger transport

Passenger transport is modeled in an aggregate way by making use of a nested CES (Constant Elasticity of Substitution) utility function. For every user class and every OD pair we calibrate a nested CES utility function with 4 levels:

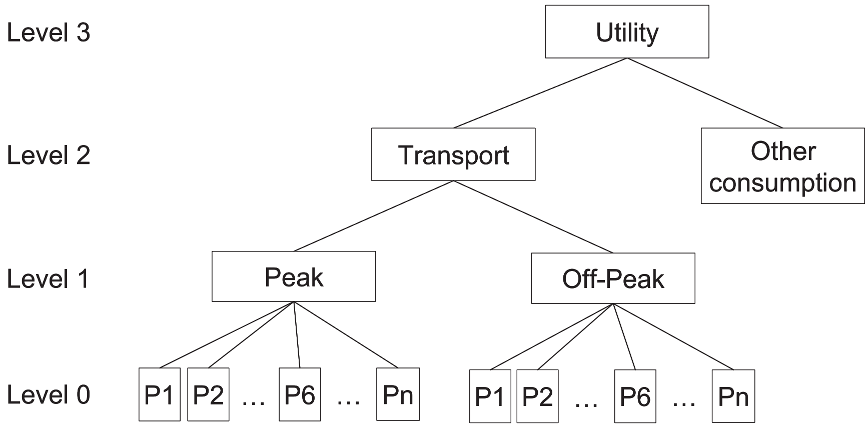

Figure 2: Nested Utility tree for passenger transport.

We allow consumers on each OD pair to choose the aggregate transport level, the period in which they travel and the path. The path can contain combinations of modes. The elasticity of substitution chosen for every branching of the tree will determine the ease of substitution and the cross price elasticity between different paths and implicitly also modes. For perfect substitution possibilities between paths we end up in the Wardrop equilibrium but substitution can also be imperfect. So we do not necessarily use the Wardrop principle for the choice of paths. The main advantage of this utility function specification is that only a limited set of data is needed for the calibration: there are the elasticities of substitution at each branch plus the total quantities and prices at the lowest level.

We specify the nested utility function by specifying the different utility components. Following Keller (1976), we assume that all the utility components are linear homogeneous CES functions of the associated components at the next lower level[1]. Formally, at the nth level, the utility component $q_{n,i}$ is given by $\forall n = 1, 2,$and $\forall i$

$$q_{n,i} = \left[\sum_{j \in i} (\alpha_{n-1,j})^{1-\rho_{n,i}} (q_{n-1,j})^{\rho_{n,i}} \right]^{\frac{1}{1-\rho_{n,j}}}, \quad \rho_{n,i} = \frac{\sigma_{n,i} - 1}{\sigma_{n,i}}, \quad \forall n, i \qquad (3)$$

where $\alpha_{n-1,j} \geq 0$, $0 \leq \sigma_{n,i} \leq \infty$ and $\sum_{j \in i} \alpha_{n-1,j} = 1$. Note that we suppress here the superscripts d and k corresponding to the OD pair and user type in order to lighten the notation. The parameter $\sigma_{n,i}$ in eq(3) is the elasticity of

[1]The utility components at a different level are said to be associated if the higher-level component is a function of the component at the lower level. If two utility componentns $q_{n,i}$ and $q_{m,j}$ (with $m < n$) we write $q_{m,j} \in q_{n,i}$. Notice that for utility components at level $n \geq 1$ the notation is not necessarily unique.

substitution at level n of the tree and the parameter $\alpha_{n-1,i}$ is a share parameter at the next lower level. The notation "$j \in i$ " indicates those's j's for which $q_{n-1,j} \in q_{n,i}$.

For each utility component, an aggregate quantity index and corresponding aggregate price index can be computed. It is a property of CES functions that the utility component, $q_{n,i}$, is itself a consistent quantity index and that the corresponding price index, $p_{n,i}$, takes similar functional forms, i.e.:

$$p_{n,i} = \left[\sum_{j \in i} \alpha_{n-1,j} \left(p_{n-1,j}\right)^{\rho'_{n,i}} \right]^{\frac{1}{\rho'_{n,j}}}, \quad \rho'_{n,i} = \frac{\sigma'_{n,i} - 1}{\sigma'_{n,i}}, \quad \sigma'_{n,i} = \frac{1}{\sigma_{n,i}}, \qquad \forall n, i \tag{4}$$

At each level the sum of the expenditures of the lower level equals the total income computed with the price and quantity indexes at that level,

$$y_{n,i} = \sum_{j \in i} y_{n-1,j} = p_{n,i} q_{n,i}, \qquad \forall n, i \tag{5}$$

It can be shown that the demand functions are:

$$q_{0,i} = \frac{y}{p_3} \prod_{n=1}^{3} \alpha_{n-1,i} \left(\frac{p_{n,i}}{p_{n-1,i}} \right)^{\sigma_{n,i}}, \qquad \forall i \ . \tag{6}$$

The demand for transport services $q_{0,i}$ will correspond to the aggregate number of trips on a path r during a period m for a category of users k on OD pair d also denoted by X^{dk}_{mr} . The lowest price index $p_{0,i}$ corresponds with the generalized price of making a trip using path r during period m for a category of users k on OD pair d previously denoted by p^{dk}_{mr} given in eq(1).

