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The impact of pecuniary costs on commuting flows*

David Philip McArthur[†], Gisle Kleppe[‡], Inge Thorsen[§] and Jan Ubøe[¶]

Abstract

In western Norway, fjords cause disconnections in the road network, necessitating the use of ferries. In several cases, ferries have been replaced by roads, often part-financed by tolls. We use data on commuting from a region with a high number of ferries, tunnels and bridges. Using a doubly-constrained gravity-based model specification, we focus on how commuting responds to varying tolls and ferry prices. Focus is placed on the role played by tolls on infrastructure in inhibiting spatial interaction. We show there is considerable latent demand, and suggest that these tolls contradict the aim of greater territorial cohesion.

Keywords: Commuting; Pecuniary costs; Gravity model; Toll charges; Investment financing
JEL Codes: R41, R48, R12

1 Introduction

The presence of topographical barriers like mountains and fjords often cause disconnections in the road network. In coastal areas of western Norway some large-scale investments have been carried through that remove the effect of such barriers through the construction of bridges and tunnels. Other road infrastructure investments are being planned, connecting areas that, in a Norwegian perspective, are relatively densely populated. Economic evaluations of such investments call for predictions of generated traffic, and the willingness-to-pay for new road

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connections. This paper focuses on commuting flows, which represent one important component of travel demand.

In most cases, a new tunnel or bridge is at least partly financed by toll charges. The main ambition in this paper is to study how pecuniary costs, represented by ferry prices and toll charges, contribute to deter commuting flows in a geography. The analysis is based on cross-section data from a region in western Norway with a high number of ferries and tunnels/bridges. The region is topographically very heterogeneous, with fjords causing disconnections in the road transportation network. It is probably difficult to find other regions, anywhere, with a higher density of ferry connections. It is also fortunate for our purpose that the different connections are varying considerably both with respect to travelling time and with price. This region has a high number of origin-destination combinations involving either a ferry, tunnel, bridge or toll road, and this makes it a very appropriate study area for empirical analysis of how pecuniary commuting costs affect the spatial labour market behaviour.

Gitlesen and Thorsen (2000) estimated some parameters which reflect the effects of reduced travelling time. Possible changes in money expenses were not considered, and no attempts were made to transform such pecuniary costs into time units. In this paper, the estimated demand function for journeys-to-work is used to discuss how generated commuting flows depend on the pricing policy chosen for a new road connection. In addition, the analysis provides estimates of how commuting flows are affected by reductions in travelling time. The chosen model formulation also accounts for 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 was empirically tested and compared to other specifications of gravity-based spatial interaction models. This evaluation was also based on Norwegian commuting flow data. This family of models is 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 ideally not be made within a static, doubly constrained modelling framework. Our predictions represent conditional statements, as they are based on the assumption that the location pattern remains unchanged. Thorsen (1998) focuses on long-term location consequences of new road links. For more comprehensive modelling attempts, that integrate location, land-use, and transportation flows, see Wilson (1998).

In order to explore what the price effect estimated means, two concrete examples are considered. One of these relates to the replacement of a number of ferry connections by a system of two bridges and one tunnel financed in part by road tolls. The second case considers the construction of a tunnel through a mountain. This tunnel was also part-financed by a toll charge. We consider how commuting flows might vary in response to changes in this toll, and what toll might be optimal, both from society's perspective and from the perspective of the private sector operators of the tunnels and bridges. Issues relating to the equity and justice aspects of toll charging will also be discussed.

The paper is structured as follows. The modelling framework is presented in Section 2. Section 3 presents the data and the region, focusing in particular on the two concrete examples which will be discussed later. Section 4 will present the estimation results and a discussion of the two examples chosen. Finally, some concluding remarks are offered in Section 5.

2 The modelling framework

The model used 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, represented by Equations (1), (2), and (3), is, however, somewhat extended compared to a standard gravity model specification.

$$T_{ij} = A_i O_i B_j D_j S_{ij}^\rho \left(O_i^{\alpha_1} D_j^{\alpha_2} \right)^{\delta_{ij}} e^{(-\beta d_{ij} - \sigma c_{ij} + \mu \delta_{ij})} \quad (1)$$

$$A_i = \left[\sum_j B_j D_j S_{ij}^\rho \left(O_i^{\alpha_1} D_j^{\alpha_2} \right)^{\delta_{ij}} e^{(-\beta d_{ij} - \sigma c_{ij} + \mu \delta_{ij})} \right]^{-1} \quad (2)$$

$$B_j = \left[\sum_i A_i O_i S_{ij}^\rho \left(O_i^{\alpha_1} D_j^{\alpha_2} \right)^{\delta_{ij}} e^{(-\beta d_{ij} - \sigma c_{ij} + \mu \delta_{ij})} \right]^{-1} \quad (3)$$

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 terminating 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 toll charges and ferry prices of travelling between origin i and destination j

β is a distance deterrence parameter related to travelling time, while σ represents the effect of the pecuniary costs on commuting flows. δ_{ij} is the Kronecker delta,

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

while μ is a parameter which 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 α_1 and α_2 are introduced to take into account the 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 which 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 account for relevant effects of the spatial configuration of destinations, and defined by:

$$S_{ij} = \sum_{\substack{k=1 \\ k \neq i, k \neq j}}^w D_k e^{(-\beta d_{ik} - \sigma c_{ik} + \mu \delta_{ik})} \quad (4)$$

Here, w is the number of potential destinations. If n denotes the number of destinations for which there is observed interaction from origin i , then $w \geq n$. The standard reference of this kind of accessibility measure is Hansen (1959). Notice that the impact of distance and price upon the perception of accessibility is not distinguished from the direct impact of distance

and price upon commuting choices. In other words the parameters β , σ and μ in the ordinary distance deterrence function are not distinguished from the corresponding parameters in the definition of S_{ij} .

