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How unequal are travel costs? Evidence from the Paris Region

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Abstract - This paper studies the distribution of transport costs borne by the Paris region households and the issues of vertical (income) and horizontal (location) equity. Using the 2018 household travel survey, we estimate the following costs: monetary costs, time costs, air pollution costs (distinguishing between the cost caused and borne by the household) and CO_2 emission costs. We study the distribution of each dimension alone, as well as the relationship between them. Results show that monetary costs are regressive and represent the most unequal distributed dimension across income groups and space, with the lowest quartiles living in the outer suburbs (those car dependent) facing the highest effort ratios. Time costs are randomly spread across space, but do increase with income. Pollution costs are the lowest for households living in the outer suburbs, and are almost equal across income quartiles. We do find evidence of (slight) compensation between the various costs as the total private cost – the sum of monetary, time and pollution costs – has a lower Gini index than each cost alone. Time costs contribute the most (around 75%) to private cost inequalities due to their large cost share, while monetary costs contribute to around 25%. Our findings stress the importance of considering 1) both horizontal and vertical equity in policy design as both issues are empirically significant, and 2) all the main cost dimensions (money, time, and environment), and not just only one as it is often the case, as the various costs may (or may not) compensate each other.

Classification JEL
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Equity
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1. INTRODUCTION

Developed countries are increasingly confronting the complex challenge of sustainability. Sustainability implies striving for cities that are more environmentally friendly and more equitable among people. Ensuring a healthier city requires a reduction in car travel and a shift to active modes and public transport. This calls for policies such as increasing fuel prices or carbon taxes, car purchase taxes, low-emission zones and congestion pricing. In 2018, France tried to enforce a fuel price increase, upon which people immediately reacted with protests known as "gilets jaunes" movements (Leroutier and Quirion 2022). This shows the importance of clearly identifying who are the households the most impacted by a policy in order to ensure public acceptability. Therefore, it is necessary to understand the current travel cost disparities, to identify the most disadvantaged and to use these results as a guide to position future policies towards the most vulnerable.

While the issue of equity has been largely documented in the case of transport, most empirical studies to date have focused on identifying disparities on a single dimension, in most cases accessibility (Bocarejo and Oviedo 2012 ; Golub and Martens 2014 ; Bittencourt and Giannotti 2021 ; El-Geneidy et al. 2016 ; Jin et al. 2022), considering accessibility as a proxy for people's needs (Abdelwahab et al. 2021 ; Di Ciommo 2018).

Nevertheless, although many (Lucas and Martens 2019; Pereira, Schwanen, and Banister 2017) posit that we should focus on the measurement of potential mobility rather than the actual mobility in order to correct the actual situation to a more equal one, studies addressing the actual travel behaviors or mobility are numerous, and to our opinion, are fundamental and should be supported since they are the key for understanding the current inequities, the socio-demographic groups that suffer the most, and which benefits and burdens are the most unfairly distributed. These papers address people's travel behaviors in term of number of trips or travel distance (Iglesias et al. 2019), transport costs, travel time (Gebremeskel, Woldeamanuel, and Woldetensae 2022; Iglesias et al. 2019), or people’s exposure to transport externalities (Mueller et al. 2018; Poulhès and Proulhac 2022; Leroutier and Quirion 2022; Zuurbier et al. 2010). Though, the main papers focus was the identification of households’ travel expenditure and affordability inequalities (Berri et al. 2014; Nicolas and Pelé 2017; Souche, Mercier, and Ovtracht 2016; Gandelman, Serebrisky, and Suárez-Alemán 2019; Cascajo et al. 2018; Valenzuela-Levi 2021).

Yet, it is important to consider the various travel costs (money, time, pollution, safety…) first because transport poverty accounts for different dimensions of travel costs and not just only one (Lucas et al. 2016), second because they may offset each other, resulting in contrasted conclusions as opposed to just considering time or money.

