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An Empirical Evaluation of how commuting flows respond to new road connections and Toll Charges

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An Empirical Evaluation of how Commuting Flows Respond to New Road Connections and Toll Charges

(PRELIMINARY VERSION¹).

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Abstract

The presence of topographical barriers like mountains and fjords often cause disconnections in the road network. In this paper we consider investments that remove the effect of such barriers through the construction of bridges and tunnels. We focus on how travel demand responds to different levels of toll to be imposed for using the new road connection. Available data restricts the study to the context of commuting flows. Estimation results are used to predict how the generation and distribution of commuting flows is influenced when a ferry connection between two islands in western Norway is substituted by bridges and tunnels. We also estimate the willingness to pay for a new road connection, and predict how commuting flows respond to alternative pricing policies both in the case with the ferry connection and in the case when a new road link is established.

1 Introduction

The presence of topographical barriers like mountains and fjords often cause disconnections in the road network. In western Norway some large-scale investments are planned which will remove the effect of such barriers through the construction of bridges and tunnels. An economic evaluation of this kind of investments calls for predictions of generated traffic. In this paper we will focus on commuting flows, which represent one important component of travel demand.

The commuting flows that is generated by the relevant kind of road infrastructure investments will in general depend on the toll that is imposed for using a new road connection. Based on cross-section data from the southern parts of Western Norway, we estimate the impact on commuting flows of varying prices and travelling times related to

¹ We did not manage to finish the empirical parts of this paper by 30th June. A revised and extended version of the paper will be presented at the Regional Science Association European Congress, Dublin, Ireland 23-27 August 1999.

ferry connections. The region is topographically very heterogeneous, with fjords causing a lot of discontinuities in the road transportation network. It is probably difficult to find other regions, anywhere, with a higher density of ferry connections. To be specific, there were all together 24 ferry connections in the region at the time that data was collected, and the different connections were varying considerable both with respect to travelling time and with respect to price. This means that a high number of the origin-destination combinations in the region involves a ferry connection, and that a considerable variation in commuting costs will be experienced for the origin-destination combinations. This is obviously an advantage when the relevant parameters are to be estimated.

In Gitlesen and Thorsen (1999) some parameters are estimated that reflect the effects of reduced travelling time. Possible changes in money expenses are not considered, and no attempts have been made to transform such expenses into time units. When the possibility of tolls is ignored, ferries are more expensive per time unit than travelling by car. The effect of this is not taken into account when the effects of substituting ferry connections with tunnels and bridges are predicted. This effect is neither taken into account in Thorsen (1998), where long-term consequences on the intraregional location profiles of households and firms are considered.

The main ambition of this paper is to focus on how generated commuting flows depend on the pricing policy chosen for the new road connection. This discussion is of course based on the estimated demand function for journeys-to-work. In addition, our study provides estimates of the effect on commuting flows of reductions in travelling time. Our model also takes into account the effects of specific spatial structure characteristics.

The estimates and predictions which are presented in this paper are obtained from a modified version of the so called competing destinations model (see Fotheringham (1983b)). In Thorsen and Gitlesen (1998) the relevant model formulation is empirically tested and compared to alternative formulations. This evaluation is also based on Norwegian commuting flow data. All the model formulations that were evaluated belong to the gravity modelling tradition. This is the family of models which definitely is most commonly applied for predicting traffic flow consequences of changes in the transportation network.

Such models are, however, in general constructed to predict a trip distribution matrix at a given point in time, they are not constructed to account for possible long term effects on the spatial distribution of employment and population. In a long run time perspective fundamental changes in the road transportation network might affect location decisions of firms and workers, and this can be expected to influence the commuting flow pattern and generated traffic on the new road links. Hence, long run predictions for generated traffic should not be made within a static, doubly constrained modelling framework. We do not, however, attempt to take such long term impacts on the spatial structure into account in this paper.

The modelling framework is presented in Section 2. As mentioned, the chosen model specification is a modified version of the competing destinations model, which is well known in the literature. Section 3 presents the region and the data set which is applied in the analysis. In addition, we focus on a forthcoming change in the transportation infrastructure, where a ferry connection between two islands is substituted by a new road connection. The estimation procedure is briefly explained in Section 4, before the estimated parameter values are presented in Section 5.1. Subsection 5.2 deals with the estimation of demand curves for journeys to work between the two islands. This refer both to the situation before and after the new road link is introduced. We particularly

address the problem of how commuting flows respond to alternative pricing policies in the case where a new road link is established. We also estimate the willingness to pay for the new road connection. In addition, some estimation results are presented in the form of price elasticities, which are compared to the results from similar studies. Some concluding remarks are offered in Section 6.