The main advantage of the nested CES formulation is its ease of calibration. The drawback are the implied restrictions. The implicit unitary income elasticities for all transport can be mitigated by recalibrating the utility function when large income variations are foreseen.

2.2.2 Freight transport

For freight transport we use a similar approach. We assume that the production function of each firm that needs transport services is a nested CES function of the different production inputs: labor, capital and transport services. For each firm, keeping production levels constant, the minimization of the firm's production cost, generates demand functions for inputs including the demand for transport services. The demand functions for inputs are conditional on the production level of the firm and the prices of all the inputs, including the prices of non transport inputs. MOLINO-II is a partial equilibrium model that concentrates on the transport market and takes the prices of all other inputs as well as all product prices, other than transport services as given.

2.3 Behavior of stake holders and other agents

2.3.1 Behavior of operators and infrastructure managers

There are two types of agents involved for each infrastructure: the manager of the infrastructure (one for each link) and the operator of the transport services (one for each link). The manager of the infrastructure decides upon (and pays for) the capacity maintenance and investments. He receives a fee (or infrastructure-use charge) from the transport services operator (or a fraction of the net revenue of the operator). The operator sets the level of tolls, receives the toll revenue and pays for the operation cost and the infrastructure-charge to the infrastructure manager. This is schematically given in Figure 3, where arrows stand for payments.

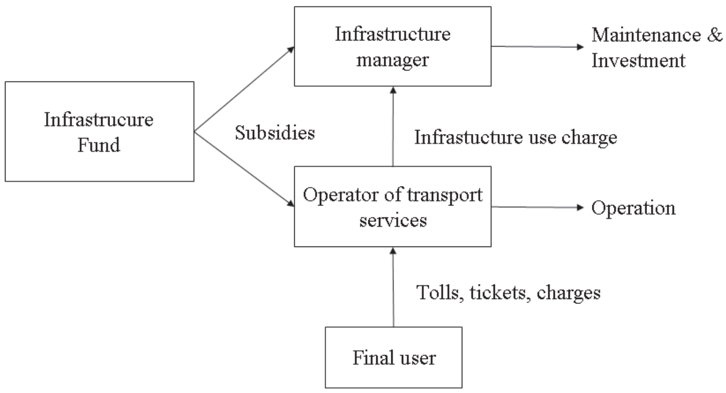

Figure 3: Money flows

The model also traces the position of the infrastructure funds that are fed by user charges or by subsidies and that are used to finance investments. Once these costs are known, the profit of the operator of link l, Π_l^{or}, can be computed. We have:

$$\Pi_l^{\mathrm{or}} = Tollrevenue_l - INFC_l - \theta_l^{\mathrm{or}} \cdot OPC_l + sub_l^{\mathrm{or}} \tag{7}$$

where $Tollrevenue_l$ are the tollrevenues on link l collected by the operator, $INFC_l$ denotes the infrastructure-use charge of link l which consists of the sum of a fixed infrastructure-use charge and a variable infrastructure-use charge per vehicle paid to the infrastructure manager by the operator, OPC_l, the operation costs on link l, which again is a sum of a fixed operational cost and a variable one depending on the number of travelers and is paid by the operator. The variable sub_l^{or} denotes possible subsidies received by operator of link l. If the same operator is in charge of different links, its profits will just be the sum of the profits on each of its links.

In the same way, the profit of infrastructure manager of link l, denoted by Π_l^{inf} is given by:

$$\Pi_l^{\text{inf}} = INFC_l - \theta_l^{\text{inf}} \cdot INVC_l - \theta_l^{\text{inf}} \cdot MC_l + sub_l^{\text{inf}} + \text{ Salvage value} \tag{8}$$

where $INVC_l$ denotes the investment costs of link l, MC_l denotes the maintenance costs of infrastructure on link l which consists of the sum a fixed maintenance cost per unit capacity and a variable cost per vehicle, sub_l^{inf} are the possible subsidies received by infrastructure manager of link l and "Salvage value" is the salvage value of the investments made by the manager of link l.

The (exogenous) parameters θ_l^{or},θ_l^{inf}, capture the efficiency of the agents as a function of the market organization. These parameters will depend on the type of contract between the principal (e.g. the infrastructure manager, operator or government) and the agent (e.g. the firm responsible for maintenance). With tendering the parameters will be close to 1 (we assume that operating, maintenance and investment costs are the minimum technologically feasible costs) while without tendering they will be higher since efficiency will then decrease.

Operators pay infrastructure charges to the infrastructure managers and set prices for transport services that maximize their objective function. We foresee two types of behavior: either profit maximization or setting prices equal to marginal social marginal costs. The first is more common for a private operator. A public operator, if he maximizes social welfare may be more interested in setting prices equal to the marginal social marginal costs. This is the resource cost plus the marginal external cost. In both cases we assume that the behavior is static (one maximizes the profit or welfare for the given year) and takes all other prices as given (Nash behavior).

Similarly, infrastructure managers charge fees for the use of their infrastructure and can decide on the investments. Again we foresee two types of behavior for user fees: profit maximization or setting prices equal to the marginal social cost.

The investment behavior is either exogenous or can be substituted by a naive rule where each year the benefit of capacity extension is compared to the cost of extension. As the model is solved year by year and is not forward looking, the benefit of capacity extension for the future years is based on an extrapolation of the current benefits. We call it therefore a naive investment rule.

