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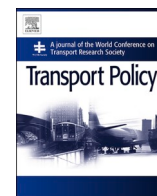
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Is flat fare fair? Equity impact of fare scheme change

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ABSTRACT

When Public Transport Administrations propose changes in fare schemes or increased fares, they are often met with concerns regarding the proposed fare schemes fairness. Implicit in these concerns is an understanding of relations governing land use and public transport, impacting equity. In this paper, we use socio-economic statistics of census areas in conjunction with public transport travel data from a transport forecast model to assess the geographical and distributional fairness of alternative fare schemes: flat, zone-based and distance-based. We discuss our result in relation to both the scientific literature and the known “truths” in the public debate. The method is applied to the Case study of Stockholm public transport. We find that high-income travelers benefit from all three fare schemes considered but, in contrast to much of the literature, least by flat fares. A strong distance-dependent fare could be horizontally equitable but has poor vertical equity.

1. Introduction

The fairness of public transport fare changes is a topic of public debate. Fares can be set flat, with the same fare for all trips, or be differentiated. When flat fares are proposed, commonly arguments of simplification and uniformity are posed, and ease-of-use and ease-of-control are stressed. Proposed differentiations are commonly peak, and off-peak fares and various forms of differentiations by distance traveled (Farber et al., 2014; Cervero, 1981; Translink, 2016; IPART, 2016). Differentiation is usually proposed to achieve a fare scheme more similar to how production costs are distributed, lowering demand for trips with high production costs and increasing demand for trips with low production cost and increasing revenues. Opposition to proposed differentiations tends to center around the fairness of the proposed changes since differentiation will advantage some groups of travelers and disadvantage others (e.g. groups living far from the CBD, and, in the case of zone fare schemes: passengers making short trips across zone boundaries.).

In the literature on fair distribution, three defining dimensions on how to assess the fairness can be discerned. First, there is a normative dimension which sets the foundations of the fairness principle. Would a fair system be a system where all outcomes are as similar as possible, or all participants have as equal opportunities as possible, or should well-

regulated markets be trusted to produce the fairest outcome? Second, authors choose what to measure. Should the equity of public transport inputs (fares, taxes), outputs (accessibility, geographic coverage) or consumption (trips made) be assessed? And, third, there is the choice on which distributional differences to measure. Evaluating horizontal equity (equity among members of the same group) such as all public transport users, or all citizens served by the public transport system (irrespective of actual PT use) or vertical equity (equity among members of different groups), such as different income, age or occupational groups.

In addition to the different methods and distributional focus in the literature, there is also the issue of transferability, since distributional effects of public transport provision is highly impacted by the distribution of land use, income levels and travel patterns, including their spatial distributions. Most of the literature is centered in an North American context with low-income residents heavily using the public transport system but doing short trips (Ballou, Mohan 1981; Cervero, 1981; Brown, 2018; Tawfik, 2014). The general consensus has been that differentiated fares are equitable for low-income users. It remains however unknown whether this conclusion is transferable to European-style cities with large public transport mode shares and high-income residents living and traveling in the center.

We study the distributional effects of different fare schemes on

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different population segments situated in Stockholm County. We show equity-differences for fare schemes with regard to horizontal equity (among PT users and among the public in general) and vertical equity (across income groups). We focus in our presentation on the potential transferability of our findings by discussing the link between land use, distribution of income groups and distributional effects of fare schemes.

Stockholm has had a high stakes public debate on fare policies for many years regarding efficiency and equity of flat versus differentiated fares. Since 2005 there have been multiple shifts between flat and differentiated fares. As a Swedish daily writes: “The political sides have for more than a decennium fought about whether to have zonal or flat fares in the county of Stockholm. The red-greens (left of center coalition) thinks that flat fare is fair, that it makes the county more connected, that it ensures that low-income residents in the periphery can use public transport. The right-of-center parties believe that it is unfair that passengers should pay the same amount for a single stop in the subway as for traveling 100 km with the public transport system (from the south to the north of the county) (Sundström 2015 April 20th).” Our general finding is that flat fares are the most vertically equitable while distance fares provide most horizontal equity. Our study show how systematic quantitative analysis of travel patterns and distributional impact can support an evidence-based professional and public debate on fare scheme choices (a.), and, support the design of win-win schemes with regard to efficiency and equity (b.). It also shows how conditions for the analysis can be presented together with the analysis in order to improve the interpretations and transferability of the results.

In section 2 we review the literature on fare-scheme equity. Section 3 describes the method and data materials. In section 4 our results are presented followed by discussing their transferability in section 5 and concluding with policy implications in section 6.

2. Literature review

What a fair distribution of a limited resource should be is at its core a normative question with differing answers. Taylor, Tassiello Norton (2009) mention three “types of Equity”: Market equity - that the result of fair and legitimate exchanges is by definition fair, Opportunity Equity - providing fair distribution of opportunity and proportional allocation of initial resources, and, Outcome Equity-producing equal levels of outcome. Studies on the distributions of fares (Bandegani, Akbarzadeh, 2016; Bennett, Shirgaokar 2016; Nahmias-Biran et al., 2014) distinguish between two different dimensions, Horizontal Equity – equity among individuals belonging to the same group, and, Vertical Equity – equity between individuals belonging to different groups. Taylor and Norton link horizontal equity to market or opportunity equity, and vertical equity to outcome equity. In the literature on fare distributions the two most common normative choices on fairness is to either: i) Assess a kind of market equity approach – how close to the distribution of fares paid and the distribution of amount of public transport used resemble each other (Cervero, 1981; Cheng et al., 2015; Bandegani, Akbarzadeh, 2016), or ii) a vertical equity approach – assessing how beneficial the distribution of fares are for low-income and other vulnerable groups (Farber et al., 2014; Nuworsoo et al., 2009; Brown, 2018; Nahmias-Biran et al., 2014). In some cases, both types of approaches are taken (Cervero, 1981; Tawfik, 2014).

Taylor, Tassiello Norton (2009) define “unit of measurement” as the term for the sort of good to be distributed. There is no consensus in the literature as to which unit of measurement should be used. Some studies look at the distribution of subsidies and level of cost recovery (Cheng et al., 2015; Bandegani, Akbarzadeh, 2016) as a way of assessing system equity, others concentrate on fare expenditures (Farber et al., 2014; Tawfik, 2014). Another approach is to study accessibility in general, comparing changes in generalized cost due to changes in fare schemes (Ma et al., 2017a; Ma et al. 2017b). Bureau, Glachant (2011) choose to include the decreasing marginal utility of fare reductions with increasing income levels when assessing vertical equity, which leads

them to conclude that an equal relative decrease in fares for all passengers constitutes a shift towards more vertical equity, since the utility of the saved fares is higher for low income passengers. Another distinction to decide upon is if the study should look at distributional effect of a specific fare schemes (Brown, 2018; Taylor, Tassiello Norton) or the distributional effects of a fare scheme change (Nahmias-Biran et al., 2014; Ballou, Mohan 1981).

To investigate the distributional impact of fare schemes, data on passengers use of public transport and, in the case of vertical equity, on their socio-economics is needed. Many studies uses travel surveys, asking respondents on both their travel patterns and their socio-economic status (Bandegani, Akbarzadeh, 2016; Brown, 2018; Nahmias-Biran et al., 2014; Farber et al., 2014; Nuworsoo et al., 2009). Cheng et al. (2015) uses smart-card data to assess travel patterns. Working with accessibility and generalized cost Ma et al. (2017a) uses census data, travel survey data and level of service data from Google directions API.