From a methodological point of view, the issue of distributional impacts (i.e. equity) has been assessed in the literature using three main approaches: mismatch analysis, statistical approach, and inequality indicator-based approaches (Guo et al. 2020). Bittencourt and Giannotti (2021) use the three equity assessment approaches to study a single dimension, namely accessibility (including travel time, costs and transfers), across 3 different cities and different social groups. Regarding French studies, several studies use the inequality indicator-based approach, but consider a single cost and its distribution along a single socio-economic dimension (income). Souche-Le Corvec et al. (2016) compare income inequality based on households surveys, using Gini, Theil and Atkinson indexes, before and after travel monetary costs. This before-after calculation method is defended by many authors because of its intuitive meanings and its biases reduction (Sastre and Trannoy 2002). Berri et al. (2014) also use the indicator-based approach to measure transport expenditures inequality between income quartiles. Breaking down transport expenditures into public and private transport expenses components, they apply the Gini decomposition per sources as proposed by Lerman and Yitzhaki (1984).

This paper aims to extend the literature by studying the distribution of the various transport costs borne by households, and how these interact with each other[1]. To do so, we develop a methodology for a comprehensive analysis of how travel costs are distributed among income groups (vertical equity) and geographical residential zones (horizontal equity). The methodology combines a mismatch analysis with a multidimensional Gini index decomposition analysis. We consider 1) monetary costs (including variable and fixed costs), 2) time opportunity costs, and 3) air pollution costs (local pollution, CO_2) borne by households. Costs are disaggregated by travel modes. Population is split into equivalized income quartiles groups, and into geographic zones. We apply the Gini index to the actual incomes and to the incomes net of monetary costs. For the Gini decomposition by source, we use both the Lerman and Yitzhaki approach (1984) and the Shapley value allocation approach (Sastre and Trannoy 2002). They are applied to the total private costs, equal to the sum of monetary costs, time costs and pollution borne costs. To check the heterogeneity within and between groups, the Gini decomposition by subpopulation proposed by Dagum (1997) was applied for the different costs components and for the incomes. To our knowledge, Gini decomposition per subpopulations has not yet been applied in the transport field (but it was applied in other economic studies). The methodology is applied to the Paris region using the 2018 household travel survey.

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[1] To the best of our knowledge, one of the only studies which analyses equity with regard to various dimensions of travel costs (and not only one) is Iglesias et al. (2019). They compare the benefits and costs of urban transport including transport systems investments (infrastructure and services), mobility levels (distances, travel times, and speeds), and social costs (monetary, accidents, pollution, and energy consumption) across income quartiles. While they look at the monetary costs (and time) paid by the household, however, for accidents and pollution, they look at the effects generated by the household and not those incurred. In addition, they do not consider the interaction between the different costs dimensions. Also, they relied on means comparison rather than using a distributive indicator, overlooking the heterogeneity within the same subgroup.

The rest of the paper is organized as follows. Section 2 describes the general methodology; section 3 applies it to the case study of the Paris region. Section 4 sets out the results of this application, and the final section discusses the results and some public policy implications.

2. METHODOLOGY

We propose to analyze the distribution of the main travel costs elements – time costs, monetary costs, air pollution costs and CO_2 emission costs – between equivalized income quartiles and zones of residence. In the case of pollution costs, we distinguish between the costs generated by the individual (e.g., the local pollutants and ensuing health costs caused by the mobility of the individual) and those borne by the individual (the exposure to local pollutants of said individual). Travel costs are analyzed separately then jointly, using the total private cost notion as detailed below.

2.1. Costs Calculation

Seven cost elements are considered in our approach:

- Time cost: daily individual travel time includes travel time of all trips made by the individual on a specific day, and costs are applied depending only on the trip purpose in accordance with the French guidelines (Commissariat général à la stratégie et à la prospective 2013).
- Travel expenses: it includes all out-of-pocket elements paid by the household per month. This encompasses all public transport passes costs, bicycles packages costs, vehicles fixed and running costs, and the cost of using a taxi or an on-demand-service if ever.
- Pollution caused cost: it includes air pollution generated by the individual on all his trips. It depends on the emission factor of the vehicle used, and on the density of the traffic area crossed.
- Pollution borne cost: it depends on how long an individual is exposed to pollution, so we calculate the time spent per individual in each zone. Each zone is associated with a different pollution cost.
- CO_2 emission cost: it is a function of the travel distance and the mode used.
- Private cost: it is considered to be the full cost borne by the individual. We therefore include the time cost, monetary costs and the pollution borne cost.