2 The modeling framework

The model that is applied for estimation and predictions in this paper belongs to the gravity modelling tradition. For a general discussion of this modelling tradition, see for example Erlander and Stewart (1990) or Sen and Smith (1995). The chosen model is, however, somewhat extended compared to a pure, traditional gravity model specification. To be more specific the model is formulated as follows:

$$T_{ij} = A_i O_i B_j D_j S_{ij}^r (O_i^{a_1} D_j^{a_2})^{d_{ij}} \exp(\mathbf{b}d_{ij} - \mathbf{l}c_{ij} + \mathbf{m}d_{ij}) \quad (1)$$

$$A_i = \left[\sum_j B_j D_j S_{ij}^r (O_i^{a_1} D_j^{a_2})^{d_{ij}} \exp(\mathbf{b}d_{ij} - \mathbf{l}c_{ij} + \mathbf{m}d_{ij}) \right]^{-1} \quad (2)$$

$$B_j = \left[\sum_i A_i O_i S_{ij}^r (O_i^{a_1} D_j^{a_2})^{d_{ij}} \exp(\mathbf{b}d_{ij} - \mathbf{l}c_{ij} + \mathbf{m}d_{ij}) \right]^{-1} \quad (3)$$

Here:

T_{ij} is the estimated number of commuters from origin i to destination j

O_i is the observed number of commuting trips originating from zone i

D_j is the observed number of commuting trips destinating in zone j

S_{ij} is the accessibility of destination j relative to all other destinations, perceived from zone i

d_{ij} is travelling time from origin i to destination j

c_{ij} is the expenses that follow as a result of ferry connections between origin i and destination j

\mathbf{b} is a distance deterrence parameter related to travelling time, while \mathbf{l} represents the effect of ferry prices on commuting flows. \mathbf{d}_{ij} is the Kronecker delta,

$$\mathbf{d}_{ij} = \begin{cases} 0 & \text{if } i \neq j \\ 1 & \text{if } i = j \end{cases}$$

while \mathbf{m} is a parameter that represents some kind of a benefit of residing and working in the same zone, or, analogously, a start up cost to be incurred if work and residence is not in the same zone. The parameters \mathbf{a}_1 and \mathbf{a}_2 are introduced to take into account possible influence of local labour market characteristics on the diagonal elements of the trip distribution matrix. A_i and B_j are the balancing factors that ensure the fulfilment of the

marginal total constraints; $\sum_j T_{ij} = O_i$ and $\sum_i T_{ij} = D_j$. Consequently, this doubly constrained model specification is constructed for a pure trip distribution problem.

The accessibility measure S_{ij} is introduced to take into account relevant effects of the spatial configuration of destinations. To be more precise, the measure is defined by

$$S_{ij} = \sum_{\substack{k=1 \\ k \neq i, k \neq j}}^w D_k^g \exp(-\mathbf{b}d_{ij} - \mathbf{l}c_{ij} + \mathbf{m}l_{ij}) \quad (4)$$

Here, w is the number of potential destinations. If n denotes the number of destinations to which there is observed interaction from origin i , then $w \geq n$. The standard reference of this kind of accessibility measure is Hansen (1959). \mathbf{m} is the weight that is attached to the size of various destination in the accessibility measure.

Due to the introduction of the accessibility term, the model is denoted as a competing destinations model. The competing destinations model was introduced by Fotheringham (1983b) to improve the ability of this modeling tradition to capture spatial structure effects. It is well known in the literature that a traditional gravity model represents a misspecification of spatial interaction if for example agglomeration or competition effects are present. If such effects are present then the distribution of trips will be affected by the clustering system of destinations in addition to distance, see for example Fotheringham (1983a, 1983b and 1984). When agglomeration kind of forces are dominant the sign of the parameter \mathbf{r} in Equation (1) will be positive, while the parameter takes on a negative value if competition like forces are dominant.

