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Evaluating the effects of fare characteristics on fare equity: A scoping review

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ABSTRACT

While public-transit fares can represent barriers to some people to use public-transit systems, they remain a major source of funding for operating it. Given the ubiquitous nature of fares in public-transit systems worldwide, understanding how characteristics of fare structures affect the distribution of fare burden (i.e., fare equity) is crucial. To do so we conducted a scoping review of the current literature on public-transit fare equity. We defined fare equity in the form of vertical equity (based on the ability-to-pay principle) and market equity (based on the beneficiary-pay principle). We then screened through 511 unique studies, retaining 24 for analysis. Findings were grouped based on fare attributes (e.g., distance-, time-, service- and user-based fare modulations), fare type and fare integration before combining results in a conceptual model. Distance-, time- and service-based fares were shown to have a positive effect on market equity while only income-based fares always positively impacted vertical equity. User-based fares have shown clear negative effects on market fare equity. The effects of most fare characteristics on fare equity were either not well researched or dependent on local contexts. Lastly, a lack of assessment of the synergies between fare characteristics in their effect on fare equity was also observed. Potential opposite effects of fare characteristics on vertical and market fare equity points to the necessity for public-transit agencies to choose which form of fare equity to promote. Recommendations for practitioners and researchers based on our findings are provided to guide the field of fare equity forward.

1. Background

Public-transit services have seen tremendous change since the COVID-19 pandemic, which has highlighted not only their essential nature within society but also the fragility of the funding structure they depend on. The public-transit market has shifted even more towards lower-income users following the pandemic (Carvalho and El-Geneidy, 2024; Fernández Pozo et al., 2022; Palm et al., 2024; Parker et al., 2021; Paul and Taylor, 2024; Soria et al., 2023). The decline in ridership led to an increase in cost per rider, particularly in higher income areas, which was accompanied by higher inflation in service delivery expenses (Rodrigue et al., 2025). This combination of changes in the transit market and increased cost of delivering service highlights the necessity to bring back the debates regarding equity of public transit fares to the forefront of policy decisions.

The equity of fares can be assessed internally (i.e., equity of fare characteristics) or externally to fare structures (i.e., the equity of having fares versus not having them). While the latter tends to gather a lot of attention in academic and public discourse, the implementability and desirability of fare-free systems remains a hotly debated topic (Kębłowski, 2020). The lingering post-COVID financial difficulties experienced by numerous public-transit agencies (Freemark and Rennert, 2023; Shibayama and Suzuki, 2024) represents a major challenge to agencies discussing fare-free systems. The fare value is decided in a region based on the societal goals while considering the actual costs of operations and debt reimbursement for capital investments. For neoliberal societies, Farebox Recovery Ratio (FRR), the percentage of costs recovered by fares, is much higher compared to more socialists' societies where non-users pay a greater share of transit cost. Nevertheless, in most regions around the world the FRR is below 100 %. While it

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remains relevant to consider the equity of having fares or not, assessing the equity within fare structures is more likely to influence policy changes in the short- and medium-term. As such, in this review we chose to focus on equity considerations within fare structures. Our primary objective was to highlight what are the impacts of different fare characteristics on fare equity. To do so, we conducted a scoping review of the literature on fare equity. We first defined the concept of fare equity according to transport and public finance equity theories. We then conducted a literature search to extract relevant studies and summarize current findings related to the effect of fare characteristics on fare equity. In doing so we highlighted key missing pieces in fare equity research necessary to orient sustainable public-transit policies. Findings from this study will be of value for public-transit agencies who are grappling with the difficult task of furthering equity while aiming to balancing strained budgets.

2. Theoretical framework

Current conceptualizations of transport equity have been informed by a wide range of theories of justice with many sharing roots in egalitarian and sufficientarian principles (Karner et al., 2024; Pereira et al., 2017). Gender, racial or environmental justice perspectives can also help identify systemic inequities caused by historic transport planning patterns, thus informing transformative societal changes. However, their limited connection to public finance and pricing means that they cannot directly inform equity-based transport pricing or funding policies (e.g., pricing or taxing cannot equitably be differentiated directly based on gender or race). Rather, concepts of transport pricing, financing, and funding equity have been primarily centered around two key principles of public finance, the ability-to-pay and beneficiary-pay principles (Litman, 2014; Lowe and Hall, 2019; Mathur, 2015; Zhao et al., 2012), which form the focus of our theoretical approach for this review.

2.1. Vertical fare equity and the ability to pay principle

The ability-to-pay principle, which draws on sufficientarianism, represents the theoretical root of vertical equity in transport research (Karner et al., 2024). According to this principle, individuals with lower capacity to pay – which may be assessed in terms of income or wealth – are expected to pay less than those with a higher ability to pay for a given service, all else being equal. This principle directly acknowledges the unequal distribution of resources and unequal ability to capitalize on said resources within populations, proposing a solution to rectify social inequities by shifting the burden of public services to those who have a larger share of resources than would be expected under perfect equality.

There are multiple ways in which vertical equity can be measured, although the most common ones in the context of pricing would be either (1) in absolute amounts or (2) in relation to income (Bureau and Glachant, 2008; Eliasson, 2016). Both approaches hold theoretical validity in the context of public-transit pricing. Comparing vertical equity based on absolute amount ensures that lower-income individuals at the very least do not pay more than higher income individuals, which Cervero (1981b) identifies as the minimum goal of vertical fare equity. This method is more easily applicable given data precision limitations. On the other hand, assessing fare costs relative to income provide a better representation of the financial strain that fares represent to a household or an individual. For instance, \$100 being paid by someone making \$25, 000 a year will have a greater impact on their financial wellbeing than \$100 being paid by someone making \$100,000 a year. As such, striving for fares proportional to income would represent the highest level of vertical fare equity (Cervero, 1981b).

2.2. Market fare equity and the beneficiary- pay principle

The beneficiary-pay principle, which is centered around the notion of fairness and draws on egalitarian principles, dictates that individuals or jurisdictions that benefit from a specific policy or service should proportionally compensate for the cost or harm of said policy or service. It represents the theoretical root of horizontal equity assessment adapted to public finance and pricing applications. In the context of pricing, the beneficiary-pay principle entails that individuals ought to pay proportionally to the cost of the service they use. The beneficiary-pay principle was first operationalized as cost efficiency by Cervero (1981b, 1982). He adopted in his studies an individual FRR (the total fare expenses divided by the total individualized cost of service used) to assess the "cost efficiency" of public-transit fares, although he recognized that calculating the "*true marginal cost of individual transit trips*" is "*an exceedingly difficult task*" (Cervero, 1981a, p. 799). Indeed, such approaches require multiple detailed data sources (e.g., operation, cost, ridership by route, stop and different time of day) which are combined according to a set of assumptions to estimate cost-distribution between service segments and then between individuals. As such, individualized FRR can be both very complex to calculate but also have the potential to introduce bias if assumptions are not carefully evaluated.