2.3.2 Local and federal governments

Every link of the network belongs to the authority of a local and of a central (or federal) government. Both can charge taxes or tolls and do so with different objectives in mind. Local governments may be interested in the user benefits of the local voters and in the toll revenue raised from the through transport users and this can give rise to a different pricing and investment behavior than a federal government would do (see De Borger, Dunkerley, Proost, JUE, 2007). We represent the objective function of each government by a social welfare function (SWF) that is a weighted sum of the welfare of its voters. If the welfare of all voters receives an equal weight, we obtain the total benefits and costs, If the weights are different, we have a political economy approach where the objective function translates the weight of different voters or lobby groups as in a common agency model (see Dixit, Grossman, Helpman (1997)).

The welfare function SWF is a weighted sum of different terms:

$$\begin{aligned} SWF \quad = \quad & \sum_{k \in p} w^k U^k - \sum_{k \in f} w^k PC^k \\ & + f_C \left(w^k\right) \Gamma_C \, \tau^k_{ml,\text{cen}} + f_L \left(w^k\right) \Gamma_L \, \tau^k_{ml,,\text{loc}} \\ & + \sum_l f_l^{\text{or}} \left(w^k\right) \Pi_l^{\text{or}} + \sum_l f_l^{\text{inf}} \left(w^k\right) \Pi_l^{\text{inf}} \\ & - w^{\text{ext}} EXTC + \text{Fund} \end{aligned} \tag{9}$$

The two first terms: U^k are the utility of an individual of type k of transport and PC^k are the production costs of a firm of type k, these are computed by the model using the nested CES utility functions. The weights w^k represent the social weight the decision maker gives to the different passenger user types or different types of freight. If the different user types correspond to different income groups, one may want to give the lower income group a higher weight than the higher ones if one values a euro that benefits these group more than a euro benefitting the more wealthier households. In the case of freight one can, for example, make the distinction between local and non local freight. For a local firm, a change in transport costs will affect the local households via the total production cost of this firm. In order to allocate this effect over different groups of voters one can allocate the benefits in proportion to the relative consumption of the two income groups. Changes in the production costs of non local transport firms do not have any effect on the local population and distributional considerations are as such not needed. In the case of a local government which is only interested in the welfare effects on its local population the weight of the production costs of the non local transport firms is set to zero. This is only one of the many possibilities, every case study will need its own interpretation.

The 3rd and 4th terms represent the total transport tax revenues collected by local and central governments. Each of these terms receives two weights: $\Gamma_{...}$

,the marginal cost of funds and a distributional weight function $f_{\dots}\left(w^k\right)$ .The marginal cost of funds parameter stands for the marginal welfare cost of one unit of public revenue raised by the marginal tax. This parameter can be larger than one when distortive labour taxes are the marginal source of tax revenue. Extra government tax revenues raised on transport allow then to decrease distortions in the rest of the economy. The second distributional weight function $f_{\dots}\left(w^k\right)$ translates tax revenues into utility changes for different income groups by using an assumption for the final incidence of the redistributed tax revenue. The way the transport tax revenues are redistributed is often more important for the final incidence of a transport charge than the relative use of the transport facility.

The 5th and 6th term compute the ultimate incidence on voter groups of the profits of operators and infrastructure managers. This requires again the specification of an incidence parameter. In order to determine $f_1^{\mathrm{or}}\left(w^k\right)$ and $f_1^{\mathrm{inf}}\left(w^k\right)$ we also need to know whether link l is privately or publicly managed (operated) and: if it is privately managed (operated), whether profit taxes go to local or central government, or if it is publicly managed (operated), whether it is managed (operated) by local or central government. The 7th term captures the effect of other external costs $EXTC$ (other then congestion), the last term is the net account of the infrastructure fund.

3 Data requirements, calibration and convergence

3.1 Data requirements

3.2 Calibration

The unknown parameters are the shares (α) of the components at each level of the nested CES utility functions. We assume that the elasticities of substitution are known. Making use of the known market demand quantities and generalized prices for each of the transport modes and preferences (as captured in the elasticities of substitution), the shares can be computed. This means that given observed quantities, generalized prices, the nest-structure and the elasticities of substitution, it is possible to calibrate the demand functions and the utility function.

We use following procedure:

1. calculate the commodity level expenditures ($y_{0,i}$) using eq(5).
2. for every cluster of nodes (utility elements associated with a common utility element one level higher up), calculate the share parameters $\alpha_{0,i}$ using the following expression

$$\alpha_{n-1,j} = \frac{y_{n-1,j}}{y_{n,j}} \left(\frac{p_{n-1,j}}{p_{n,j}}\right)^{\sigma_{n,j}-1}, \tag{10}$$

and knowing that for every cluster, the sum of the $\alpha_{0,i}$'s is 1 (see example below).