The general result from the literature is that flat fares are disadvantageous low income passengers and that distance dependent fares, in addition to having a stronger link between usage and fares paid, are vertically more equitable. Research findings have been reported for cases from the United States (Farber et al., 2014; Brown, 2018; Nuworsoo et al., 2009; Cervero, 1981; Ballou, Mohan 1981), Canada (Ma et al. 2017b; Ma et al., 2017a; Tawfik, 2014), Israel (Nahmias-Biran et al., 2014), Iran (Bandegani, Akbarzadeh, 2016) and China (Cheng et al., 2015). The vertical and horizontal equity outfall of a fare scheme are dependent on the nominal structure of the fare scheme, the land use for residents in different income brackets and their travel-patterns (both in term of average trip lengths as well as volume of trips made). There are many studies showing that both land use and travel patterns have systematic differences between cities in North America and Europe. European style cities are denser (Bertaud, 2003) with high income residents generally living closer to city centers (Brueckner et al., 1999; Glaeser et al., 2008) and public transport exercising a larger modal share (Giuliano, Dargay, 2006; Huggins, 2009). These differences warrant a closer look at the equity in a European style city.

3. Method and data materials

To study the distributional impact of fare-schemes we now turn to the case of Stockholm public transport. In section 3.1 we describe the case and data materials used. As a measure of horizontal equity among public transport users we develop a measurement of average fare paid in section 3.2. Three principles of fairness have been introduced earlier (in section 1), the first, usage fairness does not need to be measured since it can be adjudicated nominally on how proportional fares are to the amount of public transport consumed, distance-dependent fares are trivially more usage fair than flat fares. However, to assess the horizontal and vertical equity per capita, the distributional effects of the fare schemes have to be measured. In sections 3.2.2 and 3.2.3 we describe our methods for measuring fare schemes impact on peripheral and low-income residents.

3.1. Data materials – case of Stockholm

The County of Stockholm is divided into 26 different municipalities, with a total population of 2.3 million, and a total area of 6.5 thousand km². The most central municipality, the city of Stockholm, hosts approximately 40 percent of the County population. The Public transport system of Stockholm is comprised of four different modes with 2.9 million boardings on an average winter workday: Metro (1.3 million boardings), Bus (1.1), Commuter train (0.3) and Light rail (0.2).

In 2005, a center-left political coalition decided to change the fare scheme of Stockholm Public Transport from the previous zonal scheme to a flat fare scheme. The following year majorities shifted in the election, and the winning center-right coalition reinstated zone fares. In

January 2017, as a part of a broader negotiation between the ruling center-right coalition and the opposing center-left parties, flat fares were reinstated. During the period 2007 to 2016, the county was divided into three zones and fares were set in proportion to the number of zones traversed. Fig. 1 depicts these zones boundaries, and in Table 1 the fare levels are reported. Zones were arranged so that the entire metro network is contained within the inner-zone, Zone A. For our research purposes we will, in this study, examine the former zonal system (a), comparing it to the present flat fare system (b) and an envisaged, fully usage-dependent case, of kilometer fares (c). Fares (b) and (c) are set, respectively, to 30 SEK (Swedish Krona, 1 SEK is approximately 0.11 US Dollar) per trip, and 2.35 SEK per kilometer. All fares are defined in order to keep total ticket revenue equal between the different schemes. All analyses are made with the County's 1300 statistical base areas as the smallest geographical unit.

Between the left and the right side of the debate some urban myths or “truths” have been shared; a belief that the CBD encompasses most of the workplaces and that the most prevalent trip is between residence and CBD, and that high income residents tend to live more centrally than

Table 1

Fares in the zone fare scheme in proportion to zones traveled.

Traveling through	Fare (SEK)
One zone	25
Two zones	37.7
three zones	50

lower income residents. Both sides have believed for many years, without much supporting evidence, that these “truths” imply that flat fares are advantageous for low income and peripheral users and distance dependent fares advantageous for high income user. We hereby test these truths, using actual land-use data as well as trips actual origins and destinations, rather than making assumptions on which travel relations are prevalent and where workplaces and high income residents are situated.

Median incomes, number of workplaces, and, population by statistical base areas were taken from official Swedish statistics (SLL, 2018). The national four-step model Samplers (Trafikverket, 2018) is used to

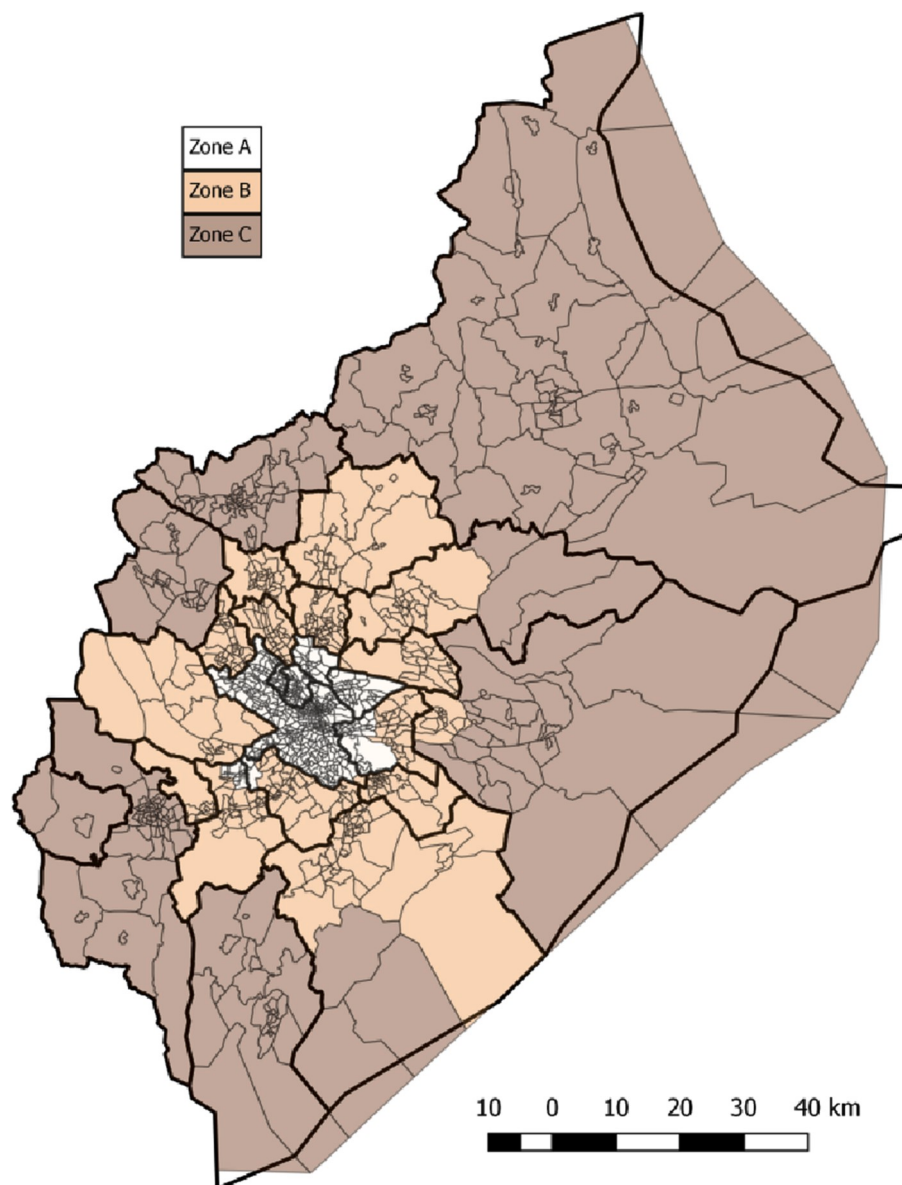


Fig. 1. Three zones that defined the zone fare system in Stockholm 2006–2016. Fares were paid in proportion to the number of zones traversed. (Black lines are municipality borders, grey are statistical base area borders).

make a present-day forecast of public transport travels in the county. The core model of Sampers is an MNL-logit with trip-, mode-, destination, and route choice. The following data materials were then extracted.

1. OD matrices for public transport trips
2. Distance matrices of public transport trips for all origin-destination pairs
3. Zone-passing matrices, defining the number of zones traversed between any origin-destination pair

All results are calculated for a given demand (i.e. fixed total number of trips in the OD matrix), not taking into account expected changes in demand with changed fares. This simplification is fairly common (see, e.g. (Bureau, Glachant 2011), for a discussion) when studying distributional impacts of fare policies.