2.2. Gini Application

The Gini index is one of the most widely used inequality indicators. Contrary to what is commonly reported, the Gini index can be easily broken down by income level and by sub-populations (Dagum 1997; Lerman and Yitzhaki 1984; Fourrey 2019; Berri et al. 2014; Sastre and Trannoy 2002). While the Theil index is more commonly used for its decomposition into inter- and intra-group terms, the Theil inter-group term only compares the average income of each group, whereas the Gini inter-group index compares the incomes of each individual in the groups.

To figure out whether travel costs are increasing or reducing social inequality of the population, we compare income distribution with and without monetary travel costs, using the Gini index. Then, by using the decomposed Gini by sources, we show how each cost element contributes to total inequality. Finally, we compute the Gini decomposition per income quartile and per geographic zone to compare the heterogeneity between and within groups, and what inequalities are the most significant.

2.2.1. Gini Decomposition by Components

Two methods for the decomposition of the Gini index were found in the literature. A first one is proposed by Lerman and Yitzhaki (1984), and a second one proposed by Chantreuil and Trannoy (1999) and Shorrocks (1999) using the Shapley value (Sastre and Trannoy 2002); we apply both of them.

Lerman & Yitzhaki Method:

Starting from the formula of the absolute Gini: $A = \int_a^b F(y)[1 - F(y)]dy$, Lerman and Yitzhaki (1984) found that the relative Gini can be written as follows:

$$G(X) = \frac{2cov(X,F_X)}{m} \quad (1)$$

with X the income (or variable of interest), Fx its cumulative distribution function and m the average of X in the population N.

Since X can be the sum of multiple sources k, the above formula led Lerman and Yitzhaki (1984) to decompose the Gini index by the different income sources by replacing X by $\sum x_k$:

$$G(X) = 2\sum \frac{cov(x_k,F_X)}{m} \quad (2)$$

$$G(X) = \sum \left[\frac{cov(x_k,F_X)}{cov(x_k,F_k)}\right] \left[\frac{2cov(x_k,F_k)}{m_k}\right] \left[\frac{m_k}{m}\right] \quad (3)$$

$$G(X) = \sum C_K G_K S_K \quad (4)$$

where C_K is the Gini correlation between element k and the rank of total X, G_K is the Gini of element k, and S_K is the mean of x_k divided by the mean of X (or the average share of x_k within X).

Equivalized Shapley Decomposition Method:

The Shapley value is a concept from cooperative game theory, which distributes among different players the gains of their coalition as a function of what they contribute to the coalition. The importance of a player in a game is the average of all his marginal contributions for all possible coalitions of players weighted by their probability. Given the formal similarities between the problem of cost allocation among a set of agents and the problem of attributing source contributions to inequality, Chantreuil and Trannoy and Shorrocks proposed decomposing the inequality indexes by income sources using Shapley's method (Sastre et Trannoy 2002).

Having k sources of income: K = {1, ...,j, ..., k}, and N individuals: N = {1, ..., i, ..., n}, X the income matrix (Xij being the revenue from source j earned by individual i) and I the inequality index chosen, the Shapley value of source j is calculated as follows:

$$Shj(K,X,I) = \sum_{s\in K\{i\}} \frac{(s-1)!(K-s)!}{K!} [I(y(S)) - I(y(S-\{j\})] \quad (5)$$

with s the number of sources in the subset S and

$$y(S) = [\sum_{j\in S} x_1^j + \sum_{j\notin S} \mu(x^j), \dots, + \sum_{j\in S} x_n^j + \sum_{j\notin S} \mu(x^j)]_{1xN} \quad (6)$$

The sum of the Shapley value inequalities of sources i over K is equal to I(K) which represents the total inequality to be distributed among the K sources.