3. calculate expenditures of the next higher level ($y_{1,i}$) using eq(5).
4. use these results to calculate price indices of the higher level ($p_{1,i}$) using eq(4).
5. repeat steps 2 to 4 to the highest level

Example of the calibration procedure
As an example, consider following simplified decision tree:

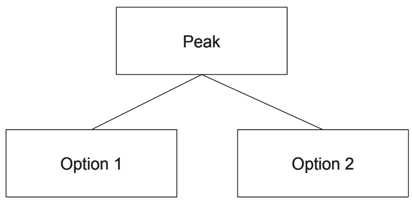

Figure 4: Example of a simplied decision tree

This cluster has two lower level elements ($q_{0,p1}$ and $q_{0,p2}$) which correspond to observed quantities (respectively during the peak on option 1 and during the peak on option 2). Together with the observed generalized prices for these commodities ($p_{0,p1}$ and $p_{0,p2}$) one can easily compute the expenditures ($y_{0,i}$) (step 1). Using equation 10 we can write $a_{0,i}$ as:

$$\alpha_{0,i} = \frac{y_{0,i}}{y_{1,i}} \left(\frac{p_{0,i}}{p_{1,i}} \right)^{\sigma_{1,i}-1}, \quad i = 1, 2. \tag{11}$$

Divide $\alpha_{0,p1}$ by $\alpha_{0,p2}$ to obtain

$$\frac{\alpha_{0,p1}}{\alpha_{0,p2}} = \frac{y_{0,p1}}{y_{1,p1}} \left(\frac{p_{0,p1}}{p_{1,p1}} \right)^{\sigma_{1p1}-1} \frac{y_{1,p2}}{y_{0,p2}} \left(\frac{p_{1,p2}}{p_{0,p2}} \right)^{\sigma_{1,p2}-1}. \tag{12}$$

The two elements $q_{0,p1}$ and $q_{0,p2}$ have a common next higher level and thus $q_{1,p1} = q_{1,p2}$. This implies that $p_{1,p1} = p_{1,p2}$, $y_{1,p1} = y_{1,p2}$ and $\sigma_{1,p1} = \sigma_{1,p2}$.The equation then simplifies to:

$$\frac{\alpha_{0,p1}}{\alpha_{0,p2}} = \frac{y_{0,p1}}{y_{0,p2}} \left(\frac{p_{0,p1}}{p_{0,p2}} \right)^{\sigma_{1p1}-1}. \tag{13}$$

Knowing that $\sum_{i=p1,p2} \alpha_{0,i} = 1$, the parameters can be easily calculated knowing the expenditures and prices at this level. For the example considered the procedure stops here. If however there are several higher levels, we compute the next higher level parameters $\alpha_{1,i}$ in similar way using the total expenditure of that particular level; $y_{1,i} = y_{0,p1} + y_{0,p2}$ (using eq(5)) and price indexes $p_{1,i}$ which are computed using eq(4).

3.3 Simulations

Once the model is calibrated and the parameters $\alpha_{n,i}$ are fixed, we can calculate the behavioral response in quantities X_{mr}^{dk} (or $q_{0,i}$) after a change of the generalized prices p_{mr}^{dk} (or $p_{0,i}$). A change in the generalized price can be due to a change in the level of the toll, taxes or other component of the monetary term $T_{ml}^{k}(t)$ in eq(1) or due to a change of the speed-flow relation relation defined in eq(2) that specifies the time cost. A change in the generalized price on a specific link will have an effect on the demand of all links in the network. The change in volume implies on its turn a change in congestion conditions on the different links which on their turn influences demands. It is therefore clear that we need an iterative procedure to compute the new equilibrium.

3.3.1 Simulation of the effects of a change in the toll levels

We will consider, for example, a change in the level of the toll on some link l :

$$\tau_{ml}^{k} \rightarrow \hat{\tau}_{ml}^{k}$$

which implies a change in the monetary term $T_{ml}^{k} \rightarrow \hat{T}_{ml}^{k}$. The iterative procedure goes as follows:

1. First compute the new generalized prices holding the quantities constant $\widehat{p}_{mr}^{dk}(0)$ (where the argument 0 does not stand for the time but should be interpreted here as an iteration index):

$$\widehat{p}_{mr}^{dk}(0) = \sum_{l \in r} \left[\hat{T}_{ml}^{k} + tt_{ml}^{dk}(-1) \right] \tag{14}$$

   where $tt_{ml}^{dk}(-1)$ is the time cost when the quantities X_{mr}^{dk} are the equilibrium quantities for a toll equal to the original level τ_{ml}^{k}.

2. Using equation eq(4) one computes the induced price indices $\hat{p}_{n,i}(0)$ for the higher levels all the way up to $\hat{p}_3(0)$.

3. Starting from the top and knowing $\hat{p}_3(0)$, one calculates the expenditures using the expression given in eq(10) where now the $\alpha_{n,i}$ parameters are known. To be able to do this one needs one additional assumption. We assume that for passengers, income is constant , so that $\hat{y}_3(0) = y_3$. In the case of freight, it is not the income but the total production quantity (the quantity index at the highest level, q_3) that is assumed to be constant, so that in this case $\hat{y}_3(0) = q_3 \cdot \hat{p}_3(0)$.Using the new $\hat{y}_3(0)$ we can then compute the lower level expenditures all the way down to $\hat{y}_{0,i}(0)$. Once these lowest level expenditures are known we can easily calculate the new demands $\hat{q}_{0,i}(0)$ (or $\hat{X}_{mr}^{dk}(0)$) using eq. $\hat{y}_{0,i}(0) = \hat{p}_{0,i}(0)\,\hat{q}_{0,i}(0)$.

