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Welfare-Optimal Public Transport Fares in Denmark

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1 Introduction

In many cities, public transport systems face challenges due to increasing access to private cars and the lingering effects of the COVID-19 pandemic. Better fare policies are a relevant solution, but optimal societal fare policies are not trivial, as they require careful analyses of the derived societal and welfare economic impacts. Ensuring high accessibility while maintaining costs at acceptable levels for society is key. This requires formulating a disaggregate welfare function, including direct consumer surplus-related effects and indirect external effects, such as environmental costs or effects on public health. This enables monitoring of their distribution across the population. In addition, revenue and capacity issues should not be disregarded.

In this paper, we present a welfare economic analysis for Denmark, based on a decomposition of the fare structure as a combination of a flat fee (c_{flat}) and a distance-based penalty (c_{dist}) [Farber et al., 2014].

$$fare = c_{flat} + c_{dist} \cdot distance$$

This setup facilitates an assessment of the continuous spectrum of the two terms and the resulting outcomes of each policy. Notably, by setting the per-kilometre charge to zero, the equation can handle fixed flat fare models, such as those successfully implemented in cities like Stockholm, Vienna, and Athens [Streeting et al., 2023].

Utilising a detailed micro-econometric demand model for the choice of mode and destination within the Danish population, we express a welfare function based on the parameters c_{flat} and c_{dist} and derive the welfare contributions from the various parameter combinations. The welfare function quantifies and monetises accessibility using value-of-time estimates [Rich and Vandet, 2019] while accounting for health impacts from substitution to and from active modes of transport (i.e. walking, bicycle, and e-bike). Additionally, it incorporates various external cost estimates, including those related to emissions, noise, safety, and climate effects [Santos et al., 2010].

2 Methodology

We present a destination and mode choice model from which we formulate a welfare function. Then we apply a Bayesian optimisation method to identify the optimal public transport fare strategy and introduce the Suits coefficient to measure equity effects. The overall methodological approach is presented in Figure 1.

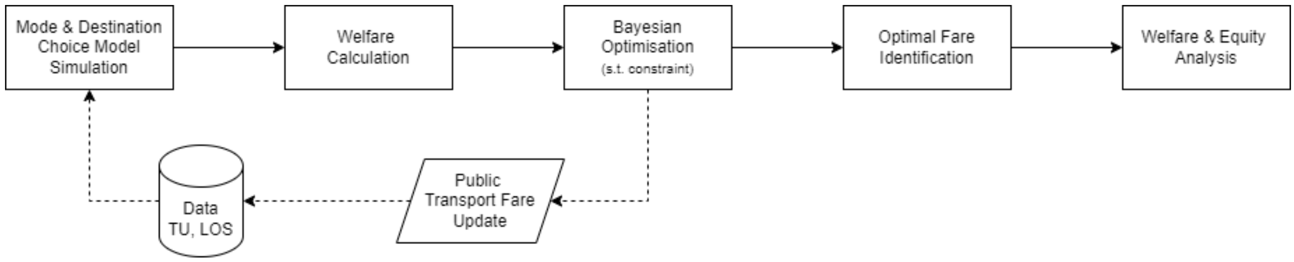

Figure 1: Diagram of the methodological approach

The model is based on a large set of daily travel schedules for respondents $n = 1, \ldots, N$. From this data, we estimate a demand model (i.e., multinomial logit model) to reflect the link between attributes and travel demand probabilities. We consider choice of mode $m = 1, \ldots, M$ and destination $d = 1, \ldots, D$. It is indirectly understood that destination choice is conditional on the origin of n represented by i. In total, six different modes are considered: (1) walk, (2) bicycle, (3) e-bike, (4) car, (5) car passenger, and (6) public transport. After estimating the model parameters, we can utilise it to calculate the probabilities of each individual selecting a mode-destination alternative under various public transport fares. Lastly, for optimising the public transport fare function a Bayesian optimisation (BO) approach was used.