The evaluation of the competing destinations model has diverged in the literature. Empirical results presented in Ishikawa (1987) and Desta and Pigozzi (1991) are not very optimistic with respect to potential benefits of a competing destinations specification to explain trip distribution. Lo (1992) tests out the competing destinations model in a series of simulation experiments. Her results support Fotheringham's competing destinations formulation. In a previous paper, Thorsen and Gitlesen (1998), we find that the competing destinations formulation performs significantly better than the traditional gravity model. In earlier empirical works on the competing destinations model (Fotheringham (1983b, 1984); Ishikawa (1987) and Desta and Pigozzi (1991)), the parameters attached to distance and attraction size variables in the accessibility measure are assigned some fixed values rather than being estimated. From data on commuting flows it is documented in Thorsen and Gitlesen (1998) that such a practice might induce an incorrect evaluation of the competing destinations formulation. It is claimed to be important that all spatial structure parameters are simultaneously estimated.

In Thorsen and Gitlesen (1998) we test a hypothesis that special care should be taken to potential benefits of residing and working in the same zone. We find that such approaches contribute significantly to the ability of the model to fit the data. It is argued that the possibility that workers reside and work in the same zone should be distinguished from other options concerning the combination of work and residential location. Such considerations are not captured adequately through a simple exponential distance deterrence function. We tested out a specification where an additive constant term is attached to the diagonal elements of the trip distribution matrix. In some respect this specification is analogous to the so called Chamberknowne deterrence function, which incorporates an additive constant start-up cost in addition to distance, see for example Sen and Smith (1995). This additive constant attached to the diagonal elements can also be motivated by the possible existence of measurement errors, see Thorsen and Gitlesen (1998).

In Thorsen and Gitlesen (1998) we also proposed an approach where the diagonal elements of the trip distribution matrix are influenced by local labour market characteristics. Labour market characteristics is reflected by the demand for labour originating from the firms in a specific zone, relative to the supply of labour originating from the zone. We find that a hypothesis is accepted which states that the relative frequency of within-zone journeys-to-work is high in a zone where employment is low relative to the labour force. This hypothesis corresponds to a situation with parameter values $a_1 > 0$ and $a_2 < 0$.

Gitlesen and Thorsen (1999) offer a general economic interpretation of the chosen variant of the competing destinations model as a framework for studying problems related to commuting flows. The interpretation is based on a random utility approach, and also draws on ideas from spatial search theory.

3 The region and the data

The study area is located in southern parts of Western Norway. The road transportation network in this area is disconnected due to the presence of numerous fjords, that splits the study area into separate subareas. In this paper a distinction is made between the southern area and to the northern area. The southern part represents a more or less comprehensive region with a high degree of intradependency, and a connected road network with few topographical transportation barriers. This area comes close to what is defined as “an economic area” in Barkley et al. (1995), with a relatively self-contained labour market, and a relatively large central place (Haugesund) which influences economic activity in a peripheral region. The northern area, on the other hand, consists of several islands and separated subareas with no road link between them. For the separate subareas a high degree of intradependency is very much due to physical, topographical, transportation barriers, that lengthen travel distances, and thereby deter economic relationships with other areas.

The study area does not correspond to the administrative regions; some parts of the area belong to Rogaland county, while the other parts belong to Hordaland county. The further division of the area into zones, however, takes as its starting point a lower administrative level, the municipality. To be precise, our analysis is based on data from 13 municipalities. The northern area consists of 6 municipalities, all belonging to Hordaland county. The southern area represents 7 municipalities; Sveio, Ølen, and Etne belong to Hordaland county, while Haugesund, Karmøy, Tysvær, and Vindafjord belong to Rogaland county, see figure 1. In the final division of the region into zones, each municipality is divided into postal delivery zones. This division of the region into zones corresponds to the most detailed level of information which is available on residential and work location of each individual worker within the region. All in all the region is divided into 100 (postal delivery) zones. To avoid problems in the estimation, 8 very small and isolated zones are ignored. Some of those zones have not even a ferry connection to other zones or areas. The corresponding transportation network is illustrated in figure 1.