4. Since the time cost is a function of the quantities, these will change and we thus have to compute the time cost $\widehat{tt}_{ml}^{dk}(0)$ by substituting $\hat{X}_{mr}^{dk}(0)$ into eq(2)

Define the new time costs as

$$tt_{ml}^{dk}(0) = \tilde{\lambda}_0 tt_{ml}^{dk}(-1) + \left(1 - \tilde{\lambda}_0\right) \widehat{tt}_{ml}^{dk}(0)$$

where

$$\tilde{\lambda}_n = \frac{\tilde{\lambda}}{n+1}, \qquad 0 \leq \tilde{\lambda} \leq 1$$

5. Compute the new generalized prices

$$\widehat{p}_{mr}^{dk}(1) = \sum_{l \in r} \left[\hat{T}_{ml}^{k} + tt_{ml}^{dk}(0)\right]$$

One repeats steps 2-5 until convergence, i.e.:

$$\frac{tt_{ml}^{dk}(n) - tt_{ml}^{dk}(n-1)}{tt_{ml}^{dk}(n)} < \varepsilon$$

When the last inequality holds, we have the new equilibrium quantities and generalized prices.

3.3.2 Simulation of the effects of new investments

Improvement of an existing link: Investments on an existing link aim to improve the quality or the speed on that given link, so it will change the parameter values of the speedflow relation. Denote the new speed-flow relation by $\widetilde{tt}_{ml}^{dk}$. To compute the new equilibrium after the improvement we use very much the same procedure as described above. As before we first compute the new generalized prices holding the quantities fixed but now using the new speed-flow relation $\widetilde{tt}_{ml}^{dk}$:

$$\widehat{p}_{mr}^{dk}(0) = \sum_{l \in r} \left[T_{ml}^{k} + \widetilde{tt}_{ml}^{dk}(-1)\right]$$

The remainder of the procedure stays the same.

Adding a new link: MOLINO-II is not a forecasting model, so we assume that the effects on demand flows and generalized prices once the new link is added are known. The model is then recalibrated using the new paths and quantities. Parameters such as the elasticities of substitution are fitted as to recreate the actual situation without new link by setting extremely high generalized prices on the new link when it is not available.

4 Software implementation

A research version of MOLINO I has been programmed in Mathematica 5.0 with input and output via Excel worksheets . The MOLINO-II model was reprogrammed in a more user-friendly way using WinDev that contains an appropriate user interface. The user interface operates as follows.

It first asks to define types of agents (users, operators, governments), number of subperiods and number years in the planning horizon. This is followed by the construction of the network. First the nodes are labeled. Next one selects the links between nodes that make sense and the user help is also required to define the paths of interest as an automatic generation of all possible paths gives quickly a very high number of paths to deal with.

For every link one needs information on length, speed flow relation, capacity of the link, variable operating cost, number and type of users as well as the type of operator (private/public and what type of public operator), resource costs, values of time, local and central taxes on use.

When elasticities of substitution are provided by type of user, the model is automatically calibrated for every year by computing users' costs and combining these with quantity of trips to construct utility and demand functions as explained in 3.1.1. Once the model is calibrated one can specify the policy simulations of interest.

Running an illustration as described in section 5 takes of the order of a couple of minutes on a PC.

5 Illustrations of the use of MOLINO-II

MOLINO-II can be used for cost benefit analysis of real world investments in a transport network but it also allows for more general analyzes like the simulation of Nash equilibria between competing profit maximizing operators who each control part of the network. We first illustrate this feature for a simple parallel and a simple serial network, then we discuss a real world case-study, namely the investment in the Brenner tunnel.

5.1 Nash equilibrium tolls

We will illustrate how a model such as MOLINO-II can be used to analyze Nash competition between operators on a network. Computing Nash equilibria can, even for very simple networks, quickly become a difficult analytical exercise if one wishes to use general functional forms for the demand functions. To be able to say something about how Nash tolls are influenced by some of the parameters of the model one needs to rely on numerical simulations. MOLINO-II is very well suited to deal with such matter as will be illustrated below.

Nash equilibrium tolls in a parallel network

Consider a network consisting of two nodes, A and B with two links connecting the two nodes.

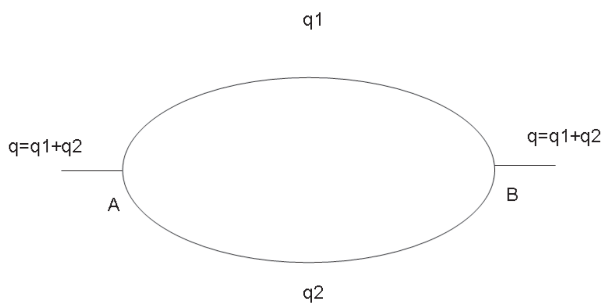

Figure 5: Parallel network

For simplicity we assume only one type of user and one subperiod. Each link is operated by a different agent which has following objective function Π_l^{or} :

$$\Pi_l^{\mathrm{or}} = (\tau_l - c_l)\, q_l, \qquad l = 1, 2 \tag{15}$$

where τ_l is the toll on link l, c_l the operating cost and q_l the demand on link l. Demand is described by the nested CES functions as described in eq(6). Here we write them in an abbreviate form: ultimately the demand function can be written as a function of the generalized prices p_l on both links:

$$q_1 = F(p_1, p_2) \tag{16}$$

$$q_2 = G(p_1, p_2) \tag{17}$$

For the sake of clarity we assume a simple form for the generalized prices: we take them to be a linear function of the volume: $a_l + b_l q_l + \tau_l$.
In a Nash equilibrium, operators will set their tolls such that their profits are maximized taking the toll of the competitor as given. The first order conditions are:

$$\frac{\partial \Pi^1}{\partial \tau_1} = q_1 + (\tau_1 - c_1)\frac{\partial q_1}{\partial \tau_1} = 0, \tag{18}$$

$$\frac{\partial \Pi^2}{\partial \tau_2} = q_2 + (\tau_2 - c_2)\frac{\partial q_2}{\partial \tau_2} = 0. \tag{19}$$

so

$$\tau^{*l} = c_l - \frac{q_l}{\frac{\partial q_l}{\partial \tau_l}}$$

Defining $F_l \equiv \frac{\partial F}{\partial p_l}$ and $G_l \equiv \frac{\partial G}{\partial p_l}$, and deriving the equations $q_1 - F = 0$ and $q_2 - G = 0$ w.r.t. τ_1 gives us:

$$\frac{dq_1}{d\tau_1} - F_1 \cdot \left[b_1 \frac{dq_1}{d\tau_1} + 1\right] - F_2 \cdot \left[b_2 \frac{dq_2}{d\tau_1}\right] = 0 \tag{20}$$

$$\frac{dq_2}{d\tau_1} - G_1 \cdot \left[b_1 \frac{dq_1}{d\tau_1} + 1\right] - G_2 \cdot \left[b_2 \frac{dq_2}{d\tau_1}\right] = 0 \tag{21}$$

From the last equation we get

$$\frac{dq_2}{d\tau_1}\left[1 - G_2 \cdot b_2\right] = G_1 \cdot \left[b_1 \frac{dq_1}{d\tau_1} + 1\right] \tag{22}$$

Substituting this into eq(20) yields

$$\frac{dq_1}{d\tau_1} - F_1 \left[b_1 \frac{dq_1}{d\tau_1} + 1\right] + \frac{b_2 F_2 G_1}{[1 - b_2 G_2]} \left[b_1 \frac{dq_1}{d\tau_1} + 1\right] = 0 \tag{23}$$

$$\frac{dq_1}{d\tau_1}\left[1 - b_1 F_1 - \frac{b_1 b_2 F_2 G_1}{1 - b_2 G_2}\right] = F_1 + \frac{b_2 F_2 G_1}{1 - b_2 G_2} \tag{24}$$

In the symmetric case we have that $b_1 = b_2 = b$, and the direct- (resp. cross-) price derivatives are equal: $F_2 = G_1$ and $F_1 = G_2$. The equations then simplify to

$$\frac{dq_1}{d\tau_1}\left[\frac{(1 - bF_1)^2 - (bF_2)^2}{1 - bF_1}\right] = \frac{(1 - bF_1) F_1 + b (F_2)^2}{1 - bF_1} \tag{25}$$

or

$$\frac{dq_1}{d\tau_1} = \frac{F_1 + b\left[(F_2)^2 - (F_1)^2\right]}{(1 - bF_1)^2 - (bF_2)^2} \tag{26}$$

If there is no congestion ($b = 0$) the increase in demand due to an increase in the toll will be equal to F_1, the direct price effect. For $b > 0$, the increase in demand will be smaller because some of the traffic will be deviated to the other route which increases the generalized price on the other route, causing some of the traffic to return to its the original route.

We can use MOLINO-II to test the sensitivity of the Nash tolls to the congestion function parameter and to the substitutability between the two routes. For the symmetric case we use the values given in Table 3:

veh/h per link when $\tau = 0$	2
a (the free flow time)	0.5
operation cost per veh (c)	1
elasticity of subst between transp and other consumption (σ_{troc})	3
all other user costs	0

Table 3: Parameter values for the parallel network

To test the sensitivity to the congestion parameter we, furthermore, assume an elasticity of substitution between the two routes of 1.1. The Nash tolls τ^* are given in function of the parameter b in Figure 6:

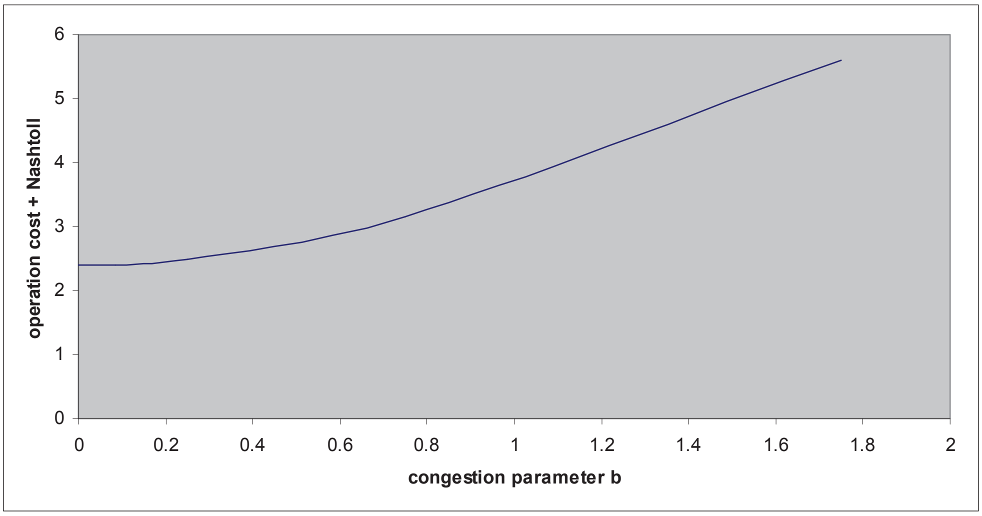

Figure 6: Nashtoll in function of the congestion parameter for a parallel network