As a result of these practical limitations, subsequent studies have adopted a modified version of the "cost efficiency" concept, separating it into the (1) the benefit criterion, according to which public-transit users should pay based on the benefit provided by the service they use (e.g., differences in terms of quality and speed of service); and (2) the cost criterion, according to which public-transit users should pay based on the cost of the service they use (e.g., differences in terms of distance travelled and time of day) (Brown, 2018; Nuworsoo et al., 2009). While practical applications will often differ from theoretical ideals, the dissociation of costs and benefits within horizontal equity assessments of fare equity directly transgress the beneficiary-pay principles. Another limitation of the cost efficiency concept and its subsequent adaptations is that they are limited only to pricing applications by virtue of only considering user benefits and not benefits due to public good provision, thus restricting the development of a broader interconnected transport funding and pricing theoretical framework.

A more recent theoretical conceptualization of transport finance and pricing equity by Taylor and Tassiello Norton (2009) proposed three equity concepts: opportunity equity, outcome equity and market equity. Opportunity equity in the context of public-transit pricing entails that everyone would pay the same to have access to the transit system notwithstanding their level of usage (from none to frequent), thus directly violating the beneficiary-pay principle. Outcome equity is similarly flawed in its application to fares as it would entail charging based on willingness to pay to equalize travel behaviour outcomes. Such an approach directly ignores transit usage's dependency on access to alternatives mode of transport and flexibility in travel habits, which varies greatly based on income. This was observed clearly with the recent shift in the transit market towards lower-income individuals in the aftermath of the COVID-19 pandemic (Carvalho and El-Geneidy, 2024; Fernández Pozo et al., 2022; Palm et al., 2024; Parker et al., 2021; Paul and Taylor, 2024; Soria et al., 2023). While the two previous equity concepts present major limitations in their application to transport funding and pricing, market equity directly operationalizes the beneficiary-pay principle by expanding on Cervero's cost efficiency concept through the widening of the term beneficiary to include users and non-users. Indeed, market equity in transport theory posits that individuals ought to pay for a service proportionally to the benefits they get from it, including both user and non-user (or public good) benefits. This theoretical conceptualization makes market equity suitable both for transport pricing and funding assessments, which is crucial given their interrelated nature.

3. Methods

This study employs a scoping review approach to thematically analyze the literature on the effects of the pathways between fare attributes and fare equity. To gather relevant articles to consider, a search of three databases (Scopus, Web of Science and TRID) was conducted on November 13th, 2023 using the search terms in Table 1. For Scopus, the search was performed for Abstract, title and keywords, while all fields were considered for Web of Science. For TRID, results were filtered to keep only records with abstracts as well as only articles and papers to remove inadequate result types (e.g., databases, projects, reports).

The screening process (Fig. 1) was conducted using Rayyan, an open-source systematic literature review software (Ouzzani et al., 2016). For the first title and abstract screening, only peer-reviewed publications focused on local public-transit fares were kept (n = 63). Papers on high-speed rail were removed given the significant difference in type of service (local vs long-distance / travel) and pricing (i.e., high speed rail is priced at a significantly higher level than local public transit) which are likely to affect equity dynamics. From the 58 records with available full texts, 34 were removed following full-text review: 23 were removed for not having fare cost as the main variable of interest; nine were removed for not measuring equity in fare cost distribution; and two were removed for presenting data covered in another included publication by the same author(s). The final sample for this review consisted of 24 quantitative empirical papers (Table 2).

4. Results

The selected studies assessing the equity of fare structures are mostly recent, with 13 of them having been published since 2018. Most studies were conducted either in North America (n = 8) or in Europe (n = 8), denoting a bias towards global north contexts. The majority of studies (n = 17) focused on individual level analyses which allow more accurate assessments of fare equity. Regarding the approach to fare equity, fifteen studies considered only vertical equity, four studies considered only market equity and five considered both. Lastly, there was a high level of heterogeneity in terms of the measures used to evaluate fare burden, denoting a lack of consensus on how to operationalize fare equity. Only three studies used individual FRR, which is the measure most closely linked to market equity. Instead, the most common measures used to assess fare equity were absolute or relative changes in fare cost (n = 10), which do not account for the quantity or cost of service used.

4.1. Fare attributes

The section presents findings from the literature separated by fare attributes. We first present fare equity findings pertaining to distance-, time-, service type-, and user-based modulations of fares before commenting on the limited literature assessing the interactions between fare attributes and their impact on fare equity.

4.1.1. Distance dimension

Distance-based fares can take many forms, including zonal systems where fares are paid once moving from a geographic zone to another, stage-based fares where fares are paid by the distance based on pre-determined increments or granular distance-based fares where fares are paid proportionally to the distance travelled. These fare modulations aim at capturing the greater cost imposed on the public-transit network from longer trips. For instance, Cervero (1981b) observed that riders conducting trips shorter than a mile had much larger average individual FRR (1.37–2.22) than riders conducting trips between one and two miles in length (0.48–0.66) and even more so than those conducting trips above 20 miles in length (0.06–0.14). Similarly, Zhou et al. (2019) found similar patterns in Southeast Queensland, Australia, where the cost per kilometer for people travelling within just one zone was on average two times that of riders travelling in two or more zones. As such, distance-based fare modulations can be seen as theoretically rooted in the achievement of market fare equity by making users pay proportionally to the quantity of service they use.

Distance-based fares are more challenging when applied in practice. Riders are required to tap when entering and exiting the system (i.e., tap-in / tap-out system) to calculate the distance travelled and subsequently the fare to pay. Such fare systems have non-negligible operational implications, particularly for buses as each tap adds around 3 s to a bus trip (Diab and El-Geneidy, 2013). Considering a bus system that serves one million unlinked trips daily, this would translate to ~ 800 additional operating hours per day or ~ $160,000 extra operating costs per day (assuming ~ $200 per hour of bus operation). Consequently, applying such a policy would be easier for systems where passengers pay outside the vehicles (e.g., light-rail, heavy rail), although enforcement costs would still remain. Overall, distance was the most studied fare dimension, with 14 out of 24 studies assessing its equity impacts.