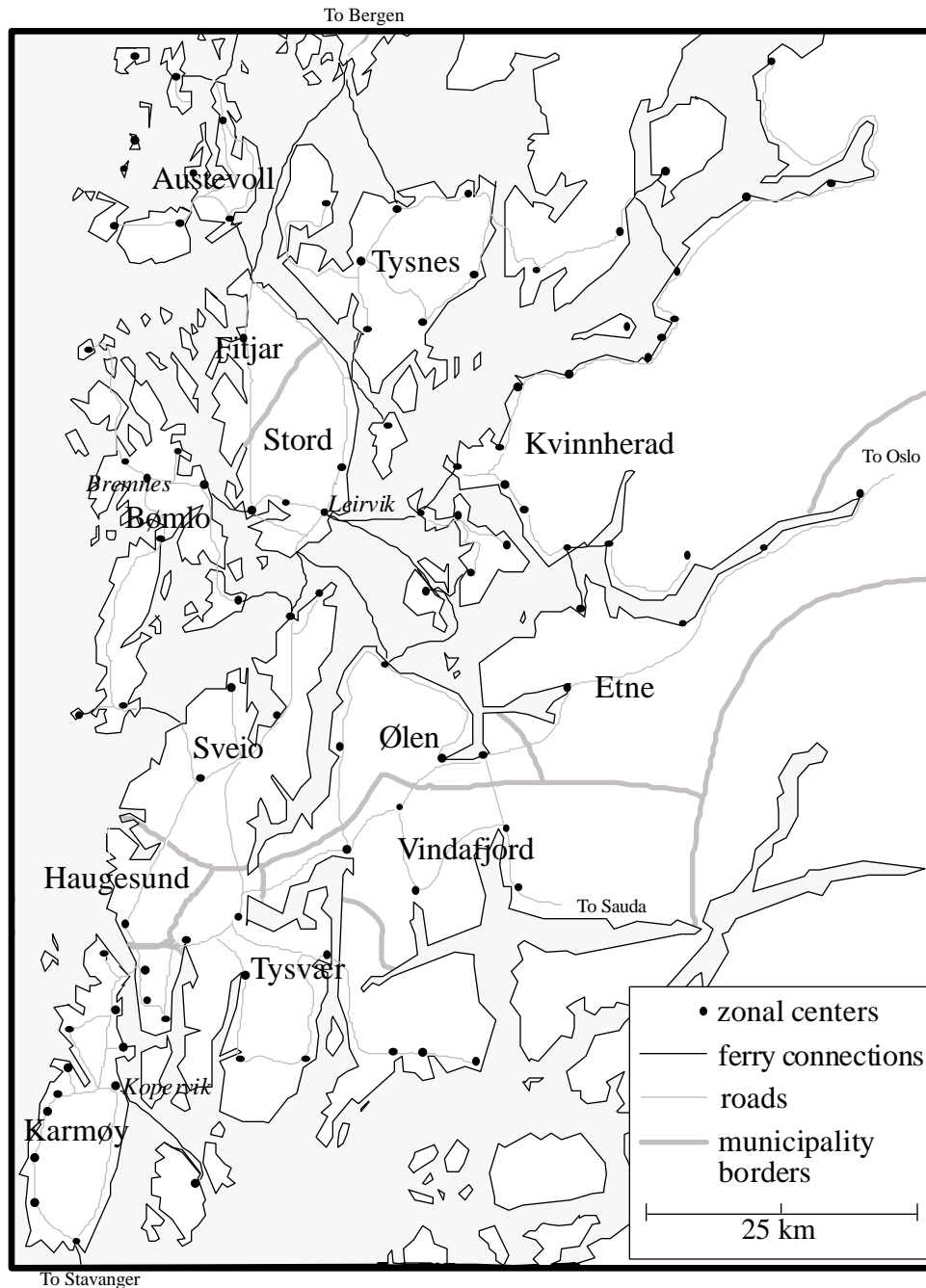


Figure 1: The municipalities in the study area and the main transportation network in 1989.

Total population in the region was 135000 in 1989, out of which approximately 88000 lived in the southern area. Far the biggest zone is the regional center Haugesund, with 27250 inhabitants in 1989. The second biggest central place is Leirvik (Stord) in the northern area, with a population of 14400 in 1989.

The information is based on the so called AA-register (Employer-Employee register), which belongs to the National Insurance Administration of Norway, and includes a code for the postal delivery zone of both residence and work location. A trip distribution matrix was constructed after a correction for some faults in the data that was provided for us. This register includes only employees, and not those who are engaged in their own business, the firm owners.

The spatial pattern of population and employment in this region is very appropriate for our problem. Population and employment is concentrated to the zonal centers rather than more evenly dispersed, and most centers are not too isolated and distant from each other to prevent a considerable interzonal commuting. The division of zones corresponds to a natural kind of clustering, where the interzonal distances are in general significantly longer than intrazonal distances.