3.2. Measuring equity

We apply three different measures to capture different aspects of equity, in section 3.2.1 we define a measure of the average fare per trip given the passengers place of residence (horizontal equity between public transport users), in section 3.2.2 we describe a distributional measure of fare expenses per capita (horizontal equity between county citizens), and, finally in section 3.2.3 we show a distributional measure of fare expenses for different income groups (vertical equity).

3.2.1. Measuring average fare paid – equity between travelers

We compare the nominal fare between residence and CBD with the weighted average fare (WAF). The WAF is the average fare for a resident living in a home area i . WAF is calculated using the travel patterns from that specific area. Calculating delta WAF between two fare schemes produces a measure of how, on average, fares paid by travelers from the base area change due to the introduction of a new fare scheme. Assuming a fare, f_{ij} , between origin base area i and destination base area j , and having a demand (number of trips) between those two areas of d_{ij} , then the WAF, $\bar{f}_i$, for that origin base area (area of residence) is:

$$\bar{f}_i = \frac{1}{\sum_j d_{ij}} \sum_j d_{ij} f_{ij} \quad (1)$$

If the trip between the residence and the CBD is the most relevant and prevalent trip, then the WAF will be close to the nominal fare between residence and CBD. If there are other systematic differences in travel patterns between central and peripheral areas, then WAF will diverge from nominal center-to-residence fares.

3.2.2. Horizontal equity, fairness between equals – Gini coefficient

Horizontal equity, or fairness between equals, is the notion that all members of some group are equal and therefore should be treated equally. The argument for applying the same public transport fare for all citizens irrespective of place of residence is an example of an appeal for horizontal equity. In our setting, we operationalize the measurement of horizontal equity among citizens using the Gini coefficient (Gini, 1912). We measure total fare expenses by travelers from each base area and then, relating it to the areas' population, the total fare expenses per capita. Ordering the zones by increasing fare expenses per capita on the abscissa, the Lorenz-curve (Lorenz, 1905) of accumulated total fare expenses paid can be plotted on the ordinate (Fig. 2).

The area delimited by the triangle OAB is denoted K . K equals 5000 ($100 \times 100 / 2$). The area delimited by OA, AB and the Lorenz-curve (C) is denoted L . Then the Gini-coefficient is defined as (this description of the calculation is adopted from the description found in (Suits, 1977)):

$$Gini = \frac{K - L}{K} = 1 - \frac{L}{K} \quad (2)$$

With the expenditure from a certain fare f at segment y of the

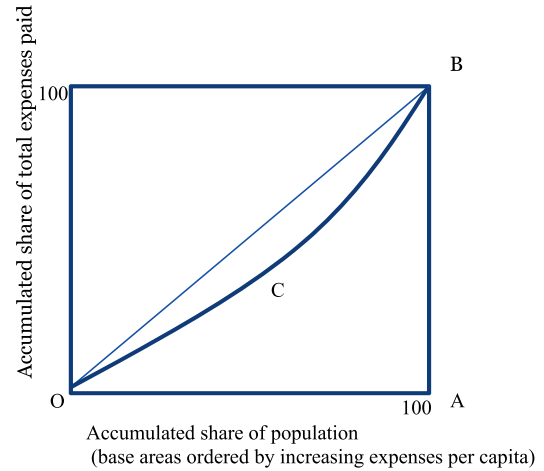


Fig. 2. Schematic illustration of the Lorenz-curve, the area between the diagonal and the Lorenz-curve (C) as a share of the area under the diagonal is the Gini-coefficient.

population, the accumulated share of total expenditures is $T_f(y)$ for the population in segment y and the population in the areas with lower expenses per capita than y . Then the functional form of L_f (the Lorenz-curve for fare f) is:

$$L_f = \int_0^{100} T_f(y) dy \quad (3)$$

And the Gini-coefficient can then be approximated, over the base areas i , using:

$$\gamma = 1 - \frac{1}{K} \int_0^{100} T_f(y) dy \approx 1 - \frac{1}{k} \sum_i \left(\frac{1}{2} \right) [T_f(y_i) + T_f(y_{i-1})] (y_i - y_{i-1}) \quad (4)$$

The Gini coefficient can vary from perfect horizontal equality 0 (when $L = K$ and fare expenses per capita are equal for all citizens) to extreme inequality, 1 (when $L = 0$ and there is theoretically only one person bearing all expenses). We calculate the Gini-coefficients for all three examined fare-schemes to investigate the second research question, i.e. whether burdens of fare expenses are unequally distributed among county citizens on the basis of residence.

3.2.3. Vertical equity, fairness between groups – Suits coefficient

Vertical equity, or fairness between groups, is based on the reasoning that some groups might be more deserving, or more in need, of support than other groups. In the tax code, this is often achieved by taxes proportional to income (levying larger shares of tax revenues from those with higher income). In public transport policy discussions, a common, vertical equity informed argument, is that public transport fares should be set to help low-income travelers. To measure vertical equity in this study, the Suits index is applied (Suits, 1977). The Suits-coefficient is calculated similarly to the Gini-coefficient (see section 3.2.2) albeit with one exception: when drawing the Lorenz-curve for Suits, the population on the x-axis is ordered by increasing income rather than by per capita expenses (Fig. 3).

When the population is ordered by income and not by the accumulated metric on the x-axis (total expenses paid), the Lorenz-curve can be on either side of the diagonal. The calculation of the Suits-coefficient is equivalent to that of the Gini-coefficient (equations (2)–(4)), but the Suits-coefficient can result with either positive (when the Lorenz-curve looks like C) or negative (Lorenz-curve as C') values. The interpretation of the Suits-coefficient is that zero indicates proportionality, all income-groups pay an equal share of public transport fares, -1 corresponds to an extreme policy where the individual with the lowest

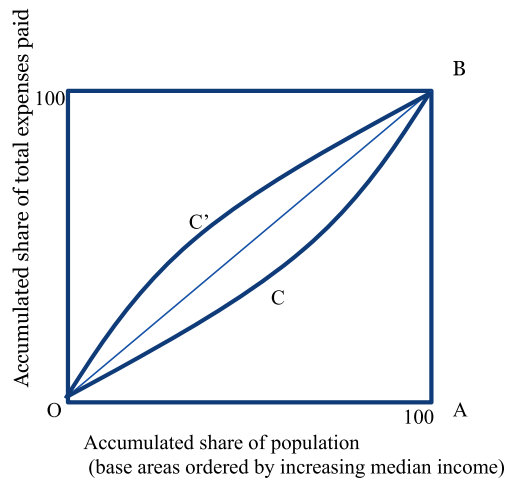


Fig. 3. Schematic illustration of the Lorenz-curve, but with the population ordered by income showing if high-income (C) or low-income (C') citizens pay a disproportional share of public transport expenses. In this case, the Lorenz-curve could be either over or under the diagonal.

income pays all fares and 1 implies extreme reverse unevenness where the wealthiest individual pays all fares. Hence, the Suits-coefficient gives a measure of to what extent a fare scheme is vertically equitable.

4. Results

In our introduction, we outlined different philosophical concepts on what constitutes fair fare schemes. The choice between these concepts is a normative choice but how well they are met by different fare schemes can be measured and evaluated. Further, in section 3.1 some common held beliefs from public debate in Stockholm have been described: (i) the most prevalent and important trip is between residence and CBD, (ii) high-income residents live more centrally, and; (iii) flat fares are advantageous for low-income and peripheral residents.

We hereby test three fare schemes both for their performance against the concepts of fairness and the notions prevalent in the public debate. Section 4.1 studies the nominal fare between residence and CBD as an approximation for fare change effects and the horizontal equity for public transport users of fare changes. In 4.2 the horizontal equity between citizens residing in different parts of the county is examined. Section 4.3 studies the vertical equity between high-income and low-income citizens of fare-changes and in section 4.4 we offer explanations for some of the results in the previous sections.