4.1.1.1. Market equity. In accordance with its theoretical justifications, distance-based fares have been empirically shown to promote greater market equity than flat fares (Bandegani and Akbarzadeh, 2016; Cervero, 1981b, 1982; Rubensson et al., 2020; Zhou et al., 2019). Cervero (1981b) highlighted that granular distance-based fares would lead to a reduction in inequities in individual FRR compared to the existing flat-fare system in Los Angeles, US. Similarly, Bandegani and Akbarzadeh (2016) found that a distance-based fare would lead to a lower Gini coefficient (0.17) compared to flat fares (0.38) if implemented in Isfahan, Iran. The type of distance-based fare was also shown to have an impact on this association. Cervero (1982) observed that granular distance-based fares led to a more even distribution of individual FRR (i.e., greater market equity) than stage-based ones. Rubensson et al. (2020) found similar results in Stockholm, Sweden, with granular distance-based fares yielding a Gini-Coefficient of 0.04 compared to a 0.07 value for a zonal system and 0.11 for a flat fare system. Given this equalizing effect, fare reductions in distance-based systems will tend to benefit more peripheral areas, as shown by Bureau and Glachant (2011) by modelling the effect of a 10 % fare reduction in Paris' zonal pricing structure. That said, Wang et al. (2021) did find that a fare change in Brisbane, Australia, including primarily a reduction in the number of zones (from 23 to 8), meaning a movement towards flatter fares, increased market equity for adults, older adults, and concession fare users but not for children as measured by the Gini coefficient. These results might be attributable to the metric used for calculation (cost per zone) which has not been used in other studies discussed and cannot therefore be compared to the rest of the scholarship.

4.1.1.2. Vertical equity. Results regarding the effects of distance-based fares on vertical equity are much more nuanced. Two studies (both conducted in the United-States) have shown that distance-based fares increased vertical equity on average compared to flat fares (Brown, 2018; Farber et al., 2014), while two studies showed that flat fares were more vertically equitable (Rubensson et al., 2020; Tiznado-Aitken et al., 2020). Brown (2018) observed that distance-based fare with a minimum and maximum fare led to a reduction in inequities in average fare per mile between low-income and high-income users compared to flat fares while totally granular distance-based fares led to a complete erasure of vertical inequities. Similarly, Farber et al. (2014) found that distance-based fares reduced the amount paid by the lowest income users by 28.1 % on average while increasing the fare paid by the highest income users by 20.1 % on average. Conversely, Rubensson et al. (2020) found that distance-based fares in Stockholm, Sweden, led to greater inequities between high-income and low-income areas (Suits coefficient

Table 1
Search terms used for database search.

Theme	Search Terms
Public transit	"public-transit" OR "public transit" OR "public transport" OR "public-transport"
Fare	fare* OR pric* OR tarif*
Equity	equit* OR inequit*

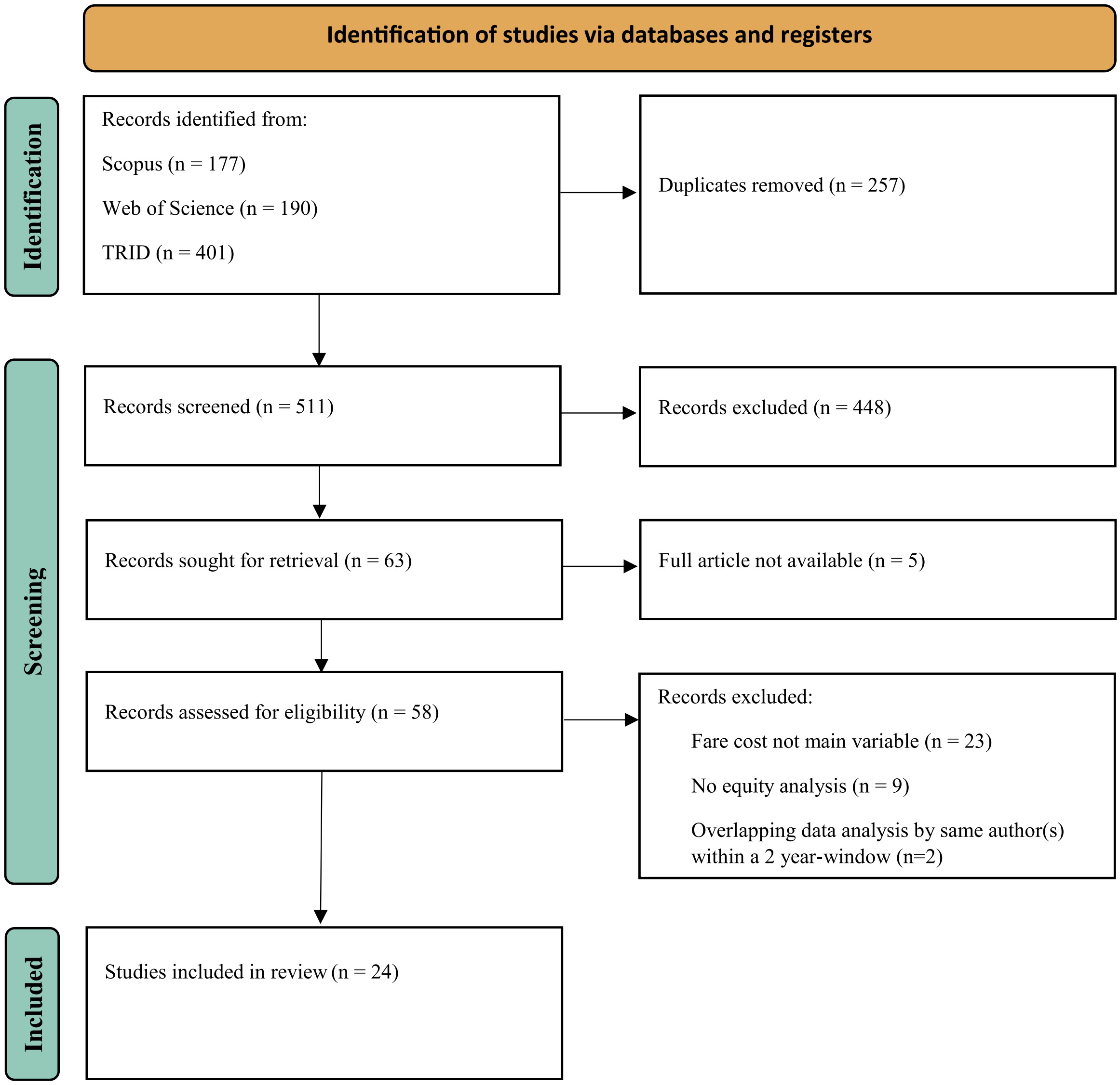

Fig. 1. PRISMA chart of the scoping review process.

of −0.1 for granular fares and −0.02 for zonal fares) compared to flat fares (-0.01). Tiznado-Aitken et al. (2020) found a similar pattern in Santiago, Chile, with lower-income majority neighborhoods being more likely to experience an increase in average fares under a granular distance-based system than other neighborhoods. In both cases, findings were attributed to differences in spatial distribution and travel distance between income groups. For instance, in Latin American context, low-income groups tend to reside more in the suburbs and travel longer distances to reach their destinations compared to higher income groups, representing a reversal of what is observed in most North American contexts.