3 Results

The current public transport fare system in Denmark is zone-based, where the fare increases with the number of zones travelled, similar to a distance-based system. Given that the current pricing regime represents a baseline, we conducted a regression analysis on the current fares to derive an equivalent distance-based structure. Hence, we estimated a linear regression model for the observed public transport fees. This baseline combines a 13.1 DKK flat fee with a 0.92 DKK/km distance charge and closely replicates the current zone-based scheme ($R^2 = 0.74$).

The mode shares for the baseline are as follows: walking at 15.73%, bicycle at 18.73%, e-bike at 1.37%, car at 46.39%, car passengers at 10.75%, and public transport at 7.12%. The average trip lengths for each mode are 2.49 km for walking, 6.22 km for bicycle, 9.18 km for e-bike, 28.2 km for car, 23.25 km for car passengers, and 23.16 km for public transport.

3.1 Fare Optimisation

After establishing the baseline scenario, the next step is to refine the fare scheme according to the current conditions. By applying BO over 50 iterations, we identified an optimal flat fare of 23 DKK. In Figure 2, the coloured area shows the combinations of distance and flat fare parameters that lead to a marginal average operational cost per traveller (i.e. a maximum 1% change in the total number of travellers) based on the estimated welfare and constraint GP regressions.

We notice that as travel patterns evolve along the curve, welfare benefits increase when prices shift towards heavier flat fare policies. Compared to the baseline fare, implementing a 23 DKK flat fare results in a welfare gain of 0.34 DKK per person, which equates to approximately 1 million DKK per day. It's important to highlight that the flat fee would enhance consumer surplus and reduce external costs by 0.38 and 0.095 DKK per person, respectively. However, it would also lead to a reduction in public transport revenue by 0.13 DKK per person.

This policy has resulted in positive gains across most transport modes, primarily through health benefits from increased cycling and walking, as well as reduced car emissions. While e-bikes show a negative change in mileage leading to some health losses, the data shows varying impacts across modes (Figure 3). Mode share changes of 0.71% for walking, 0.36% for bikes, 0.25% for e-bikes, -0.25% for