2.2.2. Gini Decomposition per Subpopulation

Given the Gini ratio defined by Dagum (1997) as:

$$G = \frac{1}{2\bar{y}N^2} \sum_{i=1}^{N} \sum_{j=1}^{N} |y_j - y_i| \quad (7)$$

Dagum proposed its decomposition into two main components: (i) the Gini inequality within subpopulations, and (ii) the gross contribution of the extended Gini inequality between subpopulations which is equal to the sum of (a) the net contribution of the extended Gini inequality between subpopulations, and (b) the contribution of the intensity of transvariation between subpopulations. These components are a function of the population shares and the income shares of the corresponding subpopulations in addition to their Gini inequality.

$$G = G_W + G_{nb} + G_t \quad (8)$$

with: $G_w = \sum_{j=1}^{k} G_{jj} p_j s_j$ (9)

$$G_{gb} = G_{nb} + G_t = \sum_{j=2}^{k} \sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j) \quad (10)$$

If population is split into income quartiles, the transvariation effect is null since incomes are ranked increasingly.

3. CASE STUDY

3.1. The Paris Region

The Paris region (IdF) is spread over an area of 12,012 km^2, divided into 8 departments (Figure 1). In 2018, the population of the Paris region was recorded as the densest in France (1016.7 inhabitants / km^2) with 12.2 million inhabitants (almost 19% of the French population). However, the IdF presents important demographic and social disproportions between its departments (municipalities more precisely) (Table 1). These disproportions are remarkable by a concentric distribution, between the center, the inner suburbs and the outer suburbs. The population density in the center of Paris is about 50 times higher than in the outer suburbs. Similarly, the transport supply in central Paris is much more developed than in the suburbs, which explains the difference in modes of transport and the reliance on cars in the Paris suburbs.

3.2. Data

The data used in our study are from the EGT 2018, a household travel survey carried out every 10 years in the Paris Region. The survey collects data on the travel choices of 11,292 individuals from 5,143 households in the Paris Region on a given weekday. Household socio-economic characteristics are also reported. The survey records and geolocates all the places visited by each individual during the day. For each journey (called trip) defined by an origin and destination, the data describes the various legs, one leg corresponding to a single transportation mode (trips and legs being identical when only one mode is used).

Table 1. Socioeconomic data (2019)

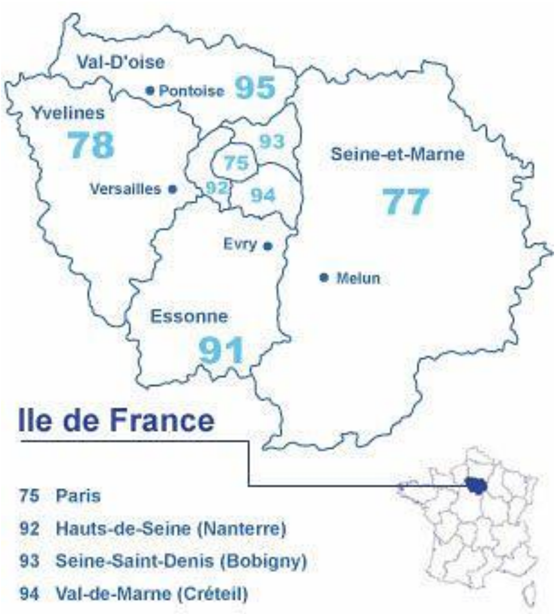
	Paris (75)	Hauts-de-Seine (92)	Seine-Saint-Denis (93)	Val-de-Marne (94)	Essonne (91)	Val-d'Oise (95)	Seine-et-Marne (77)	Yvelines (78)
Population	2,165,423	1,624,357	1,644,903	1,407,124	1,301,659	1,249,674	1,421,197	1,448,207
Population density (inhabitants/km²)	20,544.8	9,249.8	6,964	5,742.7	721.4	1,003	240.3	633.9
Area (km²)	105.4	175.6	236.2	245	1,804.4	1,245.9	5,915.3	2,284.4
Number of households	1,137,759	724,639	638,197	598,392	523,349	478,885	564,817	590,685
Median equivalized income (€)	28,570	28,310	18,070	23,060	24,010	22,220	23,590	26,970
Poverty rate	15	11.9	27.9	16.6	13.3	17	11.7	9.9
Activity rate	78.3	78.8	72.9	76	76	74.9	76.5	76.7
Unemployment rate	11.5	10.7	17.9	12.5	11	12.9	11.2	10.2