A higher b corresponds with more congestion. If the free-flow speed is 120 km/h, then a b of 0.25 corresponds to a peak speed of 60 km/h, a b of 1.75 with a peak speed of 15 km/h and a b of 0.08333 corresponds with a peak speed of 90 km/h. The fact that for higher levels of congestion, the equilibrium toll increases is in line with previous literature e.g. de Palma, Leruth (1989).

In Figure 7 we show the sensitivity of the nash toll to the substitutability between the two routes. The Y-axis reports the sum of the variable operation cost per vehicle plus the toll charged by an operator. The X-axis reports the substitution elasticity between the two routes. We assume the congestion parameter b_l for both links to be equal to 0.25. As can be seen, a higher substitutability between the two routes reduces the toll by a factor ([3.5-1] to [1.5-1]). In the limit, with perfect substitutability, the toll converges to the marginal external congestion cost as this is a Bertrand equilibrium: the marginal external congestion cost equals here bq or approximately $(0.25)\,(2) = 0.5$.

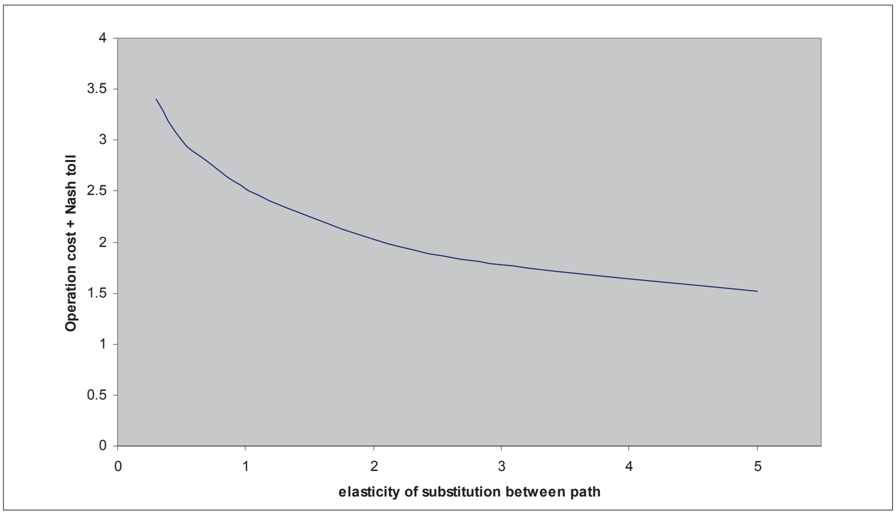

Figure 7: Nashtoll in function of the elasticity of substitution between the two routes.

Nash equilibrium tolls in a serial network

The two operators now deal with the same traffic flow that has to pass through segment AB and segment BC in Figure 8:

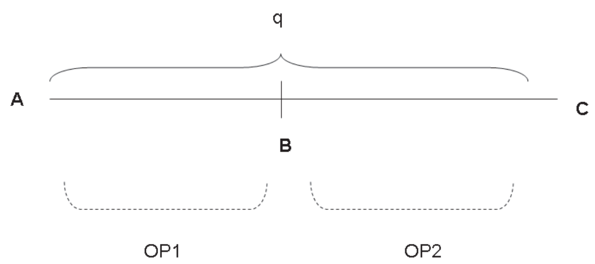

Figure 8: serial network

Each segment (or link) is again operated by a different agent which has the same objective function Π_l^{or} as in the parallel network but now each agent charges the same demand q :

$$\Pi^l = (\tau_l - c_l)\, q, \qquad l = 1,2 \tag{27}$$

where τ_l is the toll on link l, c_l the operating cost and q the demand. Again, demand is described by a nested-CES function and can be written as a function of the generalized price p:

$$q = F(p) \tag{28}$$

where

$$p = p_1 + p_2 \tag{29}$$

and

$$p_l = a_l + b_l q + \tau_l, \qquad l = 1,2 \tag{30}$$

Let $F_p \equiv \frac{\partial F}{\partial p}$, then deriving $q - F = 0$, yields

$$\frac{dq}{d\tau_1} - F_p \cdot \left[(b_1 + b_2)\frac{dq}{d\tau_1} + 1\right] = 0 \tag{31}$$

$$\frac{dq}{d\tau_2} - F_p \cdot \left[(b_1 + b_2)\frac{dq}{d\tau_2} + 1\right] = 0 \tag{32}$$

or

$$\frac{dq}{d\tau_1} = \frac{F_p}{1 - (b_1 + b_2)\, F_p} = \frac{dq}{d\tau_2} \tag{33}$$

As for the parallel case, MOLINO-II can again be used to test the sensitivity of the Nash toll to the congestion parameter. For the symmetric case, the values of the other relevant parameters are given in the following table:

veh/h per link when $\tau = 0$	4
a (free flow time cost)	0.5
variable OPC per veh (c)	1
elasticity of subst between transp and other consumption (σ_{troc})	3
all other user costs	0