Due to the introduction of the accessibility term, the model is termed a competing destinations model. Sheppard (1978) introduced the idea that the probability of choosing a destination depends on how this destination is located relative to alternative opportunities. The competing destinations model was introduced by Fotheringham (1983b) to improve the ability of this modelling 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 forces are dominant, the sign of the parameter ρ in Equation (1) will be positive, while the parameter takes a negative value if competition forces are dominant.

Thorsen and Gitlesen (1998) tested a hypothesis that special care should be taken regarding the potential benefits of residing and working in the same zone, represented by the additive constant $\exp(\mu\delta_{ij})$ to the diagonal elements of the trip distribution model specification. This approach was found to contribute significantly to the explanatory power of the model, suggesting that the option of residing and working in the same zone should be specifically accounted for in a model explaining commuting flows. In some respects, the additive constant attached to the diagonal elements is analogous to specifying the so called Champernowne distance 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).

Thorsen and Gitlesen (1998) also proposed an approach where the diagonal elements of the trip distribution matrix are influenced by local labour market characteristics. Labour market characteristics are reflected by the demand for labour originating from the firms in a specific zone, relative to the supply of labour originating from the zone. The results presented in Thorsen and Gitlesen (1998) supported a hypothesis 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 $\alpha_1 > 0$ and $\alpha_2 < 0$.

3 The region and the data

The study area is the southern parts of Hordaland county, in western Norway. As is clear from the map in Figure 1, there are 8 municipalities in the region. The road transportation network in the area is to a high degree disconnected, mainly due to the presence of numerous fjords, splitting the study area into separate subareas. For the separate subareas, a high degree of intradependency is very much due to physical, topographical and transportation barriers, which lengthen travel distances, and thereby deter economic relationships with other areas.

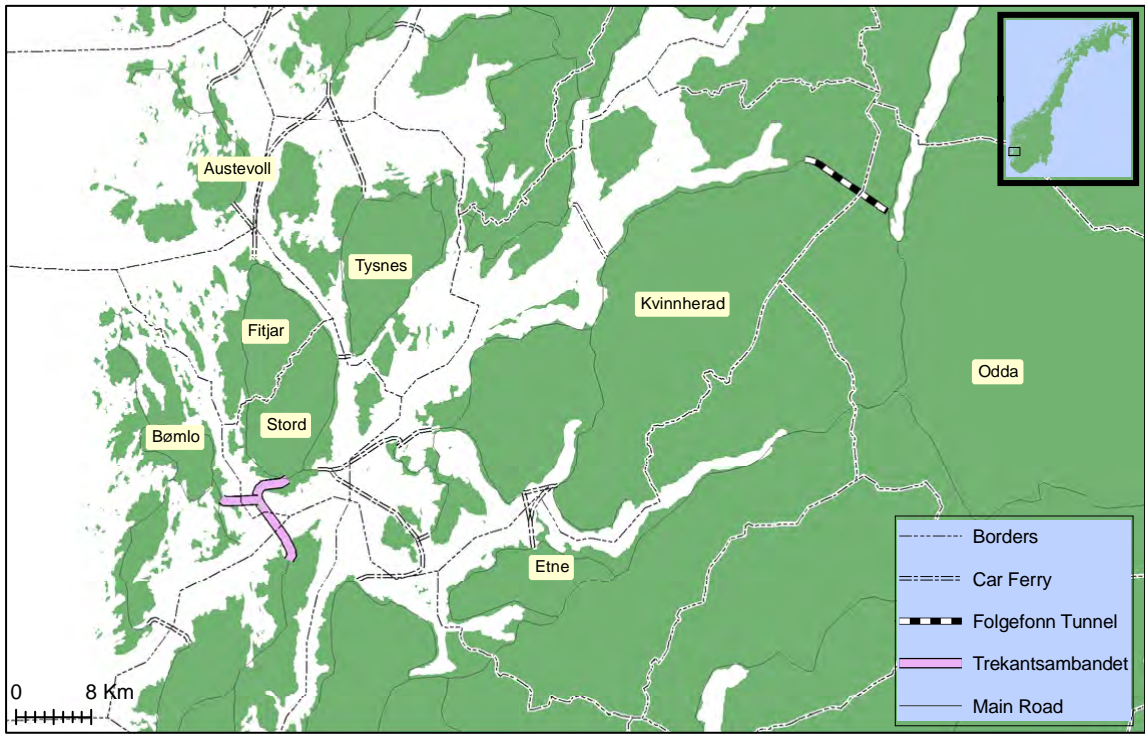


Figure 1: The municipalities in the study area and the main transportation network in 2006.

Estimation results in this paper are based on a subdivision of the region into 58 postal delivery zones. This corresponds to the most detailed level of information that is available on residential and work location of each individual worker within the region. The information on the spatial distribution of jobs is based on the Employer-Employee register, and was provided by Statistics Norway. The register includes only employees and not the self-employed. Data refer to the autumn of 2006. For each ferry, there is not one single price. A discount is available

if trips are bought in advance. For journeys-to-work, it seems reasonable to apply the cheapest alternative. This means that the price per trip is calculated based on workers purchasing 40 per-pay journeys.

The matrices of travelling times were prepared by the Norwegian Mapping Authority, who have at their disposal all the required information in the road network and the spatial residential pattern. The calculations were based on the specification of the road network into separate links, with known distances and speed limits, account is taken for the fact that that actual speed depends on road category. Information on speed limits and road categories is converted into travelling times through instructions worked out by the Institute of Transport Economics. The centre of each (postal delivery) zone is found through detailed information on residential densities and the road network. Finally, the matrix of travelling times is constructed from a shortest route algorithm.

The spatial pattern of population and employment in this region is appropriate for our problem. Population and employment tend to be concentrated in the zonal centres rather than more evenly dispersed, and most intramunicipality centres 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.