Highlighting the contradictory findings on the vertical equity of distance-based fares are five additional studies that observed nuanced or inconclusive findings (Bureau and Glachant, 2011; Cervero, 1982; Lovely and Brand, 1982; Matas et al., 2020; Zhao et al., 2012). Zhao and Zhang (2019) found that changes from flat fares to distance-based fares in Beijing, China, did not lead to a reduction in the gap in affordability of public transit between low-income and high-income users even when controlling for total fare revenues. Matas et al. (2020) found that changing from zonal to flat fares at the metropolitan scale in Barcelona would lead to a mild progressive effect for non-commuting trips when the flat fare is fixed at the current rate of the first zone while they would have a regressive effect for commuting trips if the flat fare rate is set to the average fare paid. They also observed that granular distance-based fares would produce a mild progressive effect for commuting trips only compared to the existing zonal system. Bureau and Glachant (2011) found that a 10 % reduction in fares in Paris' zonal system would lead to reductions getting larger with income in the urban core and outer suburbs, while the opposite was observed in the inner suburbs (although the significance of these trends was not assessed). Cervero (1982) found that moving towards stage distance-based fares in Los Angeles would keep the small progressive effect of the existing flat fare system whereas graduated fares would equalize FRR between low and high income riders, reducing vertical equity. Encapsulating the high variability in the effects of distance-based fares on vertical equity is the Lovely and Brand (1982) study which observed that distance-based fares had the lowest target efficiency (i.e., percentage of investments going towards fare reductions for low-income users) and second lowest coverage (i.e., percentage of low-income users benefitting from the fare change) of the different fare options they studied for Atlanta, US. Such poor target efficiency and coverage for low-income riders exemplifies the lack of theoretical linkage between distance-based fares and vertical equity which makes them poorly suited to address vertical inequities.

Table 2
Selected empirical papers from the database search.

Study	Location	Sample	Scale	Fare dimension(s)	Equity type	Equity assessment
Arranz et al. (2022)	Madrid, Spain	722 households	Household	Targeted fares (older adults)	Vertical equity	Fare expenditure (absolute value) at the household level compared between income groups.
Bandegani and Akbarzadeh (2016)	Isfahan, Iran	301 public-transit riders	Individual	Flat and distance-based fares	Market equity	Gini Coefficient of FRR at the individual level.
Bondemark et al. (2021)	Sweden	5302 public-transit users	Individual	Fare type	Vertical equity	Comparison of monthly travel pass purchase between income groups.
Brown (2018)	Los Angeles, United-States	537 adults	Individual	Flat, distance-based, time-based, service-based and user-based fares	Vertical equity	Average fare per mile between low-income and high-income users.
Bueno Cadena et al. (2016)	Madrid, Spain	Not available	Neighborhood	User-based fares (youth and older adults)	Vertical equity	Comparison of travel pass usage and average cost per trip between neighborhood categorized by income.
Bureau and Glachant (2011)	Paris, France	10,500 households	Household	Distance-based fares (zonal)	Vertical & market equity	Comparison of household level change in fare amount between income quintiles and home location.
Cervero (1981)	Los Angeles, Oakland and San Diego, United-States	Not available	Individual	Flat, distance-based (stage and granular), time-dependent fares	Vertical & market equity	Differences in individual FRR between different types of trips and users' sociodemographic characteristics
Cervero (1982)	Los Angeles, United-States	Not available	Individual	Distance-based (stage and granular) and time of day (peak / off-peak) fares	Vertical & market equity	Differences in individual FRR between different types of trips and users' sociodemographic characteristics
Farber et al. (2014)	Wasatch region, United-States	16071 individuals	Individual	Flat and distance-based fares	Vertical equity	Fare paid comparison between sociodemographic groups
Hickey et al. (2010)	New York City, United-States	Not available	Individual	Fare type & time-of-day (peak / off-peak) fares	Vertical equity	Comparison of fare changes between low- and high-income groups.
Huang et al. (2021)	Not available (fictional network)	Not applicable	Network	Distance-based fares (Euclidean and network-based)	Market equity	Gini Coefficient of benefits at the network level.
Laverty et al. (2018)	United-Kingdom	579 older adults	Individual	Targeted fares (older adults)	Vertical equity	Comparison in uptake of travel pass and change in public-transit use between income groups.
Lovely and Brand (1982)	Atlanta, United-States	No sample size	Individual	Distance-based, time-based, quality based (service), route-based, user-based (low-income)	Vertical equity	Target efficiency and coverage of different fare policies for low-income users.
Matas et al. (2020)	Barcelona, Spain	19,111 trips	Individual	Flat, distance-based (zonal and gradual) and fare integration.	Vertical equity	Comparison of average subsidy per trip between income groups.
Nahmias-Biran et al. (2013)	Harifa, Israel	3866 trips	Individual	Fare integration.	Vertical & market equity	Comparison of number of people observing fare increases / decreases between neighborhoods of different socioeconomic status. Gini coefficient for cumulative proportion of change in fares as a function of population.
Nuworsoo et al. (2009)	Oakland, United-States	15,370 trips	Individual	Flat, reduced (youth, seniors & people with disability) and transfer-based fares	Vertical equity	Comparison of changes in fare paid between income groups.
Rubenson et al., 2020	Stockholm, Sweden	Not applicable (forecasted trips)	Individual	Flat, distance-based (zonal and gradual)	Vertical & market equity	Comparison of fare changes between urban and peripheral. Gini coefficient for total fare expenses as function of total population. Suits coefficient for total fare expenses as a function of population ordered by income.
Silver et al. (2023)	Lisbon, Portugal	1302 adults	Individual	Fare integration.	Vertical equity	Changes in travel cost, travel cost as % of income, cost/time (including time to earn wage) and effective speed (distance travelled / total time) per income group
Tiznado-Aitken et al. (2021)	Santiago, Chile	2.9 million trips	Neighborhood	Flat and distance-based fares	Vertical equity	Comparison of fare variation in % and % of trips with increased fare across neighborhoods based on their income.
Vecchio et al. (2022)	Santiago, Chile	Not available	Individual	User-based fares (older adults)	Vertical equity	Comparison of pubic-transit affordability (measured relatively to income) between income groups with different fare structures.
Verbich and El-Geneidy (2017)	Montréal, Canada	292,933 pass purchase and 5395 unique trip purchasers	Neighborhood	Fare type	Vertical equity	Comparison of purchasing patterns across public-transit vendors based on the neighborhood sociodemographic characteristics.
Wang et al. (2021)	Brisbane, Australia	2056,871 trips in 2016 and 2322,782 trips in 2017	Individual	Distance and user-based (children) fares	Market equity	Gini coefficient of the cumulative proportion of cost per zone as a function of cumulative proportion of passengers within type of fares

(*continued on next page*)

Table 2 (*continued*)

Study	Location	Sample	Scale	Fare dimension(s)	Equity type	Equity assessment
Zhao and Zhang (2019)	Beijing, China	772 PT users	Individual	Distance-based fares	Vertical equity	Comparison of public-transit affordability (measured relatively to income) between income groups
Zhou et al. (2019)	Southeast Queensland, Australia	205,578 trips	Zonal	Distance-based fares (zonal)	Market equity	Comparison of fare / km across different number of zones crossed.