Source : Insee, Comparateur de territoire-2019.

Household income is reported as a class defined by an income interval. We make the assumption that each income class has a homogeneous distribution of income, with households having the mean income of the class interval. To take into consideration household size and composition, we use equivalized income for the results analysis. Unit of consumptions are calculated based on the Insee (the French statistical institute) recommendations.

We exclude from the sample households who did not report their income, who travelled outside the Paris region, or who travelled by plane or by high-speed train. Only weekdays trips are considered. Moreover, after analyzing the data, we noticed multiple errors of statement or recording that can bias our results. These errors are mainly at the level of the distance and time given (for example a route of more than 30km walking, a route with a duration longer than 140 minutes, or a route with a distance longer than 200 km, a trip with a train speed <8km/h, or a trip which distance differs highly from the sum of its journeys stages distances). After excluding households with any of the above errors, we got finally 2,102 (with weights representing 67.8% of total IdF households) households with 17,122 travels, representing 68% of total IdF travels.

Figure 1. The Île-de-France region



Source : Actuacity.

3.3. Costs Calculation

The following subsections describes how each cost item is estimated at the trip level. The total daily travel cost per individual is then calculated by summing up costs over all his trips. Finally, to go from the individual level to the household level, we sum up daily travel costs of all the individuals belonging to the same household and add fixed costs (such as monthly passes and vehicles fixed costs).

3.3.1. Time Cost

Travel time is reported by individuals for each trip. An "equivalent travel time" is then derived based on the French guidelines (Commissariat général à la stratégie et à la prospective 2013), by penalizing transfers and walking time.

The monetary cost of each trip d is finally estimated by multiplying the equivalent travel time $ET_{d,p}$ by V_p, the value of time for purpose p in the French guidelines:

$$CT_d = ET_{d,p} * V_p \quad (11)$$

3.3.2. Travel Expenses

Taking into consideration the fuel type and the age of the vehicle, we can calculate its energy consumption cost per €/km as the sum of the product of its consumption of energy type t (diesel, gasoline, electricity) (L/km or Kwh/Km) by its unitary cost (€/L or €/kwh):

$$EnergyCost\_Veh_i = \sum_t Consumption\_Energy_t * UnitaryCost\_Energy_t$$

Since households may own several cars, without indicating at the trip level which car was used, we take for each household the average consumption of all its cars (€/km). To include running costs (maintenance, accessories, parking, fuel, except tolls, considering that no tolls are imposed to travel between IdF zones), we consider the cost per km to be (ADETEC 2020):

$$Running\_Cost_{Veh\,h} = 2{,}19 * Cost_{Fuel\_Consumption_{Veh\,h}} \quad (12)$$

We proceed the same way to calculate motorcycles and bicycles consumption.

Based on the mode used, we apply a cost per unit kilometer travelled (€/km) to get the cost of the route r made by individual i of household h by mode m:

$$Cost_{r,m_{i_h}} = Cost\_Mode_m * d' \quad (13)$$

where d’ is 1.3 time the as the crow flies distance.

When using one travel pass, or one day pass to travel by public transport, real fares are applied based on the travel pass used, the origin and destination of the trip and the mode used (tramway, subway, bus, train). Transfers between routes are also considered because some permit using the same ticket.