4.1. The weighted average fare paid by public transport users or nominal fare residence-CBD

The weighted average fare (WAF) of the zone fare scheme is reported in Fig. 4. It is evident that this fare-scheme results in higher WAF for those residents living in the outskirts of the county and lower WAF for those who are living in the central parts. In fact, the average fare paid by users of public transport seems to correspond well to the division into

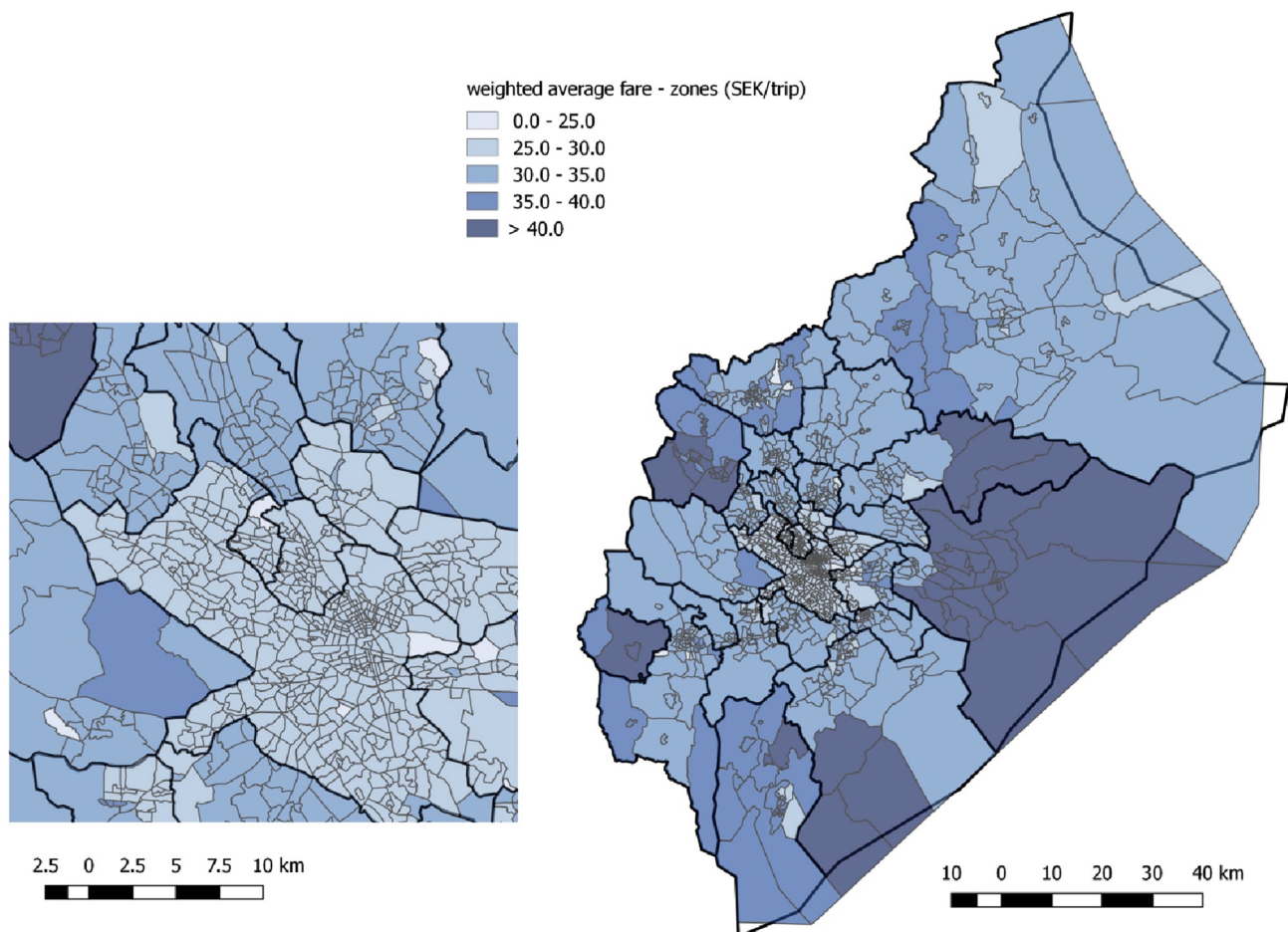


Fig. 4. Weighted average fare paid by residents in the 1300 base areas of the county when the zone fare scheme is applied. Lowest fares in central areas and the more out of the center the inhabitants live the higher the fare is.

fare zones (Fig. 1). Lower average fares for zone A than for zone B and mostly lower fares for zone B than for zone C. There are fluctuations, especially in zone C. This trend arguably stems from the rather varied land-use profile of Stockholm county, outside the city of Stockholm. Small cities, suburban areas, semi-rural and rural areas are spread over the county. Living in a dense pocket, such as a city, with many amenities close-by will lead to a lower WAF, whereas living in a rural part of the county will lead to a higher WAF.

The zone fare scheme offers a proxy of usage-based, with longer trips resulting in higher fares. This link to usage, in theory, can potentially improve efficiency by reflecting the production cost difference between long and short trips in user paid fares. But from the WAF it is evident that the horizontal equity among users of public transport could be improved. With zone fares public transport users have different average fares depending on their place of residence.

In January 2017, Stockholm changed the fare-scheme into flat fares for the entire public transport system. With a flat fare of 30 SEK (between the fares previously charged for single-zone and two-zone trips), central areas manifest an increase in the WAF while almost all other base areas see a decrease. Fig. 5 shows the difference in average fare paid (delta WAF).

With flat fares, the fares are much less usage-based than with zone fares. At the same time, the horizontal equity among public transport users has vastly improved. The weighted average fare is the same for all zones (since all fares are the same).

As an alternative aiming at a better linkage between usage and fares paid, we introduce a distance-based fare scheme (similarly to the one deployed in the Netherlands based on a tap-in and tap-out ticket

validation scheme). Each trip is paid for in proportion to the distance traveled. The distance fare is set to 2.35 SEK per km to ensure that the total revenue remains unchanged. The WAF changes then, compared to WAF for zone fares, with increasing average fares everywhere except in the most central parts of Stockholm County (Fig. 6).

Comparing the three fare schemes, the average fares paid differs most with distance-based fares (with some zones having WAF surpassing 100 SEK) and least with flat fares (WAF is equal everywhere). The distance-based fares represent a robust usage-based incitement for shorter trips at the cost of a lower horizontal equity of fares between public transport users.

4.2. Horizontal equity – the degree to which paid fares/capita are equal irrespective of place of residence

Fig. 7 presents the Lorenz-curves and the Gini-coefficients for the three fare schemes analyzed in this study. Distance-based fares have the lowest Gini-coefficient (0.04) indicating that this fare-scheme yields the most evenly distributed fare expenses per capita over base areas. Flat fares have the most uneven distribution of fare expenses per capita (Gini-coefficient of 0.1). Zone fares are more uneven than distance fares but less uneven than flat fares with a Gini-coefficient of 0.07. With flat fare, all public transport users pay the same fare per trip; however, this means that those groups that travel more frequently pay a larger share of total fares, making flat fares horizontally not equitable. With distance dependence, the frequency of trips is counteracted by the length of trips: those who travel long trips pay higher fares, and those who travel many trips pay more often. Residents of central areas make many shorter trips