4.1.1.3. Measuring distance. One final consideration when assessing the equity of distance-based fares is the distance measured (i.e., Euclidean or network distance). Huang et al. (2021) found in their modelling of a fictional transit network that Euclidean distance led to greater market equity in fare systems than network distance, although this relationship did not hold when separating into trip length, as network distance leads to greater market equity at longer distances. Such potential differences in outcomes is coherent with past research on network circuity that found that areas with higher share of low-income residents tended to have higher circuity values (longer network distance compared to the Euclidean distance) which was reflected with lower-income riders having longer trip length than higher-income riders (Dixit et al., 2021). This further highlights the importance of local context in the effects of distance-based fares and the need for more global-south fare equity research.

Overall, while there seems to be a consensus forming on the beneficial effects of distance-based fares on market equity, their impact on vertical equity is uneven and dependent on the distribution of low-income groups in the region. Service characteristics such as the distribution of route circuity can have an impact on the progressiveness of distance-based fares, although more literature is needed to confirm the strength and direction of this effect.

4.1.2. Time dimension

Temporal modulation of fares are theoretically driven by the achievement of greater market equity, being centered around the notion of marginal cost pricing. During peak periods, the marginal cost of public-transit service is higher as the network's operating resources (both human and material) are maxed out (Bruun, 2005; Guo et al., 2021; Taylor et al., 2000). Every additional increase in service provision therefore requires hiring more employees and purchasing more material. Contrastingly, off-peak service costs less to operate as service provision is below the maximum capacity of the network meaning that an incremental increase in service can be done without requiring additional labor or material resources at the network level. Accordingly, the most common temporal modulations of fares are differentiated peak (weekday morning and afternoon) and off-peak (weekday midday and night as well as weekends) fares. Still, more novel applications such as dynamic pricing based on supply-demand dynamics are possible and could in theory better account for variability in cost although their data intensiveness could present challenges for practical applications. Temporal modulation of fares acts as public-transit congestion charging, incentivizing users to use public transit more equally over time, reducing overcrowding, travel times and overall operating costs while improving overall service quality for users (Cervero, 1985).

The temporal dimension of fares was studied in four articles, all of which were conducted in the United-States. In terms of market equity, Cervero (1981b) showed that midday riders (between 9AM and 3PM) had a higher average individual FRR (~ 1.10) than peak travellers (~ 0.92). With the implementation of a peak hour surcharge and off-peak fare reduction, the gap in average individual FRR closed out between peak periods and midday denoting increased market equity. Cervero (1982) found that peak / off-peak differentiated fares in Los Angeles would lead to a reduction of inequities in individual FRR between different trip lengths, further promoting market equity. In terms of vertical equity, he showed that time-of-day fares would retain a small progressive effect comparable to that of the existing flat fare system. This is coherent with Brown (2018), who studied peak / off-peak differentiated fares in Los Angeles, finding that they would improve vertical equity slightly compared to flat fares, moving from low-income riders paying 29 % more on average than high-income riders under a flat fare system to a 25 % difference under the time-of-day fares. Lastly, Lovely and Brand (1982) noted that time-of-day fares would only be able to provide fare relief to 52 % of low-income users who would be receiving 55 % of the subsidy provided. These findings exemplify how the temporal dimension of fares – similarly to distance – lacks theoretical connection to vertical equity likely leading to uneven and unreliable effects between socioeconomic groups across contexts.

Overall, the literature on the effects of temporal modulations of fares on equity is limited and geographically biased to the global north, meaning that more research across a greater diversity of contexts is needed. Still, current research highlights their theoretical contribution to market fare equity in practice, although their efficiency in achieving vertical equity is unclear and likely context-dependent. It would be pertinent to explore different types of time-based modulation of fares (e.g., different level of temporal precision, dynamic vs static fares) and compare their effects on fare equity. Lastly, it is crucial to gather more insight into the impacts of time-based fares across socioeconomic groups to more thoroughly assess the variability in their effect on vertical equity.

4.1.3. Service dimension

The service dimension of fares refers to modulation based on service characteristics such as service line, mode, number of stops or speed, all of which are interrelated. Such modulations are once again rooted in market equity, aiming to promote fares proportional to the cost of the service used. For instance, someone making use of a heavier mode of transport (e.g. subway, commuter rail) which provides added speed at higher operating costs, should pay more than someone only using local buses, all other factors being equal. The distinction could also be made at the route level with more expensive routes to operate (due to topographical, geographical or other service-related considerations) being priced higher than less expensive routes. As a practical matter, transfer fees can be seen as a proxy of service-based fares. Service-based fares are also referred to as quality-based, mode-based, or route-based fares.

The equity of service-based fares have been assessed in three empirical articles, with none considering market equity. Brown (2018) found that higher fares for rail than buses led to a 12 % reduction in inequities between lower-income and higher income riders. Lovely and Brand (1982) found that mode-based fares would be able to provide fare relief to 73 % of low-income users (amongst the most efficient alternative studied) who would be receiving 53 % of the subsidy provided, compared to 29–78 % coverage for reduced fares on routes going through low-income areas which would target between 58 % and 77 % of the subsidy provided to low-income users. Lastly, Nuworsoo et al. (2009) found that keeping free transfers in Oakland, USA, would be more beneficial to low-income users than high-income users.

The scholarship on the effects of service-based fares on fare equity is extremely limited in addition to being constrained to studies in the United-States. Nonetheless, a theoretical connection exists between this fare dimension and increased market equity. The same cannot be said of vertical equity outcomes though, which are once again likely to be context dependent thus stressing the need for research across a wider range of context, particularly in the global south. Lastly, future studies should aim to assess and contrast the equity outcome (both market and vertical) of different types of service-based fares such as mode-based and route-based as these were not present in the existing literature.