As indicated in the introduction, a particular argument in favour of choosing this region for studying the price responsiveness of commuting flows, is that here are a high number of ferry connections, and that many origin-destination combinations involve toll charges resulting from new bridges/tunnels. In 2006, there were 17 combinations of zones directly linked by ferries, while 4 combinations of zones have relatively recently been linked by new roads, financed by toll charges. Three of those links connect the most densely populated parts of this sparsely populated region. This contributes to the fact that a relatively high number of potential origin-destination combinations involve pecuniary costs, even if only combinations corresponding to a reasonable commuting time are considered. This data set further gives sufficient variation in prices to estimate the price response in commuting.

The total population was approximately 62,000 in 2006. The largest municipality was Stord, with 16,682 inhabitants on January 1, 2006. Kvinnherad had a population of 13,071, Bømlo 10,808, Odda 7,247, Fitjar 2,901, Austevoll 4,391, while Tysnes had 2,795 inhabitants.

The discussion to follow focuses on two road infrastructure investments. One of the projects, Trekantsambandet, connects the islands Bømlo and Stord to each other and to the mainland. Stord was connected to the mainland at the end of 2000, while Bømlo was connected to Stord and the mainland in the spring 2001. The new road connections consist of a combination of bridges and subsea tunnels (260 meters beneath the ocean surface), and it substituted 4 ferry connections. The total investment costs were about 1.8 billion NOK in 2001 prices, and the project is mainly financed by toll charges. The traffic increase and the incomes from toll charges have been higher than predicted; on average more than 4,000 vehicles used the new road links per day in 2006. In addition to serving local traffic between the municipalities of the region, some of the new links are a part of the main road connecting the major population centres in Western Norway. We focus our attention on the link between Stord and Bømlo and not the tunnel connecting them to the mainland.

Another investment project which was finished in 2001 was the Folgefonn tunnel, connecting the municipalities of Odda and Kvinnherad. The 11km long tunnel has significantly reduced travelling time between the two municipalities. It is still, however, a relatively long distance between Odda and the most populated parts of Kvinnherad.

4 Results

The parameters are estimated simultaneously by the method of maximum likelihood. Maximum likelihood was found through an irregular simplex iteration sequence (Nelder and Mead 1965). Standard errors were estimated by numerical derivation. The parameter estimates are reported in Section 4.1. Section 4.2 presents demand curves for commuting between two pairs of nodes in the network. In both of these examples, new infrastructure has recently been introduced and a toll charge is levied. Section 4.3 considers the development of the commuting flows on these links over time. Section 4.4 presents a discussion of what the optimal toll charge might be, both from the perspective of society and from the perspective of private sector operator of the infrastructure. The equity issues arising from the use of toll charging are briefly considered in Section 4.5. Having analysed the performance of the infrastructure and charging regime, Section 4.6 considers the aims which were set out for both infrastructure projects at their inception. Possible inconsistencies between these aims and the subsequent execution of the

projects are discussed.

4.1 Parameter estimates

In this paper we are primarily focusing on the parameters β and σ , reflecting the response of changes in travelling time and pecuniary costs on commuting flows. It follows from the parameter estimates and their respective standard errors in Table 1 that increased travelling time and/or increased monetary costs significantly deter commuting.

Information on the goodness-of-fit is useful for an evaluation of the model. The Relative Number of Wrong Predictions (RNWP = $\frac{\sum_{i,j} (|\hat{T}_{ij} - T_{ij}|)}{\sum_{i,j} T_{ij}}$) was found to be 0.1894028, while the Standardized Root Mean Square Error (SRMSE) is 0.72095895. The maximum log likelihood value (L) for the model is -126486.24 . For a comparison, consider next a model that is defined by Equations (1)-(4), except from the fact that pecuniary costs, c_{ij} , are not accounted for. This reduced version resulted in significantly less satisfactory values of the goodness-of-fit measures; RNWP= 0.235372, SRMSE= 0.9775367, and $L = -126956.30$. The estimate of the distance deterrence parameter was $\hat{\beta} = 0.078686$ in this case.

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

| | Parameter value | Standard error |
|------------------|-----------------|----------------|
| $\hat{\beta}$ | 0.064495 | 0.001087 |
| $\hat{\sigma}$ | 0.024402 | 0.000757 |
| $\hat{\mu}$ | 4.079679 | 0.170076 |
| $\hat{\alpha}_1$ | 0.082746 | 0.045424 |
| $\hat{\alpha}_2$ | -0.584802 | 0.032903 |
| $\hat{\rho}$ | -0.075938 | 0.037708 |

According to our estimates of β and σ , the factor $\frac{0.064495}{0.024402}$ transforms changes in travelling times into monetary values. This means that a one minute reduction in travelling time corresponds to a reduction of approximately NOK 2.64 in pecuniary costs (approximately \$0.42, evaluated at the exchange rate of 6.26 NOK per USD at the end of 2006). In other words, the value of an hour spent on a journey-to-work is evaluated to be approximately NOK 159, in 2006-prices.

One complicating factor when such estimates are interpreted is that commuting expenses for many commuters can be deducted when taxable income is calculated. In Norway, this applies to workers with a commuting distance exceeding 20 km. Those workers may deduct commuting

expenses exceeding a lower limit, according to specific rates per km, and the income tax is then reduced by 28% of those expenses. If commuting expenses resulted in a proportional reduction in income tax the value of an hour spent on a journey to work would be $(159 \cdot 0.72 \approx)$ NOK 114. This estimate ignores a lot of technical details in the rules of taxation, and implicitly assumes that all expenses related to ferries and tolls are deductible.