The calculations done in this paper are based on data from September 1989. Distances are measured by the shortest route from an origin to the specific destinations. To be more precise, distances are measured as travelling time by car. In addition, travelling time by ferry is registered if the shortest route between two zones involves a ferry connection. The prices of travelling by ferry in 1989 were received from the road authorities. There is not, however, one single price for each ferry connection. For journeys to work it seems reasonable to apply the cheapest alternative, which in other words means that the price per trip is calculated from the price of a 40 trip ticket coupon.

In this paper we will consider a specific investment plan that leads to a considerable change in the transportation network in the study area. In the spring of 1996 Norwegian authorities decided that a new road link will be established that connects the two islands Bømlo and Stord to the mainland. In addition a direct link will be established between the two islands, which are rather densely populated in a Norwegian perspective, with an aggregate of around 27000 inhabitants in 1989. Technically this triangular road connection between Stord, Bømlo and Sveio (mainland) will consist of a combination of bridges and tunnels, and the project is planned to be completed at the end of 2000. This new triangular road connection substitutes four ferry connections, as can be seen from figure 2. In this paper we will primarily focus on some partial effects of the new road link between the two islands.

4 Estimation of parameters

The structural parameters in a gravity model are estimated by the method of maximum likelihood, as suggested in Erlander and Stewart (1990). The likelihood function of the model is, however, not globally concave. We have therefore replaced the Newton-Raphson procedure with a quadratic hill-climbing algorithm. A description of the Newton-Raphson procedure and the quadratic hill-climbing method can be found in Judge et al. (1985). To speed up the calibrations we introduced a variable for the steplength in the hill-climbing algorithm. The optimal steplength for each iteration was found by using a golden search approach (see Winston (1994)). In situations far from optimal values we also applied an irregular simplex iteration sequence (see Nelder and Mead (1965)).

ML estimates of the balancing factors were found by a suitable balancing algorithm, as described for example in Erlander and Stewart (1990).

The ultimate formulation of an algorithm then takes into account the mutual interdependence between the two kind of parameters. Each iteration step consists of a balancing iteration sequence for the balancing factors, followed by a quadratic hill-climbing step for the structural parameters.

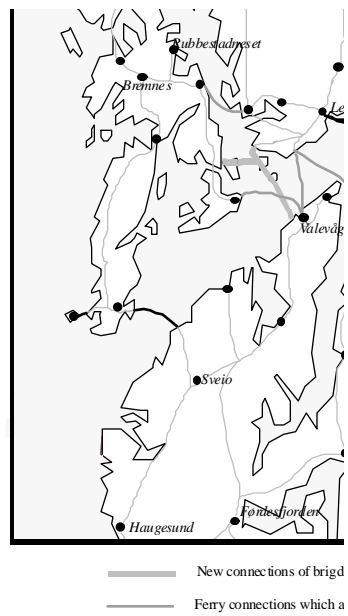


Figure 2: Forthcoming changes in the transportation network.

5 Results

5.1 Estimated parameter values

The main ambition of this paper is to estimate the response on commuting flows of changes in price and travelling times. From the parameter estimates in Table 1 and their respective standard errors it follows that the sign of the relevant responses is found to be significantly positive, which means that increased travelling time and/or increased ferry price (toll) deters commuting, as expected.

Table 1: Parameter estimates based on the model which is specified by expression (1).

	Parameter value	Standard error
\hat{b}	0.087383	0.000384
\hat{l}	0.028451	0.000640
\hat{m}	10.297735	0.411354
\hat{a}_1	0.414816	0.018119
\hat{a}_2	-0.500058	0.015295

\hat{r}	-3.192067	0.005372
\hat{g}	0.127136	0.001189

According to our estimates of \mathbf{b} and \mathbf{l} the factor $\frac{0.087383}{0.028451}$ transforms changes in travelling times into monetary values. This means that a one minute reduction in travelling time corresponds to a reduction of NOK 3.07 (approximately \$0.44) in ferry price/toll. In other words the value of an hour spent on a journey to work is evaluated to be approximately NOK 184. Notice that those monetary values are measured relative to the price level in 1989.