4.1.4. User dimension

The user dimension of fares is the only fare attribute that directly aims at promoting vertical equity by targeting users based on their ability to pay for public transit. User-based fares (also known as group-based or targeted fares) generally entail a reduced or free fare for specific sociodemographic groups. They not only aim at reducing the fare burden but also at promoting greater transit usage within populations with more limited transportation alternatives. The most vertically equitable user-based fare would be an income-based (or wealth-based) one, as it directly targets individuals with lower ability to pay. Such programs have been shown to lead to greater transit usage right after implementation denoting their uptake efficiency (Guzman and Hessel, 2022). However, such programs can be hard to implement due to the administrative verifications and inter-agency coordination they require. The effects of such barriers have been observed by Darling et al. (2021) which noted how income-based discounted fares existed in only 17 of the largest 50 public transit agencies in the US.

Instead, most transit providers will provide reduced fares based on age (both children and older adults) or on education level (i.e., student discounts) which are both based on the assumption that these groups have a lower ability to pay for transit than the rest of the population. Reduced fares for individuals with disabilities also exist, although their relationship with the ability-to-pay principle is more nuanced; while disabilities can impact a person ability to earn money to pay for public transit by limiting access to jobs, such a justification overlooks the wide range of capabilities of those with reduced mobility or disabilities. Other user-based fare for other groups such as Lisbon's family-based fare (Silver et al., 2023) are even less related to (if not completely detached from) the ability to pay principle. From the 24 peer-reviewed empirical articles assessed, seven studied the impacts of user-based fares on fare equity, with five considering older adults' fares, two analyzing either youth or students fares and another one looking at reduced fares for low-income users.

4.1.4.1. Older adult fares. Results in terms of the effectiveness of older adults' discounted fares in improving vertical equity were mixed. Brown (2018) is the only study that found a clear positive (although small) impact of reduced older adults fares on vertical fare equity, showing that the discounted fares would lead to a 3 % reduction in the gap in average fare paid between low-income and high-income users. Arranz et al. (2022) found that reduced fares for older adults led to a decrease in public-transit expenditures for the two lowest income quartiles with an unemployed main breadwinner but also for the wealthiest households quartile for households with an employed main breadwinner. Laverty et al. (2018) also had mixed results in their longitudinal study in England. While they found no significant differences in the uptake of the free older adult bus cards between income groups, individuals from the highest income group used public transit significantly more than those from the lowest-income group after the implementation of the free travel pass. Bueno Cadena et al. (2016) found that uptake of reduced fares (including older adults and youth fares) were higher in lower income areas, although those results cannot be isolated for older adults fares given that this part of the analysis was not separated by pass type. They also observed no significant difference in subsidy level per trip for users with the same type of travel pass between low income and high-income areas. It is important to note that a neighborhood approach to consider the effect of user-specific programs might not be reliable given the individual nature of the requirements to access such reduced fares. Lastly, Vecchio et al. (2022) found that the effects of discounted fares for older adults were comparable across income groups.

4.1.4.2. Youth or student fares. For the youth or student fares, the limited number of studies (two) on their vertical equity impacts did not allow much generalization. The mixed, neighborhood level results of Bueno Cadena et al. (2016) regarding older adult fares are also applicable to youth fare as they were analyzed together in terms of uptake and had the same lack of difference in terms of subsidy levels. Then, Nuworsoo et al. (2009) found that retaining student passes in a pay-to-ride system would limit the increase in fares the most for the highest-income users and those participating in CALWORKS (e.g., a California social welfare program), thus further highlighting the lack of target efficiency of such discounts to address vertical equity issues.

4.1.4.3. Income-based fares. The last type of user-based fare that was studied were reduced fares for low-income users. According to Lovely and Brand (1982), such policies would have a 70–80 % coverage of lower-income users and a near 100 % target efficiency, meaning that almost all of the money invested would benefit lower-income users. However, as detailed before, the administrative requirements they require has represented a barrier to their implementation in practice (Darling et al., 2021). Similar effects could potentially be achieved at lower costs with income-based tax rebates although added research on the feasibility and effectiveness of such policy would need to be conducted.

Overall, no clear benefits in terms of vertical equity are recognized from the limited scholarship that has studied reduced fares for older adults, youth or students. This could be explained by the fact that older adults and children can be from a variety of socioeconomic background, thus not linking directly to the ability-to-pay principle. Similarly to other dimensions of fares discussed before, it is likely that some of the differences observed between studies could be attributable to differences in social context. Additional research is needed particularly for non older adults fare, to be able to discern any consistent effects of such fares on vertical and market equity. Similarly, the limited scholarship on reduced fares for lower-income users further limits any assessment of their effect on market equity or their effectiveness in removing barriers to public-transit usage for this demographic. That said, their impact on vertical equity itself is clear as such fares are generated with the ability-to-pay principle in mind.

4.1.5. Synergistic effects of fare attributes

The synergies between multiple fare dimensions in their effect on fare equity have only be directly studied in one study. Brown (2018) found that a combination of distanced based (without minimum and maximum fares) and time-based (peak vs off-peak pricing) led to a more vertically equitable outcome than either of those policies on their own in Los Angeles, California. This finding indicates a positive synergy between distance-based and time-based modulations of fares on vertical fare equity. However, it is important to point out that such results present averages, thus masking the potential detrimental effect on lower-income users travelling long distances and/or during the rush hour. Unfortunately, this type of intersectional analysis was not conducted in such a comparative way (i.e., testing both dimensions on their own and then together) in any other article analyzed. Given that fares have the potential of having multiple modulations, it is crucial to evaluate not only each dimension separately but also in combination with one another.

4.2. Fare type

Fare type refers to the different tickets or passes that can be used to pay for public transit. At the simplest, public transit can be paid by single-usage tickets. However, such an approach is poorly suited to promoting user loyalty or ensuring service affordability. As such, transit agencies almost always provide other fare options to their users that enable greater discounts with increased usage either through prepaid fare bundles or fare capping. Such discounts are not rooted in promoting market nor vertical equity, but rather loyalty and affordability. While providing a variety of fare types directly contradicts the beneficiary-pay principle, the way in which they are implemented can impact vertical equity in addition to their intended impact on user loyalty and affordability.