Compared to the values that are officially recommended for cost benefit studies in Norway, our estimate of the value of time is very high. In Statens vegvesen (2006), the value per hour for light vehicles is recommended to be NOK 198 for time savings of work related trips, while trips to and from work should be evaluated by NOK 57 per hour per person, in 2005 prices. Statens vegvesen (2006) further recommends that this estimate should also be used for commuting trips involving ferries. 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 both with Ramjerdi et al. (1997), and with results from international empirical studies, see Small (1992) for a survey.

It is well known in the literature that there may be spatial variation in the estimates of the value of time. The deviation between our estimates and the officially recommended estimates is, however, substantially larger than suggested by the literature. 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 instance 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 transportation network that will persist for the foreseeable future, 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 the estimates in Table 1 give rise to the hypothesis that the officially recommended value of time represents an underestimate in a long run, regional, setting.

This paper is not primarily focusing on 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 relevant parameter estimates are worth some comments, however. They are not qualitatively different from the corresponding estimates in Thorsen and Gitlesen (1998), where the estimation is based on data from a different study area, adjacent to the area that is mapped in Figure 1. Our results leave no doubt that special care should be taken to within-zone journeys to work ($\mu > 0$), 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 ($\alpha_1 > 0$ and $\alpha_2 < 0$). The estimate of α_1 and ρ are substantially lower than the corresponding estimates in Thorsen and Gitlesen (1998), but the signs are the same. The estimates in Thorsen and Gitlesen (2006) were based on 1989-data from a region located south of the one considered in this paper. For a more detailed discussion of the interpretation of the parameters, see Thorsen and Gitlesen (1998).

4.2 Demand curves

The model, represented by Equations (1)-(4), can be used to predict commuting flows for specific origin-destination combinations. Assume that we have all the information we need on distances (d_{ij}) and the spatial distribution of workers (O_i) and jobs (D_j) at a specific point in time. Assume next that the pecuniary costs c_{ij} are varied systematically. Our estimated set of parameter values can then be used to predict commuting flows for different values of the pecuniary costs, and this procedure may be used to predict a demand curve for any link in the transportation network.

As a first experiment we have predicted a demand curve for commuting between the municipalities Stord/Fitjar (which occupy the island of Stord) and Bømlo. This commuting represents the major part of the commuting flows across the combination of subsea tunnels and bridges that is called Trekantsambandet in Figure 2. We have used the model to predict commuting flows between the 8 postal delivery zones on Stord, and the 8 zones on Bømlo, and then aggregated to get predictions of the flows between the two islands.

Notice first from Figure 2 that some workers are predicted to commute from Stord to Bømlo even when the toll charge is very high; the demand curve becomes completely inelastic. This is a result of the additivity constraints, rather than travelling behaviour.

In 2006 the toll charge for a one way trip was 51 NOK for commuters with a 40 trip price coupon. For this level of c_{ij} our model predicts a number of 668 commuters from Stord to Bømlo and 271 commuters in the opposite direction. According to our data from the autumn 2006, the

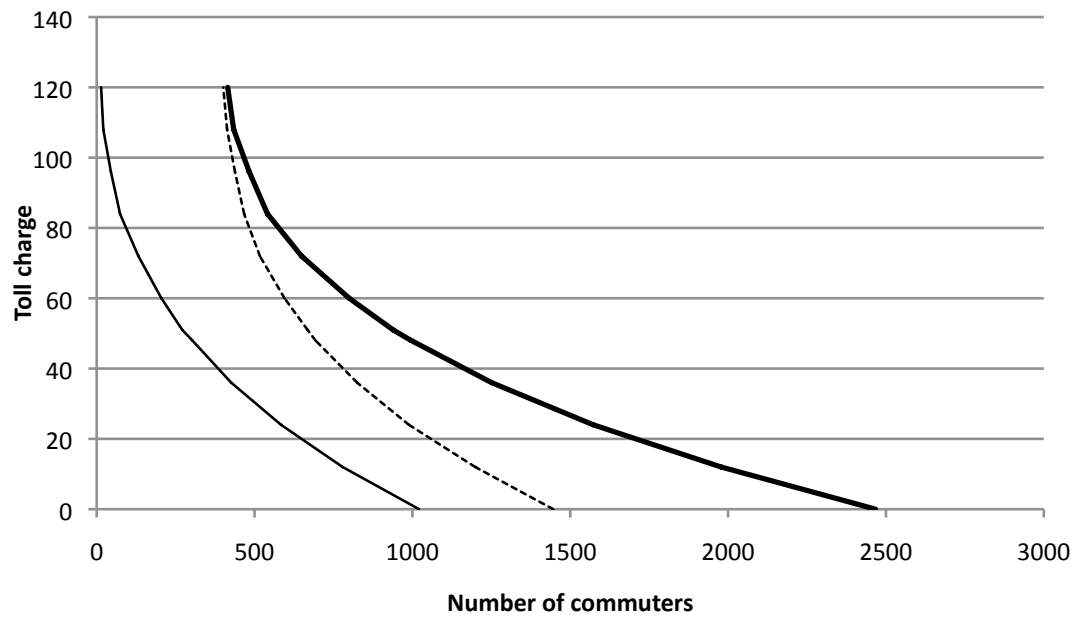


Figure 2: Predicted demand curves for commuting between the municipalities Stord/Fitjar and Bømlo. The toll charge is the price of a one way trip for commuters with a 40 trip price coupon. The dashed line represents predicted commuting from Stord/Fitjar to Bømlo, while the thin solid line predicts commuting in the opposite direction. The thick solid line represents total, aggregated, commuting between the municipalities.

corresponding observed numbers of commuters were 519 and 130, respectively. Hence, our model overestimates the commuting flows across the new road connection between the municipalities. The relative overestimation is in particular substantial for commuting flows from the rural and sparsely populated municipality of Bømlo to the somewhat more densely populated and urbanised areas on the other side of the new road connection (Stord/Fitjar).