One complicating factor when such estimates are interpreted is that commuting expenses in general can be deducted when taxable income is calculated for individual workers. In 1999 the income tax is reduced by 28% of the commuting expenses that exceed a certain lower limit. In 1989 the rules of taxation were more complicated, with a tax rate that depends on income according to specific progression steps. We have not attempted to take those matters into account in the estimation of parameter values. If all commuting expenses resulted in a reduction in income tax the value of an hour spent on a journey to work would be approximately $(184 \cdot 0,72 =)$ NOK 132. Still, the predictions to follow in forthcoming sections would not be changed in the case where real commuting expenses result in proportional reductions in income tax. Proportionality is, however, disturbed both by the lower limit of deductible expenses, and by the progression steps. In addition, deductible expenses are in general defined by prices of public transport, which might diverge from real expenses. Hence, our predictions are based on the simplifying assumption that such details in the rules of taxation do not influence commuting behaviour.

Compared to the values that are officially recommended for cost benefit studies in Norway, our estimates of the valuation of time are very high. In Statens vegvesen (1995) the values per hour of light vehicles are recommended to be NOK 198 for time savings of work related trips, while trips to and from work as well as other trip purposes should be evaluated by NOK 65 per light vehicle. Adjusting for the expected number of persons per vehicle, the corresponding figures are 146 for work related trips, 46 for journeys to work, and 31 for other trip purposes. Those recommendations refer to the price level in 1995. The officially recommended values of time savings are based both on national and international empirical studies. Based on data from the Trondheim toll ring, Tretvik (1995) finds that the value of time on average was 52 NOK/hour for commuters, and this result is in line with results of international empirical studies, see Small (1992) for a survey.

In real prices our estimate of commuters willingness to pay for time savings is about four times as high as the officially recommended value. It is well known in the literature that estimates of the value of time might vary both geographically and with respect to which mode that is considered. Such aspects are not, however, even close to explain the substantial deviation between our estimates and the officially recommended estimates. The officially recommended estimates are typically based on data collected before and after changes in toll levels at specific links in the transportation network, see for example Tretvik (1995). Our estimates are based on cross section data, and they reflect a situation where workers have chosen a location combination of residence and work for a given transportation network with ferry connections that will persist on a more or less permanent basis, and at prices that in general are not expected to vary considerably in real and relative terms. Hence, our parameter estimates can be claimed to represent long run effects of changes in the monetary and physical terms of transportation. It is not

unreasonable that the valuation of time savings in a long run time perspective for a widespread rural kind of region can diverge from the valuation of time savings in a short run time perspective for an urban area. At least our findings give rise to a hypothesis that the officially recommended value of time represent an underestimate in a long run, regional, setting. This hypothesis should be tested in other cross section studies of commuting behaviour in similar regions.

Like most empirically based multivariate studies of transportation behaviour we have been facing covariation and identification problems, as well as problems with missing variables (lack of information). For example, it can be argued that price and travelling time are not the only relevant attributes of ferry connections. One such attribute is waiting time for the ferry departure. This partly results from stochastic variations in travelling time by car, but also from irregularities concerning times of ferry departure. Such irregularities can for example be caused by varying demand and capacity problems. Another kind of inconvenience cost related to the ferry connection is restricted flexibility concerning the journey to work. The comfort of travelling and the opportunity to get a break in driving are also relevant attributes. In an attempt to account for other attributes of a ferry connection than price and travelling time, we included a dummy variable representing the presence of ferry connections in our model specification. This attempt to account for other factors was not successful. Strong covariation between the dummy variable and ferry prices resulted in obscure parameter estimates, and it proved impossible to identify reasonable parameter values for the variables involved. Still, the inclusion of the dummy variables adds significantly to the explanatory power of the model

As will be clear in the following subsections our model will be applied for other purposes than the valuation of time savings. It is not unusual that the ambitions of empirical studies exceed the possibilities set by the access of data. This enforces a pragmatic attitude and a model formulation compromising between what is theoretically requested and practically tractable. For example, the effect of missing variables can be expected to be incorporated by the parameters ***b*** and ***l***. Despite the problem to separate between different aspects of transportation behaviour, the model formulation might prove adequate for example for predictive purposes. Specific parameter estimates should, however, be interpreted with care.

Gitlesen and Thorsen (1999) apply a model formulation where no attempts are made to account for ferry prices in the explanation of commuting flows. Instead mode specific (car and ferry) travelling times are included in addition to a dummy variable to account for other aspects of ferry connections. This resulting log likelihood value for this model was found to be -222815.61. Based on the same data the model formulation given by Equation 1 resulted in a log likelihood value of -222867.63. This means that the explanatory power of the model formulation is significantly worsened when the price variable has substituted the two ferry specific variables. Still, as will be seen in following subsections, the new model formulation enables us to study the effects of changes in ferry prices and/or toll charges.