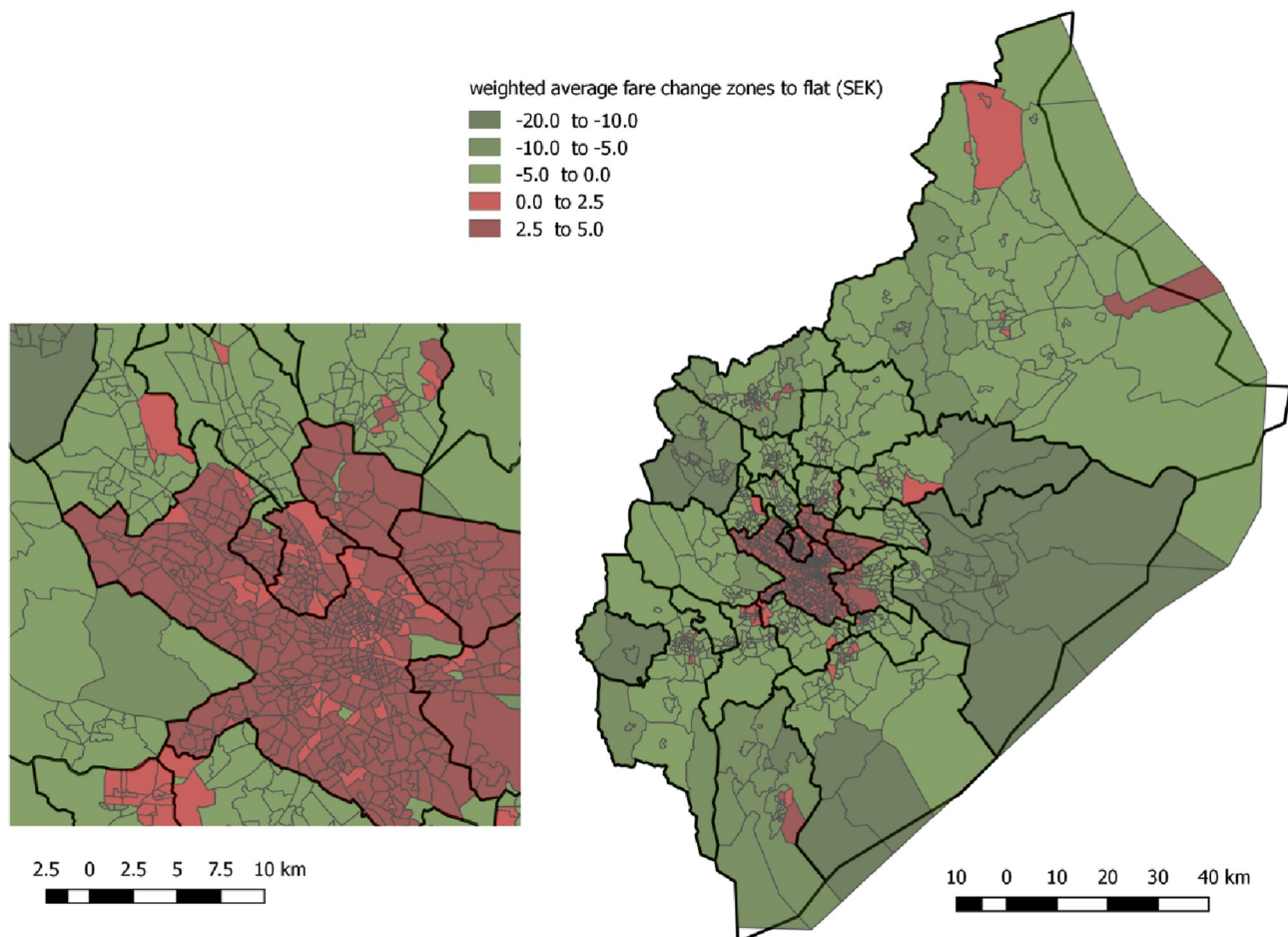


Fig. 5. Difference in weighted average fare when the fare system is changed from zone fares to flat fare. Green colors correspond to a decrease in the average fare paid and red to an increase. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

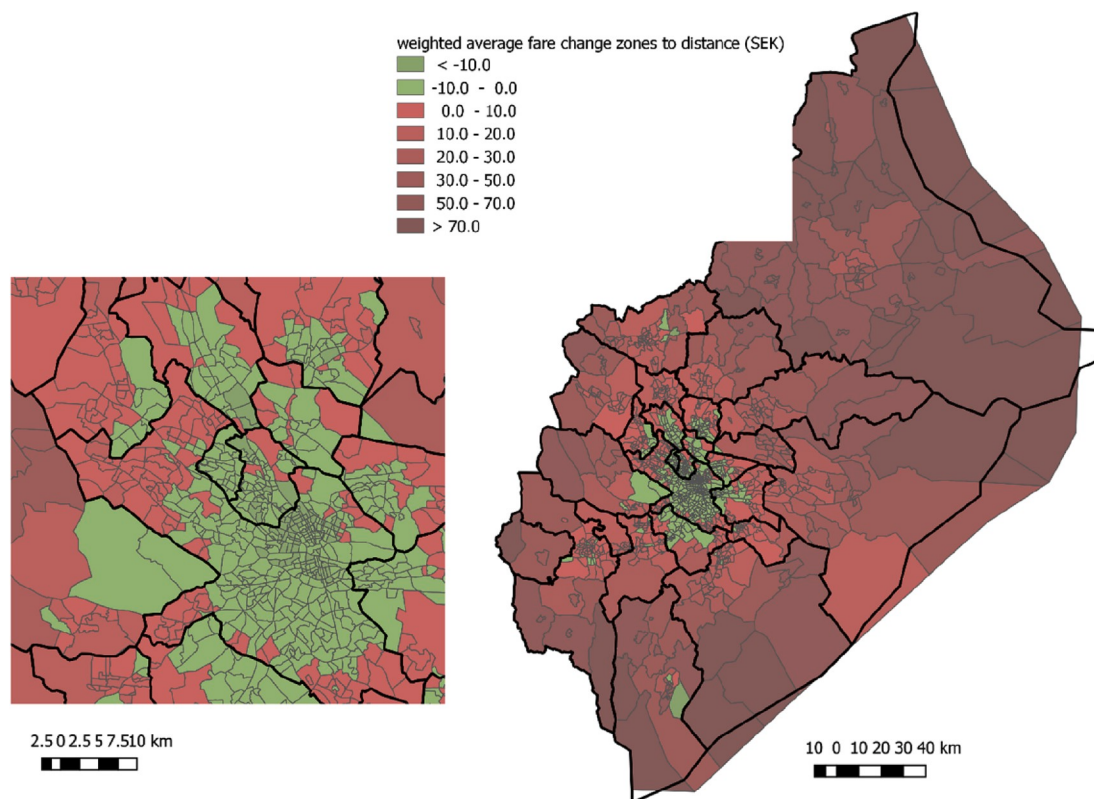


Fig. 6. Difference in weighted average fare when the fare system is changed from zone fares to distance fares (2.35 SEK/km). Green colors imply decreased average fare paid and red increased. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