The demand curves in Figure 3 represents the number of commuters between the municipalities Odda and Kvinnherad, using the Folgefonn tunnel. Those demand curves are less smooth than the demand curves for commuting flows between Stord/Fitjar and Bømlo. This reflects the fact that our model predicts a small number of commuters between Odda and Kvinnherad. The 50% discounted price for a one way trip is 30 NOK. For this price our model predicts 68 commuters from Kvinnherad to Odda, and 82 commuters in the opposite direction. Once again, however, our model overpredicts the commuting flows. The observed number of commuters from Kvinnherad to Odda was 19 in 2006, while 42 workers commuted in the opposite direction through the Folgefonn tunnel.

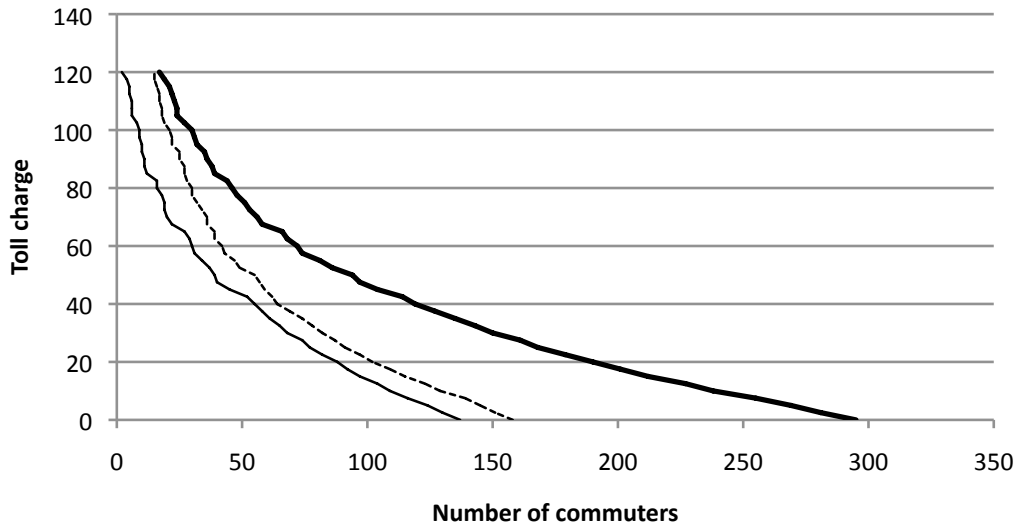


Figure 3: Predicted demand curves for commuting between the municipalities Kvinnherad and Odda. The toll charge is the price of a one way trip, rebated by 50% for regular commuters. The dashed line represents predicted commuting from Odda to Kvinnherad, while the thin solid line predicts commuting in the opposite direction. The thick solid line represents total, aggregated, commuting between the municipalities.

Kvinnherad and Odda are neighbouring municipalities, with 13,071 and 7,247 inhabitants

in 2006, respectively. Stord/Fitjar had 19,583 inhabitants in 2006, while the neighbouring municipality Bømlo had a population of 10,808. All 5 municipalities are located in a relatively long distance from other municipalities than the neighbouring municipalities connected by the relevant road infrastructure investments. Hence, the location relative to alternative labour market areas is similar, and the population sizes are reasonably equal in the two areas where the large-scale changes in road infrastructure have been introduced. Why then are there such a large difference in both the predicted and the observed commuting flows between the two pairs of municipalities that have been connected by the new road links? The major reason is that the central places at Stord/Fitjar and Bømlo are located relatively close to the new road connection, while this is not the case for the Folgefonn tunnel. Odda has a relatively concentrated population close to the tunnel, but the dominating central places in Kvinnherad are located a long distance from the tunnel. Hence, the spatial structure prevents that the labour market in the area gets substantially better integrated as a result of investments in road infrastructure. The population distribution is shown in Figure 4.

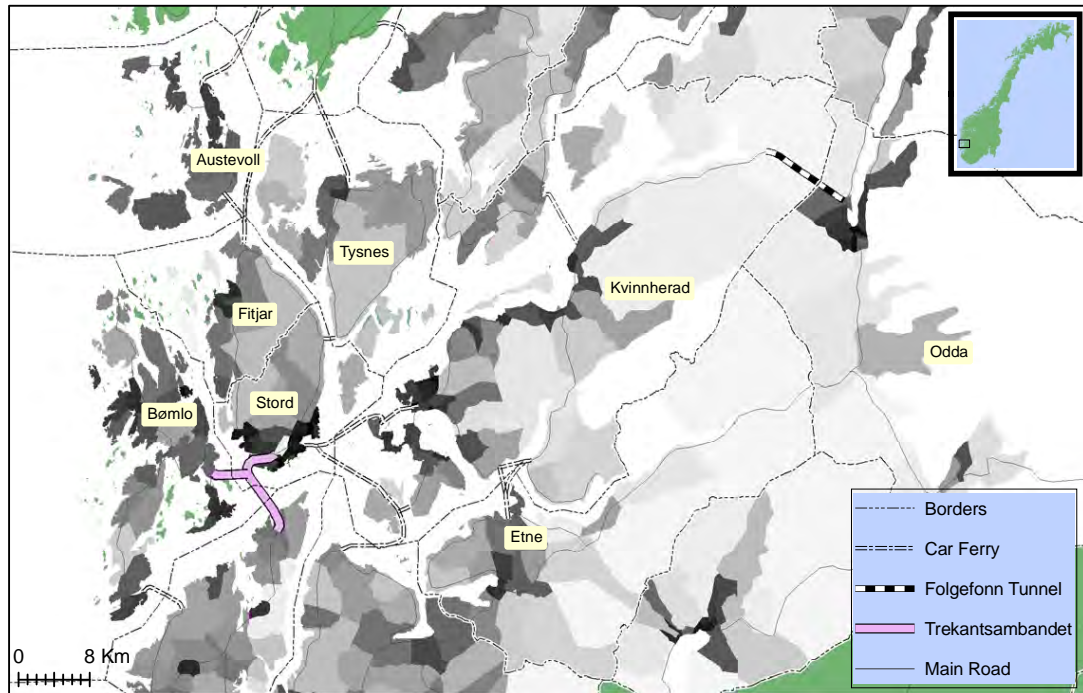


Figure 4: Population per square meter by grunnkrets (the most disaggregated measure for spatial data in Norway). Darker shading represents a denser population. As can be seen, while the population in Odda is concentrated at the entrance to the Folgefonn tunnel, this is not the case in Kvinnherad. Regarding Stord/Fitjar and Bømlo, most of the population is located close to Trekandsambandet.