We will not, in this paper, go into details concerning the parameter estimates that relate to the tendency of within-zone journeys to work, nor the parameters which are specific to the accessibility measure S_{ij} . The parameter estimates are not qualitatively different from the corresponding estimates in Thorsen and Gitlesen (1998), where the estimation is based on data from the southern parts of the study area that is mapped in figure 1. Our results leave no doubt that special care should be taken to within-zone journeys to work ($m > 0$), and the relative frequency of within-zone journeys to work is found to be high in zones where employment is low relative to the labour force, and vice

versa ($\mathbf{a}_1 > 0$ and $\mathbf{a}_2 < 0$). At the same time we find that the weights attached to distances and employment in the accessibility measure should be estimated, and we find that competition like forces are dominant ($\mathbf{r} < 0$). For a more detailed discussion on those matters, see Thorsen and Gitlesen (1998).

5.2 Demand curves, elasticities, and the willingness to pay for a new road connection.

As mentioned in subsection 5.1 Gitlesen and Thorsen (1999) include a dummy variable in the model specification, to account for other aspects than mode specific travelling times. For example, this dummy variable is intended to incorporate the effect of ferry prices. Gitlesen and Thorsen (1999) apply the model to predict how commuting flows respond to transportation investments where ferry connections are substituted by bridges/tunnels. The predictions then refer to a situation where the value of the dummy variable changes from 1 to 0 for the specific link(s), and travelling time are adjusted according to the change of mode. Hence, a commuting flow matrix is calculated that is based on the assumption that no tolls are charged at the new road connections. Such toll charges will, however, be charged for a long period, to contribute to the financing of the improvements in the road infrastructure. In this paper we consider how predicted commuting flows respond to alternative levels of toll charges. We also consider the effects of alternative transportation policy strategies. One proposal that is considered by road authorities, is to let all travelling by ferry be free of money charges. What will be the effect of such a policy on commuting behaviour, compared to the considerably more radical changes where ferries are substituted by new road links?

Before we return to such questions, we start out by addressing the problem of estimating the willingness to pay for a new road connection. As noticed in section 2 the competing destinations model can be interpreted within a random utility framework. In general the utility of an individual worker is specific both to a vector of variables that relates to attributes of the origin (place of residence), and to a vector of variables that relates to attributes of the destination (workplace). In addition, the distance between the origin and the destination relates to both the income and the time budget. According to the literature on the competing destinations model, see for example Gitlesen and Thorsen (1999), this also applies to the position, or accessibility, of a destination. Hence, distance and accessibility measures should be incorporated in the indirect utility function of the decision makers. Consequently, innovations in the road transportation network can be expected to influence location decisions and travelling behaviour of households. The doubly constrained modelling framework applies for a short run time perspective, with a given spatial pattern of employment and population. The balancing factors are introduced to ensure the fulfillment of the additivity constraints. In general any change in the road transportation network will affect the balancing factors in addition to the distance and accessibility measures. The changes in the balancing factors influence the predicted transport demand, but this effect does not reflect utility generated changes in travelling behaviour. Hence, it can be argued that a proper measure of the willingness to pay for a new road link should be based on changes in utility components, and that effects through the additivity should be ignored. For this reason we first attempted to keep the values of the balancing factors constant when the willingness to pay for a new road link is estimated.