Costs are calculated on a monthly basis, so daily costs are multiplied by 26, then we add monthly costs including PT memberships (costs depend on the package chosen) and the vehicles fixed costs (for cars we consider a fixed cost including depreciation and insurance of 137€ per car; 50€ for motorcycles and 30€ for bicycles).

3.3.3. CO_2 Emission Costs

For each car, we compute its emission factor (gCO_2/km), which is a function of the car age and fuel type. It is the product of its consumption on energy type t (diesel, gasoline, electricity) (L/km or Kwh/Km) by their unitary CO_2 emission factor (gCO_2/ L or gCO_2/Kwh):

$$Emission\_Veh_i = \sum_t Consumption\_Energy_t * Emission\_Energy_t$$

When multiple cars are owned by the household, an average emission factor of the household cars is calculated ($Emission\_Veh_h = \frac{\sum_i Emission\_Veh_i}{Nb\_Veh_h}$). The same is done for the calculation of bicycles and motorcycles emission:

$$CO2\_Emission_{r,i,m} = Emission\_Veh_h * d'_r \quad (14)$$

For other modes of transport, we use the emission factors (gCO_2/km) provided by Transilien.com. For taxis and TOD, twice the emissions are counted to take into account empty trips.

Finally, the CO_2 cost is estimated by applying the official carbon price of CO_2 for 2018 (53 €/ tCO_2) (Commissariat général à la stratégie et à la prospective 2013).

3.3.4. Pollution Costs

For the pollution costs, we distinguish between the pollution that is borne by individuals and that is caused by them.

Calculation of the Pollution Caused

The external unit cost of local pollutants is provided by the French official guidelines. These values represent the damages due to PM2.5, NOx, COVNM and SO2, and depend on the density of the area crossed and on the vehicle fuel type. Using these values, the average pollution unitary cost of the household cars is calculated, with 5 distinct values depending on the density level.

For each trip, depending on its origin and destination, we calculate the emitted pollution cost being:

$$Pollution_{Cost_{trip}} = \sum_{zones} distance_{zone\_i} * 1.3 * cost\_pollution\_vehicle_{household_{zone\_i}} \quad (15)$$

For taxis and motorcycles, we use a unit cost per zone per kilometer of a mean vehicle (one for each). For trips by bus, the cost per individual is equal to the total bus pollution cost divided by 16, representing half the bus capacity. Finally, for other modes we assume for simplicity that the cost of pollution is zero.

Calculation of the Pollution Borne

The pollution cost borne is considered to be related to the time spent per each individual in a polluted zone. Six zones with decreasing density levels are defined in the Paris region, to which are associated different pollution costs, representing pollution emitted by private vehicles and by freight traffic. From the above calculation of the emitted pollution per individual, and the associated cost, the private vehicles related pollution is defined, to which we add the pollution costs associated with freight traffic that was calculated by Coulombel et al. (2018).

For each zone, a unitary pollution cost is calculated based on the number of individuals and the time they spend in the zone, reflecting the cumulative damage of the pollution. After calculating for each individual the time spent in each of these 6 zones, the pollution cost he bears can be computed.

3.3.5. Private Costs

Since private costs should reflect the costs borne by individual, we include monetary expenses, the opportunity cost of time, and the pollution borne cost.

3.4. Calculation of Inequality Indicators

We first apply Gini indicator to households equivalized incomes, before and after paying the travel expenses (by unit of consumption), so we can deduce whether expenses are increasing or reducing income inequalities. At this stage, to decompose the income inequalities between subpopulations, we use the equation (7) to perform the Gini index.

Then we use the decomposition of Gini by sources, by the method of Lerman and Yitzhaki, and by the Shapley value applied to the Gini formula of Lerman and Yitzhaki (to exclude the error resulting from the difference of the Gini equations). We decompose the Gini index of private costs to time cost, monetary cost and pollution borne cost since private cost is considered to be the sum of these three elements. Costs are invariably compared in units of individuals per household.