In our model, commuting flows are deterred by toll charges and travelling time. Bridges and/or tunnels and the presence of toll charges may for some workers represent a kind of mental barrier, causing an additional deterrence effect. This is one possible reason why our model overestimates commuting flows across new road connections. Another possible reason is related to dynamic aspects. It may take quite a long time for the system to adjust to fundamental changes in the road infrastructure network. For both workers and employers, the adjustments to new labour market options may be sluggish, causing a lengthy divergence of commuting flows from the pattern elsewhere in the geography.

4.3 Development of commuting flows over time

As mentioned above, labour market adjustments to a substantially changed transportation network may be sluggish. Figure 5 offers information on the annual changes in the number of commuters after the opening of the two connections described in Section 3. Notice first that there was also some commuting from Kvinnherad to Odda prior to the opening of the Folgefonn tunnel. In that situation the travelling time between the two municipalities normally prohibit any daily commuting. The observed commuting reflects noise in the data, and may for instance be due to weekly based commuting, or to part time working for a limited period.

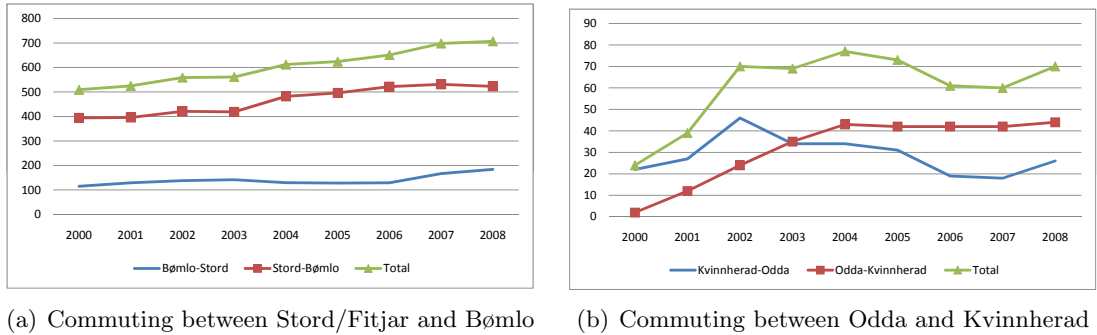


Figure 5: Observed commuting flows after the opening of Trekantsambandet and the Folgefonn tunnel. Both were opened in 2001.

According to Figure 5(b) there was a one-off increase in the number of commuters between Odda and Kvinnherad immediately after the opening of the Folgefonn tunnel in 2001. There was, however, already a slight increasing trend before this. After the immediate response, the commuting flows do not indicate a further development towards a better integrated labour market. For the new road connections between Stord/Fitjar and Bømlo, the situation is the

reverse. At best, a very minor immediate increase is observed after the opening of the new road links in 2001, but there seems to be a tendency that the labour market in the area gets better integrated over time. The adjustments are, however, apparently very sluggish. The most likely explanation for this sluggish adjustment lies in the price. Prior to the opening of Trekantsambandet, it was possible to commute by using a ferry connection. However, this option could be time consuming, particularly when waiting time is included. The opening of the new infrastructure should have reduced this cost and increased flows. However, with a toll of 51 NOK each way, commuting between these two areas remained expensive and as a result there was only a minor increase in commuting. This raises the obvious question of what an optimal toll might be.

4.4 The optimal charge

The optimal toll charge for the infrastructure depends on who is asking the question. The infrastructure was part-financed and now operated by a privately owned enterprise who has the exclusive right to charge a toll. This firm has a monopoly and can be expected to act as a profit maximiser. Since most of the costs involved in the operation of the infrastructure are fixed, profit maximisation will approximate revenue maximisation. Evaluating the optimal charge from society's perspective is more complicated.

The sort of road pricing which has received most attention from economists has been pricing which is introduced to ration scarce capacity. This is the case when the marginal social cost of commuting is greater than the marginal private cost. However, there is no congestion on Trekantsambandet or the Folgefonn tunnel. In part this reflects the nature of the infrastructure. During the planning phase, consideration must be given to the potential long-term demand. Because it is not easy to increase capacity after construction, it makes sense that the infrastructure is constructed with a capacity higher than current demand (assuming rising demand over time). This means that capacity in the early years of the project is not a scarce good. Unfortunately, this is precisely the time when charges designed to finance the infrastructure are levied.

Small and Verhoef (2007, pp. 163-190) present a discussion of rules for optimal investment choice and address the issue of financing through tolls. They show that under given assumptions, revenue from optimal congestion pricing can result in self-financing capacity expansion. They also show that this result breaks down when we consider discrete capacity. The example used by

them is a small country road where the minimum feasible capacity exceeds any conceivable level of demand for it. This mirrors the situation with both Trekantsambandet and the Folgefonn tunnel. Here, the revenue from the optimal charge is zero, so the possibility of the improvement being self-financing is ruled out.