4.2.1. Prepaid fare bundles

Prepaid fare bundles allow users to buy in advance fares for multiple trips (e.g., two-trip, 10-trip passes) or for a period of time (e.g., daily, weekly or monthly passes) with an increased discount on per-trip costs the larger the bundle is. Five studies evaluated the effects of fare type on fare equity, focusing almost exclusively on monthly and weekly discounted passes. In terms of monthly passes, Bondemark et al. (2021) found that low-income individuals in Sweden are less likely to purchase monthly passes than high-income individuals. Similar findings were observed by Hickey et al. (2010) in New York City while Nuworsoo et al. (2009) observed that the removal of monthly passes (evaluated simultaneously with the removal of free transfers) had a bigger negative impact on low-income users' fare burden than on high-income users. At the neighborhood level, Verbich and El-Geneidy (2017) did not find any difference in purchasing patterns of monthly passes between neighborhoods with different socioeconomic status (SES). Instead, they observed that lower SES areas were more likely to purchase weekly passes, including repeated weekly passes (3–4x per month), than higher SES areas. This is coherent with findings from Hickey et al. (2010) who found that lower-income users purchase more frequently weekly passes than their higher-income counterparts. Nuworsoo et al. (2009) complement these findings by highlighting how adding a weekly pass does not have any significant difference in reducing fare costs between income groups. Lastly, Bueno Cadena et al. (2016) found that lower income areas use travel passes more than high-income areas, although they did not differentiate between the type of transit passes (i.e., they looked at monthly, youth and older adult passes together) thus making it impossible to assess the uptake of different fare types.

While discounted fare bundles are aimed at providing a greater discount to all users, promoting increased affordability and user loyalty, their uptake has been observed to be more limited amongst lower-income users. The primary reason for such differences mentioned in the literature is the upfront cost of monthly (or any longer-scale) discounted passes which many low-income individuals do not have the financial means to pay (Verbich and El-Geneidy, 2017). This therefore results in discounted travel passes having a negative effect on vertical equity – which should be addressed – in addition to having a negative effect on market equity – which is a necessary trade off when prioritizing service affordability and user loyalty.

4.2.2. Fare capping

Fare capping has been discussed as a potential alternative to the current vertical inequity of discounted fare passes (Bondemark et al., 2021). This method makes users pay for each trip as they take them, but implements a maximum amount paid or a maximum number of trips that need to be paid per day, week and / or month (i.e., a cap). The advantage of such a system is that it distributes public-transit costs more evenly, making discounted fare bundles (especially longer-term ones such as monthly passes) more affordable for lower income users (in theory). It therefore could be hypothesized that fare capping would allow for discounted fare packages to be present within a fare system without the introduction of added vertical inequities although it is unlikely to have an effect on market equity compared to normal discounted passes. Unfortunately, no studies have directly evaluated the fare equity impacts of fare capping policies, thus presenting a clear gap in the literature. This is likely due to the rarity of fare capping programs. For instance, Hightower et al. (2022) found that only 21 of the largest 101 transit agencies in the United-States had fare capping policies in place, with daily fare caps being the most common policy (n = 20) followed by monthly (n = 14) and weekly caps (n = 4). They highlighted ten regions with combined fare capping and low-income discounts (i.e., providing lower fare caps to lower-income riders) which have the potential of further amplifying the beneficial vertical equity impacts. Additionally research will be needed to provide empirical evidences of the effectiveness of fare capping across different temporal scale (daily, weekly, monthly etc.) and using different metrics (cap in money or number of trips) in achieving greater vertical fare equity. Keeping in mind the lack of intersectional research on fare characteristics, it would be relevant to assess whether fare capping based on number of trips – as opposed to being based on a maximum fare amount paid – would be better compatible with fare attributes aimed at promoting market equity (distance-, time- and service- based fares).

4.3. Fare integration

Fare integration can be understood as the harmonization of fare structure between multiple transit agencies in the same region. Such integration generally allows for a reduction in fare paid by users by avoiding the need for multiple fares when conducting a trip across multiple transit operators in the same region. Three studies have analyzed the effect of metropolitan fare integration, finding that better geographical integration has a beneficial effect on vertical equity. Silver et al. (2023) showed that integration of multiple zones with different operators in Lisbon, Portugal to a single, flat fare, zone benefitted lower-income users more. Matas et al. (2020) found that removing fare integration in Barcelona would lead to an increase in fares for all users with a mild regressive effect in terms of income. Lastly, Nahmias-Biran et al. (2014) found that the change from a municipal level zonal system (more than 20 zones) to a five zone system and the harmonization of between-zones fares at the metropolitan level in Haifa led to more frequent fare reductions in the lowest income neighborhoods. While the scholarship on the effect of fare integration on vertical equity is limited, current research point towards a positive association. This could be attributed to lower-income riders making more complex multi-agency transit trips, although such a reality could vary between local contexts. Conversely, additional research needs to be conducted to assess the impacts of fare integration on market equity (e.g., does it remove superfluous charges) and to test a variety of parameters in the integration process.

5. Discussion & Conclusion

In this study we employed a scoping review approach to critically analyze the scholarship on the effects of fare characteristics on fare equity. We adopted a two-part fare equity framework: (1) market equity, based on the beneficiary-pay principle, which entails that all users should pay the proportionally to the costs of the services used; and (2) vertical equity, based on the ability-to-pay principle, which stipulates that users should pay for public transit based on their financial capacities. Through our review, we grouped empirical studies on the equity of fare burden into three main categories based on the fare characteristics considered: (1) fare attributes (i.e., distance, temporal, service, and user dimensions), (2) fare type (i.e, prepaid fare bundles and fare capping) and (3) fare integration. Looking at each characteristic individually, we highlighted conceptual links between individual fare characteristics and market and vertical equity (Fig. 2). Some links were clear such as the positive effect of distance-, time and service-based fares on market equity, the positive effect of income-based fares on vertical equity, the negative effects of user-based fares and non-single ticket fares on market equity and the negative effect of prepaid bundles on vertical equity. The rest of the associations were dependent on local contexts. This latter point is particularly important considering the high geographical bias within the current scholarship with almost all studies being conducted in

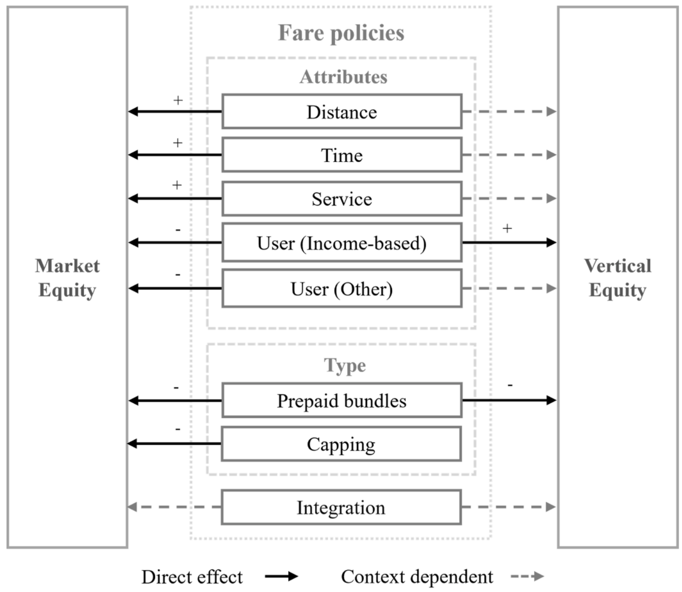

Fig. 2. Conceptual model of the effects of fare attributes on market and vertical fare equity.

the global north. As observed with the contradictory findings regarding the vertical equity effects of distance-based fares, the over-representation of global north studies could lead to the creation of biased generalizations (e.g., distance-based fares are always more progressive than flat fares) which could in turn increase inequities, particularly vertical ones, in fare structures in global south regions. Instead, fare structures need to be tailored to the particularities of each context to achieve fare equity in addition to other objectives of fare structures. It is important to remember that fare policies are directed by each regions' societal goals after FRR is determined at the system level.