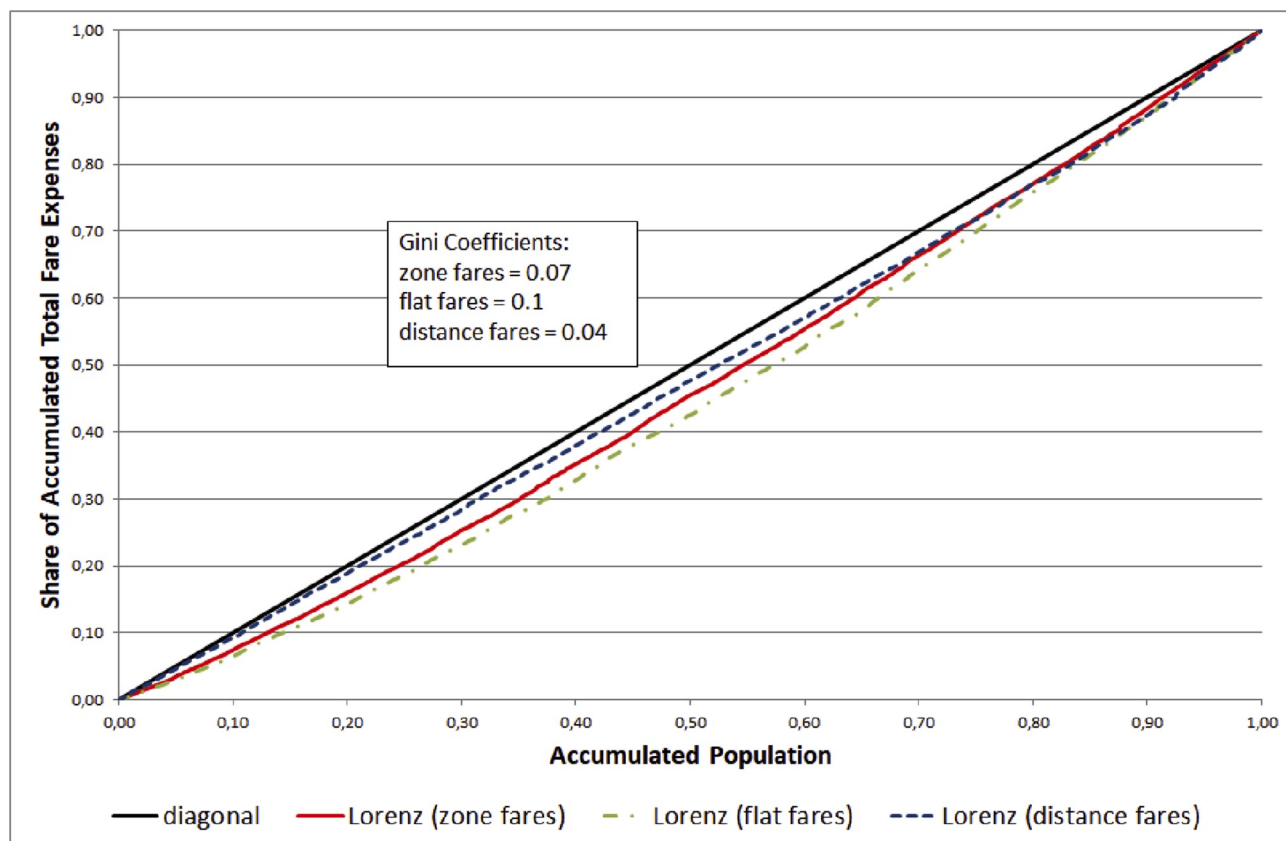


Fig. 7. The Lorenz curves and their corresponding Gini-coefficients for the total amount of fares paid for public transport rides.

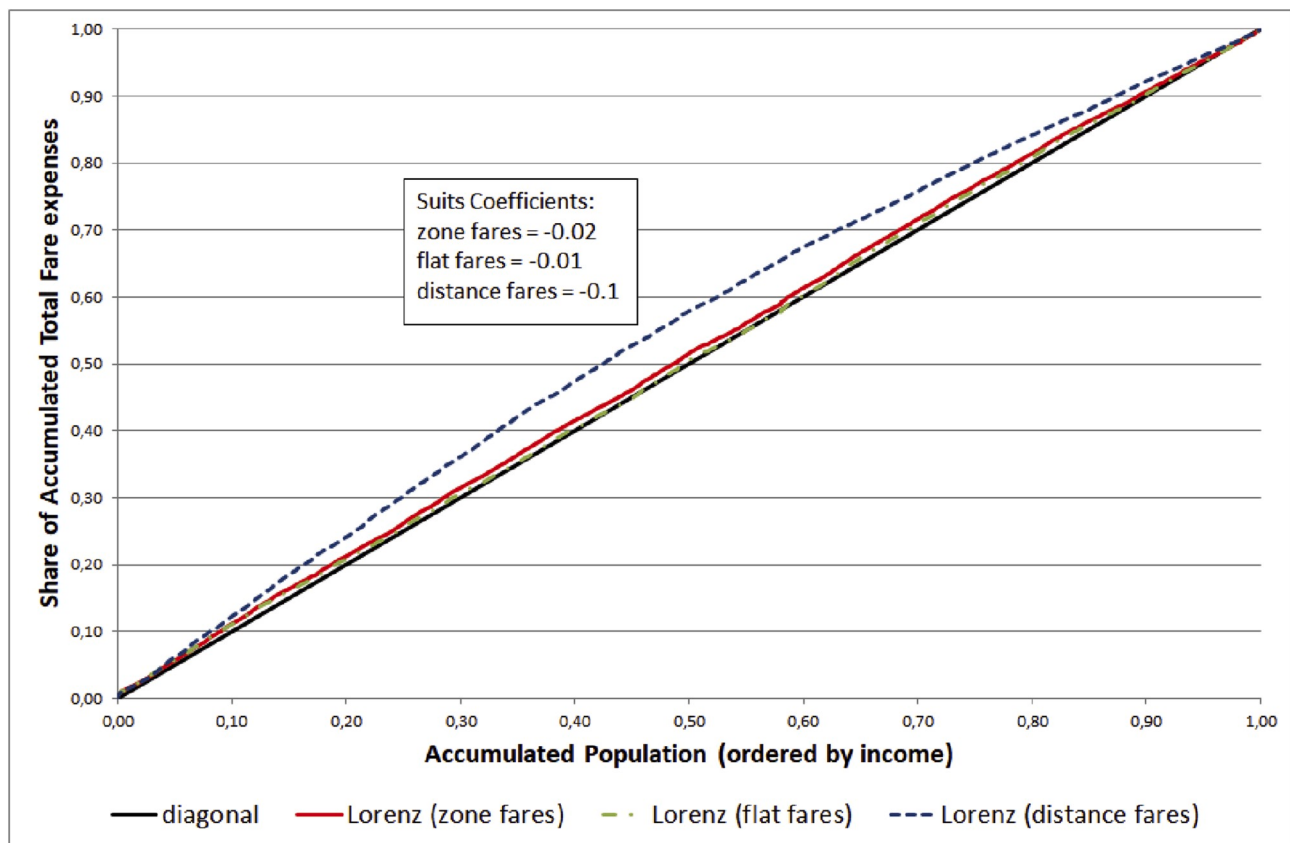


Fig. 8. The Lorenz curves and their corresponding Suits-coefficients for the total amount of fares paid for public transport rides.

while peripherally placed residents perform few but long trips. The overall effect is therefore not trivial since the outcome depends on the magnitude of these two counteracting impacts. In the case of Stockholm we find that the overall horizontal equity improves with more distance dependent fares.

4.3. Vertical equity – the degree to which fare expenditure/capita redistributes income from high-income to low-income groups

Fig. 8 shows the Lorenz-curves and the Suits-coefficients for the three fare schemes under consideration. The Suits-coefficients indicates that flat fares (Suits of -0.01) and zone fares (-0.02) achieve similar levels of vertical equity with almost no redistribution from poor to rich or vice versa. Conversely, Distance-based fares exhibit a distinctive pattern with travelers from low-income base areas paying more per capita than travelers from more affluent areas under this scheme (Suits of -0.1). These results are vertical equity assessments of fares paid assuming that money has the same value for all groups. If fares paid would be expressed as their percentage of travelers' income then the vertical equity would be worse off for all tested fare schemes, since fares as a percentage of income would be much higher for low-income travelers than for high-income travelers.

4.4. Why are distance fares so drastically inferior, compared with zone fares, for low-income residents?

Usage-based fares are believed to contribute to an effective system and pertain to a consumption-related notion of fairness. The most usage-based fare is the distance fare scheme followed by the zone fare scheme, and the least usage-based fare scheme is the flat fare. Interestingly, this sequence is repeated when assessing horizontal equity, with Gini-coefficients ordered by increasing horizontal equity: 0.04 (distance

fares), 0.07 (zone fares) and 0.1 (flat fares). Distance fares are both the most usage-based scheme and the most horizontally equitable, i.e., with the most evenly distributed fares per capita paid. However, turning to vertical equity, all fare schemes have travelers from low-income areas paying larger shares of fares than higher income travelers. In the case of distance fares, though, the vertical equity (Suits -0.1) is considerably worse compared to the other two schemes (Suits -0.01 and 0.02 respectively). Interestingly, zone fares are performing closer to how flat fares perform, rather than how distance fares perform. To explain the difference in outcomes between zone and distance fares we need to examine the distributions of trip length in kilometers as well as in terms of the number of zones traversed. Fig. 9 shows public transport demand segmented by median income and distance intervals: the average trip length (blue colors) and the average number of zones traversed (green colors). From the figure, it is evident that peak demand for trips shorter than 10 km stems from residents in base areas with a median income of 300–350 thousand SEK/year whereas peak demand for trips of 10–20 km are related to areas with median incomes of 100–250 thousand SEK/year. Hence, it can be concluded that public transport users from areas with lower median income travel in general longer distance with public transport in Stockholm. In the distance fare scheme, this translates directly to considerably higher fare costs. In the zone fare scheme, by contrast, differences are less pronounced. While differences in distance are still evident with zone-based fares, (compare the relative height of 1-1,5 and 1,5-2 staples for different income brackets), it does not translate into equally grave cost differences.