Table 4: Parameter values for the serial case

In Figure 8, we have on the Y-axis the level of the Nash toll levied on each of the links, the X-axis reports the value of the congestion parameter b :

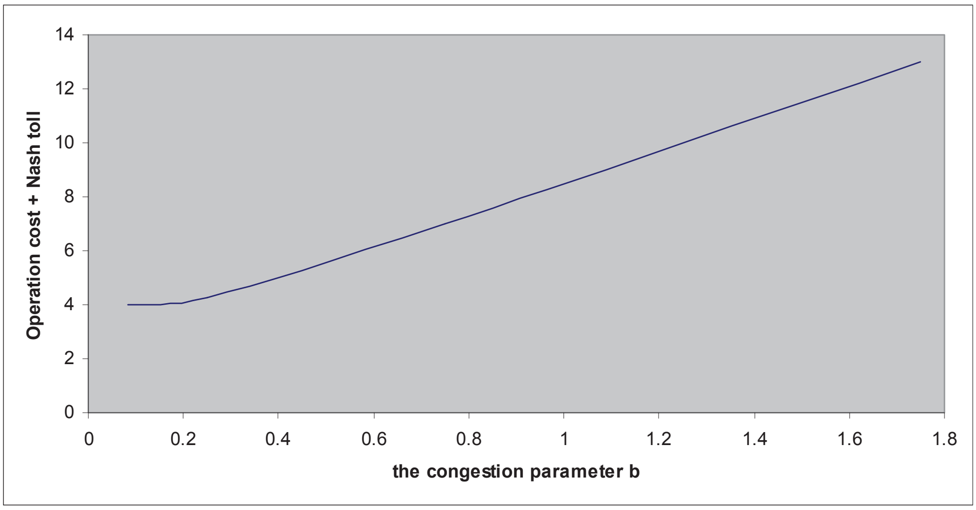

Figure 8: Nashtoll in function of the congestion parameter for a serial network

In the serial case each operator sets his toll disregarding the loss of profits for the other operator. The result is double marginalization and a toll much higher than efficient. The profit maximizing toll of one monopolist controlling the two links for $b = 0.25$, would in total be 2.1 rather than 8.5 $(4.25 + 4.25)$ in the Nash equilibrium.

5.2 A real world case-study: the Brenner tunnel

As mentioned in section 2 the Brenner Base tunnel (BBT) is one of the most important alp crossings, connecting northern Europe, especially Germany, and Italy. MOLINO-II has been used to study the investment in the rail link going through the Brenner Pass. The network used for this case study has been depicted in Figure 1. The resulting network is a simplification of the real transport network, since it covers only the most heavily used links in Germany, Switzerland, Austria and Italy. Nonetheless, the network reflects the most important characteristics of the transalpine transport networks crossing Austria and Switzerland which may be influenced by an investment in the Brenner tunnel. The investments under study are assumed to reduce the generalized costs of railway transport through an increase of the average speed on the link and a reduction in resource costs (due to larger occupancy rates and reduction of the number of locomotives needed to cross the tunnel). To study the effects of the investment, four pricing and investment scenarios have been compared:

- Base scenario: No change in tolls, no improvement on the Brenner tunnel. This scenario is used as reference case for all other scenarios.
- With Project: No change in tolls, improvement on the Brenner tunnel.
- MSC Base: Traffic is charged marginal social cost prices; no improvement on the Brenner tunnel.

- MSC Project: Traffic is charged marginal social cost prices; Brenner tunnels is improved.
- Complete compensation (CC): The Austrian Rail toll is set according to the benefits for transport users, which result from the new Brenner Base Tunnel.

The analysis is focused around two major questions: do the invetsment in the BBT result in the expected modal shift from road to rail and can the investment be financed by user revenues or is there are clear need for subsidies?

From the analysis two main conclusions can be drawn. First of all, the impact on rail transport is rather limited and implementing marginal social cost pricing seems to outperform the BBT-investment. But since MSC pricing requires a change of the tolls of all modes on all links, a cooperative action of the governments involved would be required. Secondly, the analysis shows a clear trade-off between financing and aspired transport effects. If they assume that the project operator receives a subsidy of 70 % of the investment, in the first two scenarios, the additional toll revenues are not high enough to cover the additional maintenance costs. In the third scenario the investment has to be subsidized by 90% to produce a positive Cash Flow. The BBT being a very expensive investment it thus seems questionable whether public funding will suffice to make it financially viable. In their analysis, only the option to recoup the total benefit of rail users by higher pricing (and – in addition - a reduction of maintenance costs by shutting down the old Brenner route) seem promising from a pure financial perspective.

6 Extensions and Conclusions

The MOLINO-II model is a multi-purpose model to assess transport investments using a minimum of data. It has been tested successfully on a number of investment projects. There are different avenues for extension.

First there is a need to develop a consistent approach to the huge uncertainty in long term developments in demand and costs. One can of course use a Monte Carlo approach but for this to be really useful one needs a good way to generate the joint distribution of the uncertain parameters.

The second priority is to assist the user in the generation of initial scenarios for development of demand and costs. The experience for many projects is that there is often not a solid first study available to calibrate MOLINO-II.

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Steunpunt beleidsrelevant onderzoek 2007-2011

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