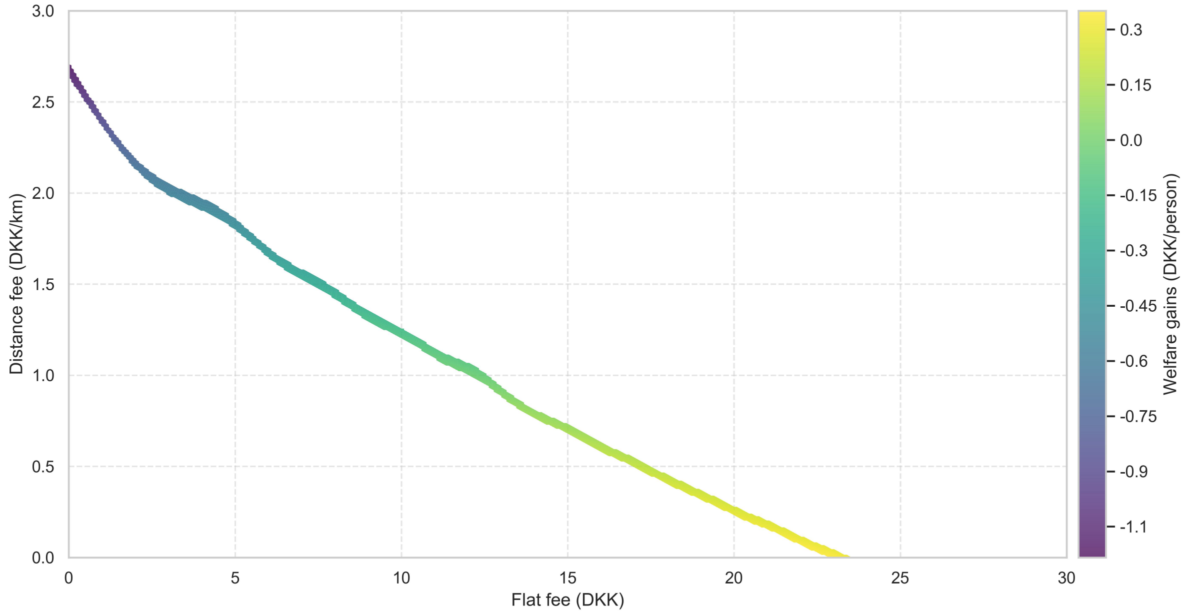

Figure 2: Bayesian optimisation (BO) of public transport fares. The welfare gains are calculated compared to the baseline fare (13.1 DKK & 0.92 DKK/km) in DKK per traveller. The coloured area represents fares that account for a maximum of 1% change in the number of travellers compared to the baseline.

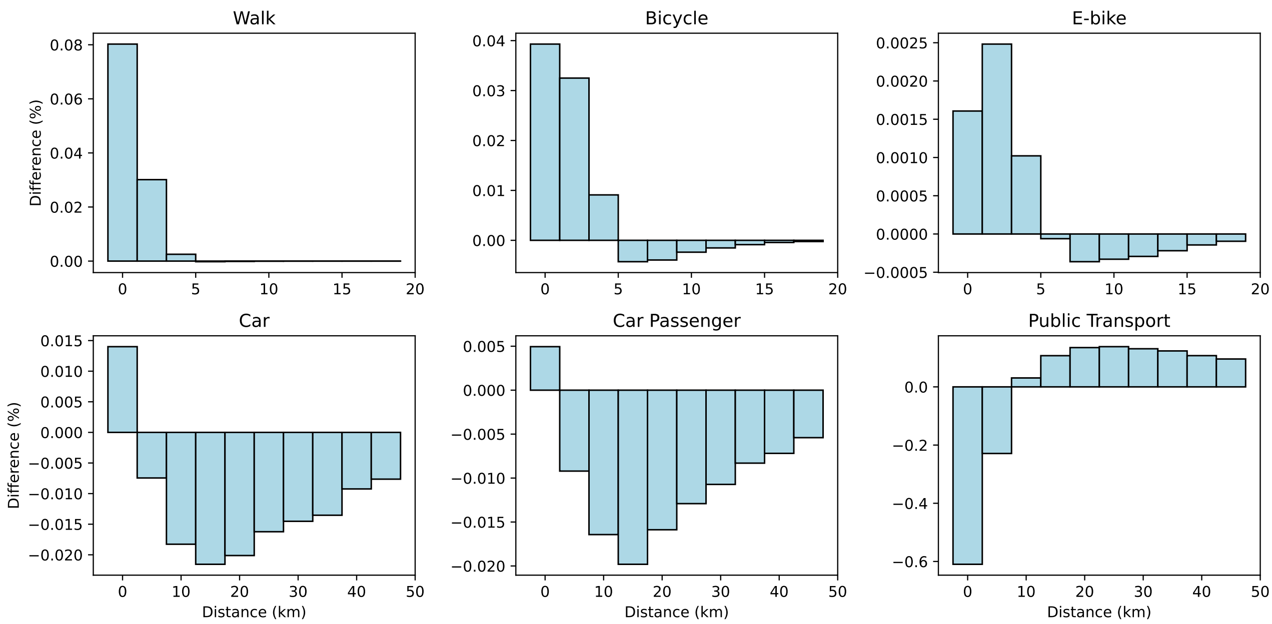

Figure 3: Mileage distributional effects (% change from the baseline) across modes and travel distances of implementing the 23 DKK flat fare scheme.

cars, -0.94% for car passengers, and 0.46% for public transport, accompanied by corresponding changes in total mileage of 0.83%, 0.06%, -0.14%, -0.53%, -1.99%, and 28.33% respectively were observed.

The most striking change is the substantial increase in public transport mileage, coupled with decreases in car-based travel both as drivers and passengers, suggesting that while people are not making more trips by public transport, they travel longer distances when using this mode.

Overall, while the 23 DKK flat fare policy offers notable welfare benefits and improvements in consumer surplus and external costs, it also presents a challenge in terms of public transport revenue.

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