5. Transferability of results

The distribution of income level of residents and residential density are together with travel patterns the main determinants of the equity effects associated with fare policies. In the predominantly American

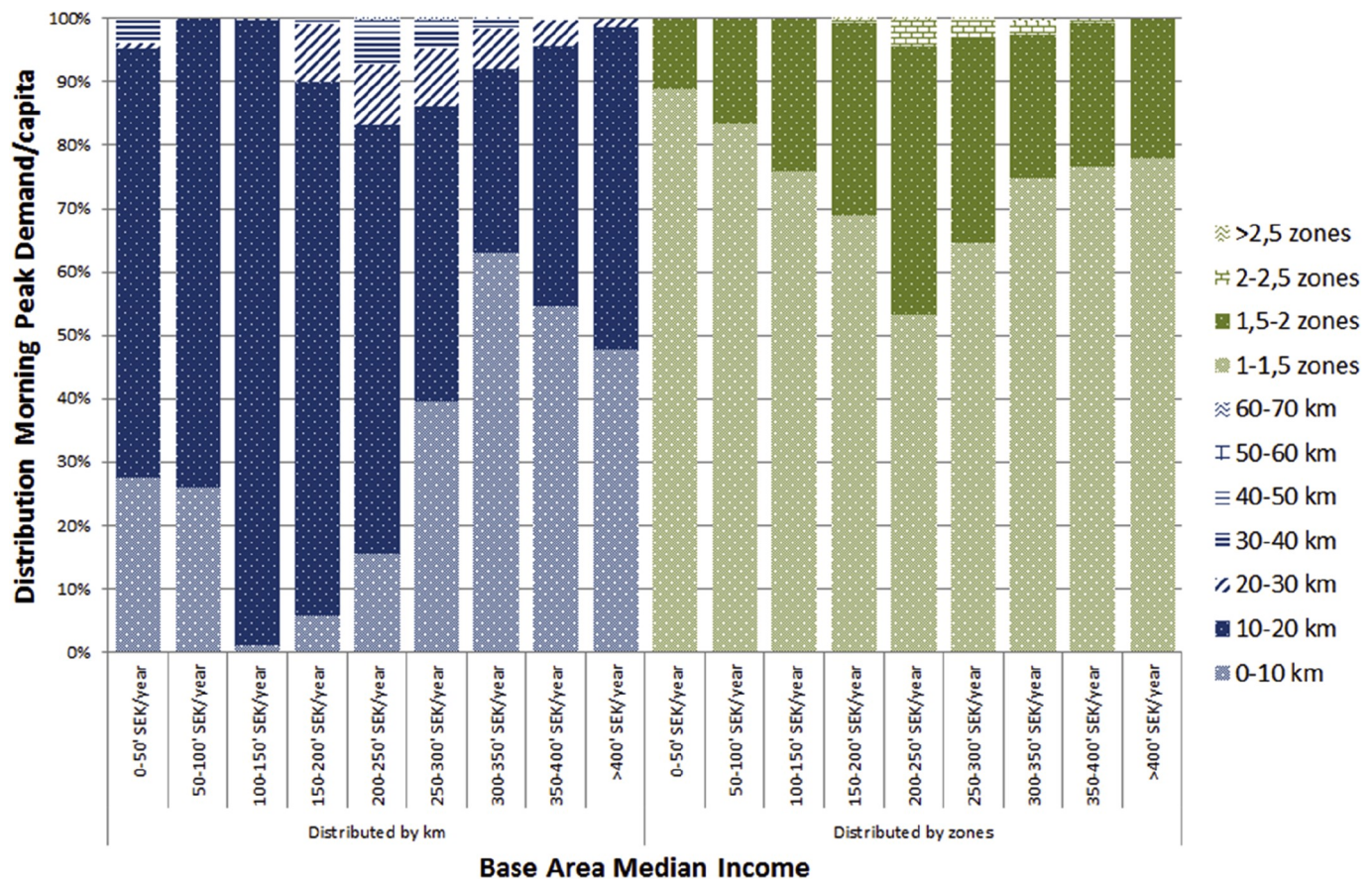


Fig. 9. The distribution of morning peak demand per capita of public transport segmented by average distance (km) and average number of zones traversed, and median income of the base area of the travelers' residence.

literature, increased distance dependence has been found to be vertically equitable, decreasing the amount paid by low income users. This has often been described as an effect of low income passengers traveling frequently but for short distances. (e.g. Tawfik (2014) writes: "[...] a large body of research has shown that most long-distance and peak time travel is taken by higher income individuals. So in reality distance-based and time-of-day pricing may shift the burden of higher cost trips from low income to high income people.") However, in our study we find, for Stockholm, that increasing distances dependence in fares leads to decreasing vertical equity. Furthermore, as we have seen in Fig. 9, low income passengers in Stockholm travel on average longer than high income travelers do. Table 2 schematically summarizes the functional directions of increasing distance dependence, usage fairness, horizontal and vertical equity.

To gauge the conditions for transferability of these findings, we

Table 2
Direction of increasing distance dependence and three concepts of fairness with different fare schemes.

Fare-policy	Increasing distance dependence	Increasing Usage Fairness	Increasing Horizontal Equity	Increasing Vertical equity
Flat Fares	↓	↓	↓	↑
Zone Fares	↓	↓	↓	↑
Distance fares	↓	↓	↓	↑

devise Fig. 10 as a way to describe fare policies in combination with spatially-related social and urban circumstances. On the x-axis we have distance to the most central point in the CBD (the central interchange hub in Stockholm). To highlight the county's metropolitan core and the municipal boundaries of Stockholm and its direct suburbs we plot a logarithmic scale (with 1, 10 and 100 km from the CBD marked). The black dotted line is the share of high income residents (left axis) living inside the radius defined by the distance from the CBD. The colored lines are the fare expenditures per capita for residents living at different distances from the CBD (right axis) for each of the fare schemes under consideration. Note that the fares per capita are in relation to how far their origins is from the CBD, but those are computed over all travel relations in the demand matrix from Sampers.

From this presentation we make the following observations. First, from the shape of the flat fare expenditure per capita (b. in Fig. 10) we can deduce that, in general, the closer to the CBD one lives the more trips per capita are performed (since all trips have the same fare in b.). Second, in Stockholm, as we stated above, high income residents live centrally (a.). Third, all fare expenditure per capita curves manifest considerable fluctuations, especially further away from the CBD. These fluctuations are due to the varying landscape of Stockholm County with sprawling suburban areas, local smaller cities and rural or semi-rural parts. Expenditures per capita with distance dependent fares (c. and d.) increases in areas with, relative to its distance from CBD, unusually long average distances traveled or unusually many trips per capita made. The expenditures decreases in areas with, relative to its distance from CBD, unusually short average distances traveled or unusually few public transport trips per capita made. For the flat fare, increases and decreases in expenditures per capita indicate differing number of trips per capita. Fourth, a horizontal equitable fare scheme should have, on