Aside from congestion, there may be other reasons why a non-zero charge on the infrastructure can be optimal for society. An important point to consider is how an optimal congestion charge (of zero in our case) interacts with other externalities connected to transport. Parry and Bento (2002) provide a review of studies looking at such issues. These issues include a consideration of congestion on unpriced routes (Liu and McDonald, 1998; Verhoef, Nijkamp and Rietveld, 1996), accident rates (Newbery, 1988), pollution externalities (Small and Kazimi, 1995), public transport subsidies (Glaister and Lewis, 1978), and petrol taxes. Parry and Bento (2002) extend this literature by looking at how distortions in markets other than the transport market affect the welfare gains from congestion charging.

The recommendations from the literature would seem to be that the optimal charge should be close to zero while capacity exceeds demand. The charge may be slightly above zero to cover variable maintenance costs and to reflect distortions in other markets. Even after such adjustments, it seems unlikely that the charge should be as high as 51 NOK for a one-way journey. Raux and Souche (2004) note that externalities such as noise and pollution will be lower if the population exposed to them is low, as is often the case in rural areas. This would apply to our case studies. It is important to note that the charge is only levied until a fixed amount of money has been collected. After this, it is abolished. This is an implicit acknowledgement that the socially optimal charge is zero. One question which has not yet been addressed is what the optimal charge is from the perspective of the private operators of the infrastructure.

As stated, the operators of the infrastructure have a monopoly. This gives them considerable price setting power. The demand curve for Trekantsambandet shown in Figure 2 can be used to determine the revenue maximising price and the price elasticities. It turns out that this demand curve can be very closely approximated with a cubic function ($R^2 \approx 1$). This allows the optimal price to be found analytically. The revenue function and price elasticities are presented in Figure 6.

Figure 6(a) shows the revenue generated by commuting flows between Stord/Fitjar and Bømlo for different prices. Solving for the revenue maximising price gives a local maximum

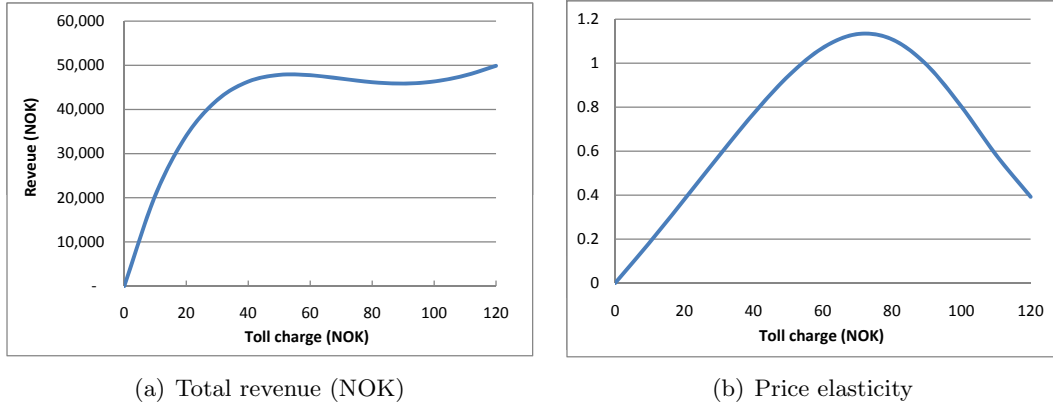


Figure 6: Total revenue collected from the toll charge between Stord/Fitjar and Bømlo and the price elasticity of demand.

at a price of 54 NOK. Increasing the price beyond this level does eventually increase revenue. However, as mentioned in the previous section, the inelastic demand in this region of the demand curve is a function of the additivity constraints of the gravity model rather than actual behaviour. For this reason, 54 NOK for a one-way trip can be thought of as the unique revenue maximising price. Interestingly, the optimal price calculated here is almost identical to the 51 NOK which was being charged in 2006. This suggests that the pricing of the infrastructure reflects the interests of the infrastructure operator rather than society as a whole.

Figure 6(b) shows the point price elasticity of demand for commuting. Demand is inelastic for prices below the optimal toll of 54 NOK. Above this, further increases in price has a negative effect on revenue due the disproportionately large fall in demand. Once again, the apparent return to inelastic demand for prices above 89 NOK reflects the additivity constraints placed on the gravity model rather than actual behaviour.

4.5 Efficiency, equity and justice considerations

For policy makers, it is important to consider the distributional impacts of toll charges. Raux and Souche (2004) construct a theoretical framework for the consideration of efficiency, equity and justice in relation to road pricing. Firstly they consider efficiency which requires correct marginal cost pricing of externalities and optimal investment, where investment continues until the discounted sum of marginal congestion cost savings equal the marginal cost of increasing capacity. As was discussed in the previous subsection, neither of these conditions are met due to the excess of capacity over demand. Raux and Souche (2004) utilise the principles of justice

proposed by Rawls (1970, p.302). They identify three which pertain to road pricing:

1. Spatial equity
2. Horizontal equity
3. Vertical equity

Spatial equity is based on the idea that citizens should have the right of access to jobs, goods and services irrespective of their location. This is an important idea in Norway where successive governments have pursued policies aimed at keeping the population spread out across the country. Our analysis of commuting allows us to say something about the access to jobs aspect of spatial equity. The lack of a substantial increase in commuting after the opening of the connection suggests that accessibility to jobs has not improved substantially. One possible explanation is that the road toll may be approximately equal to the cost and inconvenience of the ferry connections Trekantsambandet replaced. Similar logic may also apply to accessibility to goods and services.

Horizontal equity relates to the equality of treatment of different users. This is particularly relevant with regard to the ‘user pays’ principle. Raux and Souche (2004) decompose this principle into two components. The first related to the “polluter pays principal”, where road users are required to pay for the external costs they generate. The second consists of charges to pay for improvements in the infrastructure. This second component is relevant to the discussion of Trekantsambandet. The principal of user-pays has an intuitive appeal with regard to equity given that it is the people who benefit most from the investment who pay for it. However, if the investment is being financed by a toll unrelated to the marginal cost of use, economic efficiency will not be achieved. Fully financing infrastructure through marginal price charging would only be possible where congestion or environmental costs were sufficiently high.