One key caveat of our review is that it lacks an intersectional analysis of the impact of fare characteristics on fare equity which limits the extrapolation of the pathways highlighted in practice as most transit agencies will be modifying multiple fare characteristics at the same time. This is particularly important given that current research points towards potentially contradictory strategies to promote market fare equity and vertical fare equity (Fig. 2). This is not to say that it is impossible conceptually or practically to promote both increased vertical and market fare equity. For instance, distance-based fares could promote increased vertical equity in addition to market equity in certain local contexts. However, it remains more feasible for transit agencies to choose one type of fare equity and tailor fare structures based on fare characteristics that have been shown to positively impact it. For instance, the fare structure in Portland, Oregon, aims for greater vertical equity through an honoured citizen (i.e., age 65 +, Medicare recipients, people with disabilities, low-income users, veterans or active-duty military) and youth discounted fares combined with daily and monthly fare capping differentiated based on the type of users (i.e., adults, honored citizens or children). Conversely, the fare structure in Hong Kong is primarily centered around modulations based on distance, route and service type, which reflect greater emphasis on market equity, even if discounted fares are provided to older adults, students and people with disabilities as proxies for vertical equity.

The choice of pursuing fare equity and which type of equity to pursue is intrinsically linked to how public transit is defined. On one hand, if public transit is seen as a public service to which everyone should have equal access notwithstanding their financial means, then vertical fare equity should be seen as the driving goal to be achieved through fare structures. This can be seen with the approach taken in Portland, Oregon. On the other hand, if public transit is defined as a public-provided individual benefit, then achieving market fare equity should be the primary goal of the fare structure. This is more observable with the Hong Kong example, although their fare scheme does not fully reflect an individualist view of transit services. Overall, it is important to integrate discussions on the relevancy and desirability of fares in a given region (i.e., the equity of having fares or not) when engaging in these broader reflections on the role of public transit.

While we highlight these broader debates as they are important to contextualize this study' finding, we purposely chose to limit ourselves to equity within fare systems to allow for a greater level of detail. In doing so we made the assumption that fares have a place in public-transit funding structures given the current financial situation of transit agencies worldwide and that ensuring greater equity in their application is more achievable than aiming to remove them altogether in most contexts. Additionally, while we have limited our assessment to public-transit fares only, we do recognize that new multi-modal approaches to transportation pricing exist. The fare equity framework presented in this paper could be easily adapted to any other transportation pricing policies, including multi-modal ones, although greater practical limitations might arise when evaluating the combined cost of service across multiple modes. Future research should elaborate on the broader implications of the conceptualizations of the role of public transit on its pricing and funding and include more novel concepts such as mobility-as-a-service which combines both multi-modal transportation pricing with normative views of the role of shared transportation. Lastly, it is important to note that equity is not the only goal of fare structures. Striking balance between the different objectives of fare structures – which also include cost recovery, inducing modal shift as well as ensuring service affordability and simplicity for users – is also key and can in many cases restrict the extent to which equity-driven fare modulations can be pursued.

5.1. Policy recommendations and research agenda

This review highlighted several takeaways with relevance to both the implementation of fare structures in practice and the study of their equity within academic research. Starting with recommendations for transit agencies:

- Fare equity goals should be defined clearly along with other public transit objectives (e.g., cost recovery, affordability, simplicity of use, user loyalty, induced modal shift) to allow for a coherent implementation strategy.
- If market equity is a key objective, distance-, time- and service-based fare modulations should be explored.
- If greater vertical equity is part of the goals, transit agencies should implement income-based discounts and supplement existing prepaid fare bundles with fare capping systems.
- Equity-based performance measures of fares should be implemented to systematically assess the effects of fare characteristics on both market and vertical fare equity. Individualized FRR should be prioritized when possible although fare paid per distance travelled (e.g., $/km or $/mile) could be adequate given the data requirements of individual FRR (i.e., detailed cost-distribution models, localized ridership data).
- Common horizontal equity approaches (e.g., Gini or suits coefficient) could be applied to the performance measure chosen to evaluate market equity at the system level. Specific comparisons should also be conducted across specific dimensions of fares (e.g., between time periods, trip length, mode used) to evaluate market equity.
- Comparisons of key performance measures across socioeconomic groups should be conducted to evaluate vertical equity of fare policies.

Of course, as discussed earlier, the limited nature of the current literature on the equity within fare structures entails that more research also needs to be done within academia to inform practice.

- Research is critically necessary for all fare characteristics aside from distance to provide a greater body of evidence from which to assess the strength of empirical associations.
- Research is needed from a greater diversity of local contexts, mainly a shift towards more global-south fare equity research to not only enable the applicability of the literature to those contexts but to also provide greater insights applicable to global north contexts.
- Future research should aim to compare multiple applications of the same fare characteristics (e.g., static time-of-day vs dynamic fares, mode-based vs route-based fares).
- Future research should test the potential intersectional effects of fare characteristics on market and vertical fare equity to reflect how fares are actually implemented in practice. A comparative analysis should be adopted to evaluate multiple fare scenarios using either real travel behaviour data or a synthetic population. Scenarios could be evaluated in parallel (i.e., starting directly with a fixed number of scenarios with their own combinations of fare characteristics) or in a stepwise approach (i.e., building upon a base scenario by gradually adding a new fare characteristic).

Overall, the scoping approach used for this paper has enabled a broad portrait of the current evidence and gaps in the literature on the market and vertical equity within fare structures. With recommendations made above for practice and research, we hope that increased thoughtfulness will be put in the elaboration of fare systems at a time when increasing pressure on public-transit agencies to find missing revenues might lead to broad, undifferentiated fare increases. Linked to that aspect, we would highlight the need for increased research more broadly on the place fares ought to take within public-transit funding as such debates will likely enhance the ability of fare equity-based measures to have a larger societal impact.

CRediT authorship contribution statement

Lancelot Rodrigue: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Madhav G. Badami:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Ahmed El-Geneidy:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declares no conflict of interest.

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