Finally, we decompose the population per equivalized income quartiles and per geographical departments, and apply the decomposed Gini by subpopulations, so we can compare the inequalities within and between quartiles, and within and between departments as well.

4. RESULTS

We show first the inequalities by comparing the means of the different cost items, between income quartiles and departments of residence. Then, we show the inequalities using the Gini index.

4.1. Means Comparison

4.1.1. Time Costs

Travel time varies in a nondirectional way between the departments (Figure 2). However, by comparing the average time by each mode, we can see that the residents of Paris spend the longest time in public transport, followed by the residents of the inner suburbs and finally the residents of the outer suburbs who spend almost half as much time as those of Paris. The opposite is observed for car travel time: the highest value is recorded in the outer suburbs, then this value decreases progressively as we get closer to Paris, arriving to Paris with a quarter value. Regarding active mode (walking and bicycle), we note the longest travel time in Paris. Walking time is slightly higher in the inner ring than the outer ring, while bicycle usage variation is more significant between the rings. These results are easily explained by the fact that Paris is very well served by public transport, and by the very high level of accessibility (the huge number of services available, and the very well connected network). Accessibility (both factors) decreases as one moves away from Paris, which is why residents of the outer suburbs depend heavily on their cars, and use active modes less frequently.

For the distribution between quartiles, it is noticeable that the poorest spend the least time travelling. Travel time by public transit and active modes is almost the same between quartiles; it is the time by car that makes this difference.

Figure 2. Average daily travel time (min) per income level and department

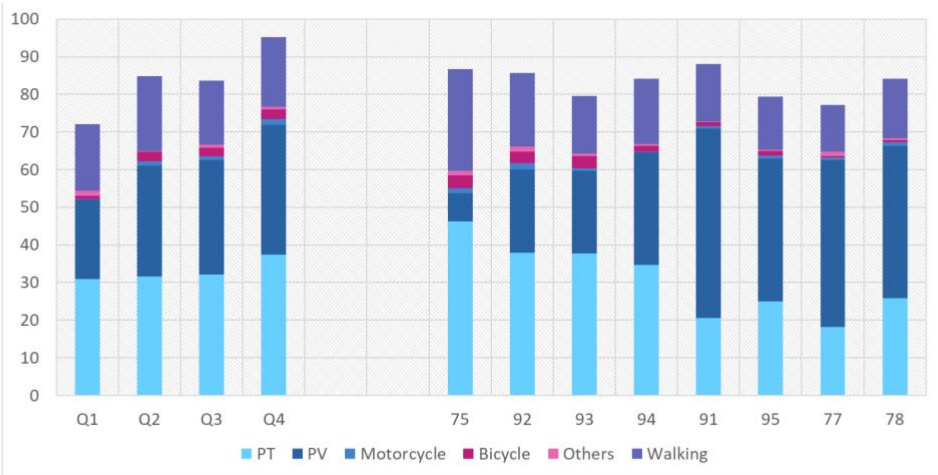
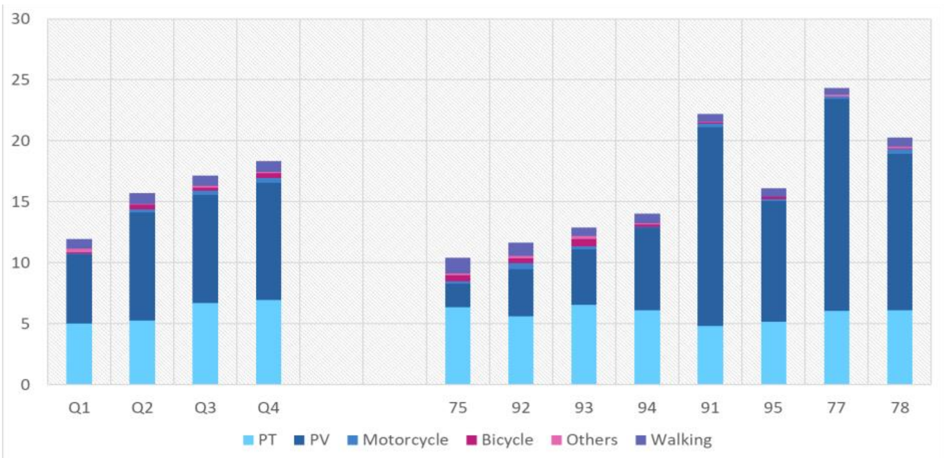