The final concept of equity is vertical equity. This concept relates to the idea of social inequality. Often, these concerns relate to socially disadvantaged groups. For example, those on low incomes may be concentrated in particular geographic areas, and may have fewer transport options. However, Norway is a relatively egalitarian society where socioeconomic differences are low. This means that such considerations are less relevant. However, another principle of vertical equity is that the access of the poorest and worst served zones should be improved. This

is relevant to the islands of Stord and Bømlo. Before the construction of Trekantsambandet, these were the largest islands communities in Norway without a fixed connection to the mainland. However, the price appears to have dampened at least some of the benefits which the connection was designed to secure. One positive remark which could be made is that islands' inhabitants may be no worse off given that the ferries which preceded Trekantsambandet also had a price while also having a greater travel time. This does not take account of the fact that some tax revenues were used to finance the infrastructure.

With regard to equity then, it seems that the investment did not worsen the situation. With regard to Trekantsambandet, costly ferries were replaced with a costly set of bridges. In the case of the Folgefonn tunnel, the existing journey time between Odda and Kvinnherad was so large that there was practically no daily commuting. Additionally, it was still possible to take this route after the opening of the tunnel. In both cases it seems reasonable to suspect that at least nobody is worse off. However, particularly in the case of Trekantsambandet, it seems there is significant scope for improving the situation for the regions' inhabitants.

4.6 The aims of the project

A number of important points have emerged from the discussion so far. The first is that the opening of the new infrastructure had only a modest effect on interregional commuting. This appears to be due to a high toll charge. Given the lack of congestion and unpriced environmental externalities, the most efficient toll is much closer to zero. The current toll is much closer to the revenue maximising toll and is therefore more closely aligned with the interests of the private sector operator than with society as a whole. A consideration of the justice and equity considerations also seems to suggest that the toll should be greatly reduced or abolished.

In order to judge the success of the investment, it is useful to consider what the aims were at the start of the project. According to the operator of Trekantsambandet¹:

*“A permanent road connection between the islands is very important for businesses in the region, to meet increasing demands for mobility in the labour market, and as a general stimulus for the economy and businesses. In addition, the connection will give increased social contact and choice with regard to education and leisure.”*²

¹www.trekantsambandet.no

²Translation from the original Norwegian.

Our analysis allows us to draw some conclusions with respect to whether these objectives have been achieved. There are, however, some important limitations. Firstly, we consider only commuting flows. Secondly, we are considering only flows between the two islands and not to the mainland. However, a consideration of commuting allows something to be said about labour market mobility between the islands of Stord and Bømlo.

The lack of an increase in commuters after the opening of the Trekantsambandet in 2001 suggests that the aim of a better integrated labour market has not been met. This could simply reflect a lack of demand. However, our gravity model suggests that around 2,500 commuters will utilise the link between Stord/Fitjar and Bømlo when the charge were abolished. This increased interaction between the labour market areas would improve the matching efficiency and would go some way to achieving the objective of a more integrated labour market. With respect to the Folgefonn tunnel, our model predicted that if the toll were abolished there would be a total of around 300 commuters. We suggest the reason for this is the distribution of the population around this infrastructure.

It is harder to say something about the other objectives of the Trekantsambandet project. However, some clues are given by the analysis of commuting flows. Firstly, it appears that the charge acts a significant deterrent. For occasional users, the charge is higher since they are less likely to purchase the 40 pre-paid journeys required to qualify for a discount. It is therefore likely that such deterrence will act to decrease the non-commuting spatial interaction which the project was designed to stimulate. This seems to be a missed opportunity given the spare capacity available.

5 Concluding remarks

Like most empirical research within the social sciences, our approach is based on a set of practically motivated simplifying assumptions concerning the definition and measurement of independent variables. We have for instance 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, 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 pecuniary costs and travelling time.

The paper was successful in its primary aim of estimating the effect of pecuniary travel costs on commuting flows. This is not a straightforward matter since it requires a number of charges to be present on the network and significant variation in price. These requirements seem to have been met in our data. The ability to forecast how commuting flows will respond to changes in tolls and ferry prices is useful for policy makers as well as the private enterprises operating the ferries and tunnels.

As an example, demand curves were estimated for two links where tolls are charged. These tolls are temporary and designed to finance the investment rather than to correct for congestion or environmental externalities. An analysis of the development of commuting flows since the opening of the infrastructure showed that there was only a modest increase in interregional commuting. Our gravity model suggests that this modest increase was not the result of a lack of demand, but the toll being prohibitively high. This had two main negative effects. The first is that the toll has significantly degraded the ability of the projects to meet their objectives of increased spatial interaction. The second is that the charge has resulted in a large amount of spare capacity being wasted. This is a particularly important issue since part of the infrastructure is financed with public funds.

We suggest that it would be more effective to fully finance such infrastructure out of general taxation. This way, the local economy could benefit from the increased connectivity as soon as the project is complete, rather than having to wait until the toll is abolished. This benefit could then be captured through general taxation in order to pay for the infrastructure. Local government could also contribute funding, as it currently does, if they felt that their region would benefit from new infrastructure. Over time, it is possible that the demand curve we estimate will shift outwards, as workers and jobs relocate to benefit from the new infrastructure. If this resulted in congestion, marginal cost pricing could be introduced since capacity will have become scarce. This could also contribute to financing the infrastructure.

The tolls on these projects will be removed once a pre-determined level of revenue has

been collected. Future research should focus on the response of commuting flows and the local economy to this development. This information would indicate what benefits might have been achieved when the infrastructure opened 2001 if a toll had not been levied. An estimate of the cost of delaying these benefit could then be made.

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