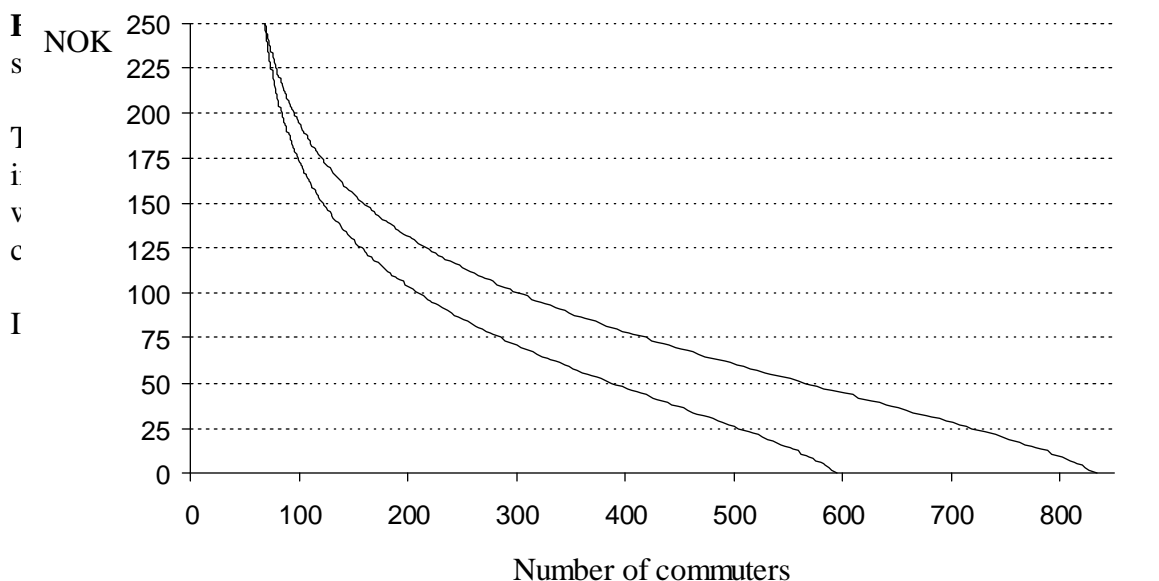
As mentioned in section 3 we focus on a forthcoming road link between the islands Stord and Bømlo. From figure 2 it was clear that this link is one part of the triangular road

connection, which also includes connections from both islands to the mainland. To predict partial effects of this link, the remaining road transportation network is left unchanged in our calculations. This also applies to the other links of the triangular road connection.

As a first step our intention was to compare the expected maximum utility in the situation after the new road link was introduced to the expected maximum utility prior to the innovation in the road transportation network. It is well known from the random utility theory that expected maximum utility, as well as the (marshallian) consumer surplus, corresponds to the log sum formula, defined through the numerator in the expression of the choice probabilities. Concerning the situation after the relevant change in transportation network, the consumer surplus depends on what toll that is introduced on the new road link. We intended to estimate the level of this toll that left the worker with the same utility as in the situation with the ferry boat. Hence, such an estimate, which is founded on random utility theory, represents the willingness to pay for the new road.

The prescribed procedure did not produce reliable estimates of the willingness to pay for the new road. This is a result of the practice of keeping the balancing factors constant. With no constraints on the spatial distribution of households and employment, the system proves to be very unstable. The changed distances for example produced substantial changes in the zonal values of the accessibility measure. With no balancing mechanism for the resulting changes in the trip distribution probability matrix, a very high toll is required to outweigh the predicted effects of changes in accessibility on utility. Hence, this procedure resulted in obscurely high values of the willingness to pay for the new road connection.

It proved too ambitious to apply the chosen modelling framework for long run predictions where marginal constraints are not taken into account. Hence, we dropped the ambition to obtain an estimate of the willingness to pay that is founded on random utility theory. Instead we have chosen the more pragmatic approach that is based on the estimation of a demand curve for journeys to work. To be more specific, travel demand is estimated for alternative prices (tolls or ferry charges) of travelling on the relevant link, given the additivity constraints. The resulting demand curves are illustrated in figure 3.



6 Concluding remarks

Like most empirical research in social sciences our approach is based on a set of practically motivated simplifying assumptions concerning the definition and measurement of independent variables. For example the matrix of travelling times is based on the assumption of a constant average speed for all commuters. Hence, no concern is taken to possible congestion problems in this rural kind of study area. As mentioned in section 5.1 we have also ignored some potentially relevant aspects concerning the calculation of income tax. Our data neither allows for taking into account the possibility that colleagues and/or neighbours might coordinate their journey to work, with several commuters per vehicle. Similarly, our data do not allow us to account for the fact that some commuting might be on a weekly rather than daily basis. Another effect that is not accounted for is the fact that no variable costs, such as fuel consumption, are attached to the car as the ferry is crossing the fjord, and we do not consider any other modes of transportation than ferries and cars. Hence, this study is of course objected to problems of missing variables and measurement errors as a result of data restrictions and standard aggregation problems. Still, we think that our definitions of travelling time and price represent adequate proxy variables of the relevant attributes, and we think that our parameter estimates adequately represent the average response to changes in ferry prices, tolls, and travelling time.

In this paper we have seen that

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