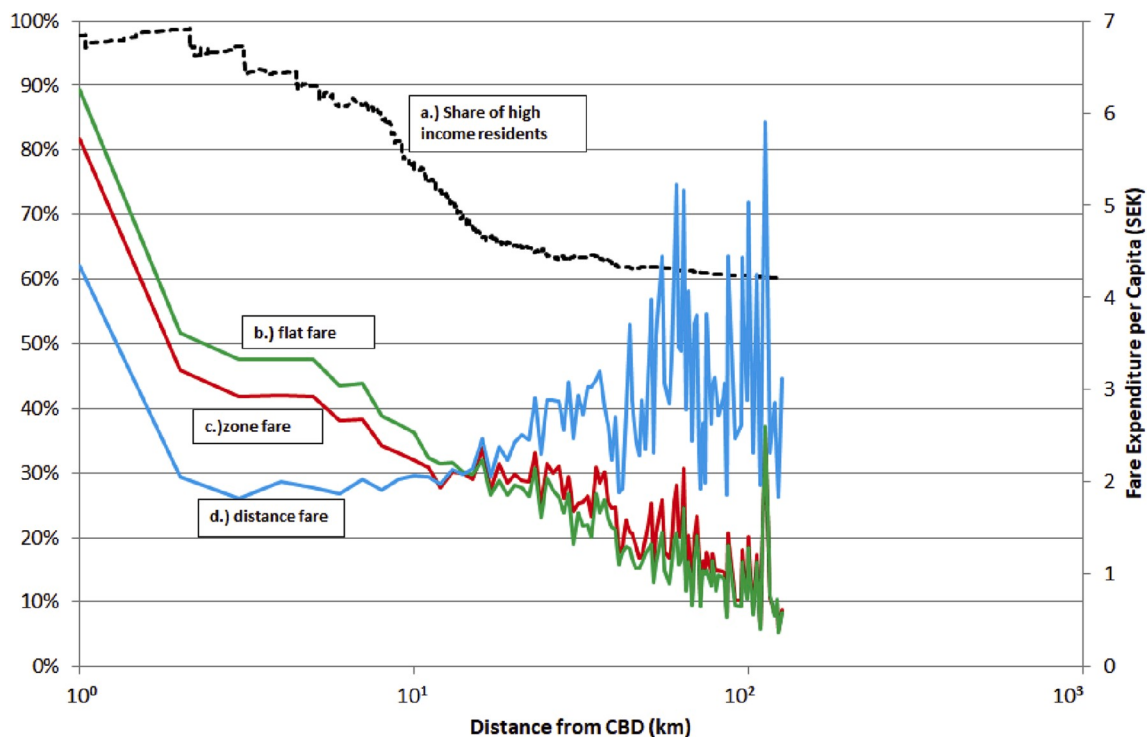


Fig. 10. Illustration of distribution of high-income residents and the per-capita total fare-expenditures paid under the three evaluated fare-scheme. The share of high-income residents inside a radius from the city center (a. primary vertical axis), Total fare per capita paid as a function of distance from CBD (b. c. and d. secondary vertical axis).

average, equal fare expenditure per capita irrespective of distance from the CBD. The fare policy closest to horizontal equity is, as found in terms of the Gini-coefficients, the distance fare scheme (see section 4.2). In Fig. 10 this is also evident from fare expenditures for distance fares (d.) having similar levels both close to the CBD and far out in the county. This is different from the flat fare and zone fare which show a clear decreasing trend in fare expenditure per capita with distance from CBD. Fifth, with these boundaries for zones, zone fares per capita are lower than flat fares per capita close to the CBD but are more similar in peripheral parts of the county. Sixth, at a glance it is possible to decide that flat fares are more vertically equitable than zone fares and distance fares by seeing that where incomes are higher (centrally) fare expenditure per capita is the highest and where incomes are lower (>10 km from the CBD) fare expenses per capita with flat fares are the lowest.

6. Conclusions

This paper analyses the horizontal- and vertical equity of three fare schemes with increasing distance dependence, namely (i) flat fares, (ii) zone fares and (iii) kilometer fares. The literature indicates that more distance dependence in the fare-scheme will yield better vertical equity while public debate in Stockholm since long is based on the consensus belief that less distance dependence would increase both vertical and horizontal equity while deteriorating usage fairness. This study resolves this apparent contradiction and examines the conditions under which equity results are transferrable. We hereby provide the three main conclusions of our study.

First, with decreasing distance dependence in fares, vertical equity increases. This increase is due to high-income groups on average performing shorter trips and therefore paying more than low-income groups in less distance dependent schemes. Still, all fare schemes result with travelers with low income paying a higher part of total fares than their share of the population and it would be even more so if fares as shares of disposable income were used as a metric rather than fares in absolute terms.

Second, interestingly, an increasing distance-dependent fare scheme is associated with increasing horizontal equity. The underlying mechanism being that central areas have higher trip frequencies but short trips in comparison to peripheral areas where residents make fewer but longer trips. With fares determined based on distance, the more frequent payment of fares paid by short-trip travelers is balanced by the higher fares per trip paid by the long-trip travelers.

Third, seemingly the nominal fares between residence and CBD do largely resemble actual average fares paid. Notwithstanding, there are variations due to the real-world deviations from an idealized perfectly monocentric city model. From an empirical analysis of Stockholm urban structure based on public transport ridership patterns, Cats et al. (2015) concluded that even though regional planning policies aimed at transforming the metropolitan area into a multi-centric structure, this has not yet been realized. Nevertheless, they identify initial indications of a growing core cluster and sub-centers while the central business district still greatly dominates travel patterns. From a policy perspective, the variation in fare expenditure per capita can be seen as an indicator of areas in need of increased scrutiny to avoid singularly disadvantaged ‘valleys of inaccessibility’ or great unearned advantages for relatively small groups of passengers. Steps to remedy such anomalies can potentially help in gaining acceptance for fare scheme changes.

This study uses model data for travel patterns and base area statistics for land use and income distributions, there are obviously limitations associated with this type of data. An alternative data source could have been a travel survey with socio-economic data at the individual or household level. Travel surveys covering large areas with high resolution are only seldom performed due to their costs. Model data and area statistics have the advantage of being all encompassing, including the whole population and all trips.

In public economic literature many studies show that it is more efficient to address income inequality with more direct subsidies or tax relief rather than setting prices. We refrain from concluding on the fairness of the complete set of distributional outcomes that residents face: house prices differ in different locations, tax brackets differ for

residents with different incomes, level of subsidies differ between one trip and the other.

But, despite fare schemes not being the most efficient method of addressing inequity, and despite fare schemes alone not capturing the complete description of residents outcomes, fare scheme changes do have distributional effects. And our conviction is that these effects need to be assessed and evaluated (this is also often required by law, as in the differential impact analysis decreed in the American Federal law (Farber et al., 2014)). Moreover, we assert that distributional effects have and should have an impact on policy planning and political debate.

We have noted in the outset of this paper that there are several perspectives on what constitutes a fair fare scheme. Should it be usage-based where passengers pay in proportion to their consumption? Should the distribution of cost be evenly distributed among all citizens (horizontal equity)? Or should there be a system where passengers with a lower income pay less than high-income passengers? These are normative questions, the answers for which are subject to public debate.

Notwithstanding, all of these perspectives can be objectively grounded. Is this fare scheme really crafted so that passengers pay fares according to the prescribed logic of usage fairness, horizontal equity or vertical equity? It is precisely this question for which our framework can be of assistance. To exemplify, in a public debate where proponents for distance-dependent fares argue against proponents for flat fares and the former states usage fairness and the latter state vertical equity as their motivations, it is clearly beneficial to examine if, in fact, flat fares result in a distribution that is less vertically equitable than distance dependent fares. Then the difference, in stated opinions at least, between the proponents should be resolved.

Finally, this study shows that city structure and land use do influence if vertical equity is improved by more or less price differentiation. Further, it presents a framework by which obtained results can be interpreted to have a rather high degree of generality. Cities with similar structures, i.e., with a similar distribution of residents by income and travel length, will exhibit similarities also in the distributional outcomes.

Declaration of competing interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

CRedit authorship contribution statement

Isak Rubensson: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing - original draft. **Yusak Susilo:** Conceptualization, Formal analysis, Supervision, Writing - review & editing. **Oded Cats:** Conceptualization, Formal analysis, Supervision, Writing - review & editing.

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