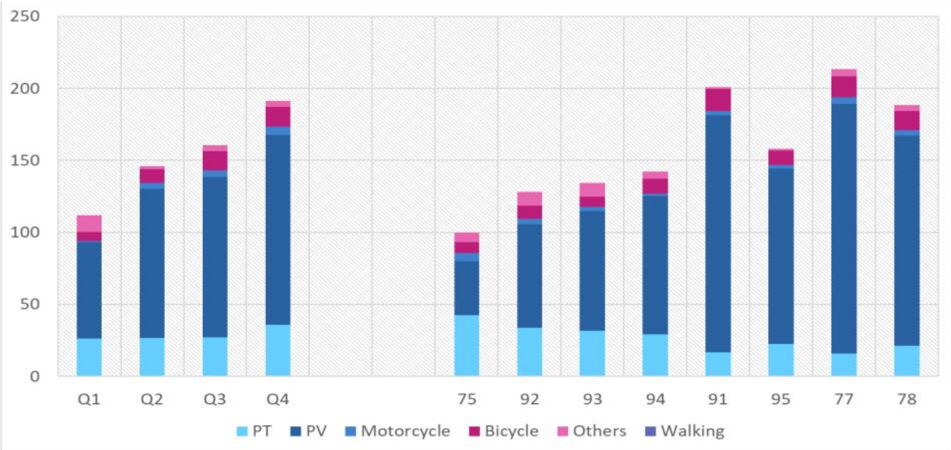
Figure 3. Average travel distance (Km) per household member



4.1.2. Travel Expenses

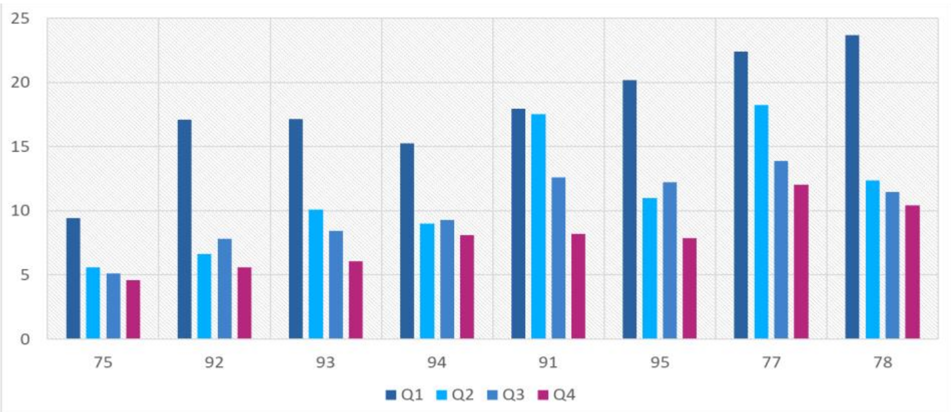
Travel costs strongly depend on the place of residence (Figure 4). Expenses on public transport are approximately the same in departments well served by public transports. In departments with poorer connectivity, residents rely more on their cars (Figure 3), pay more on their car usage, and less on public transport due to its limited use. Also, due to their distant residence, these people have to travel longer distances to reach the services they need. Added to the higher costs of cars compared to PT (per km), the residents of areas with under-served public transport suffer from higher expenses on average.

Figure 4. Average monthly travel expenses (€) per household member



When comparing between income quartiles, it is clear that low-income households pay less on transport, because of their limited use of private cars. Higher income households pay more on private cars because of their greater car use and car ownership rate. On average, all quartiles pay almost the same on public transport.

Figure 5. Transport expenses as a share (%) of income

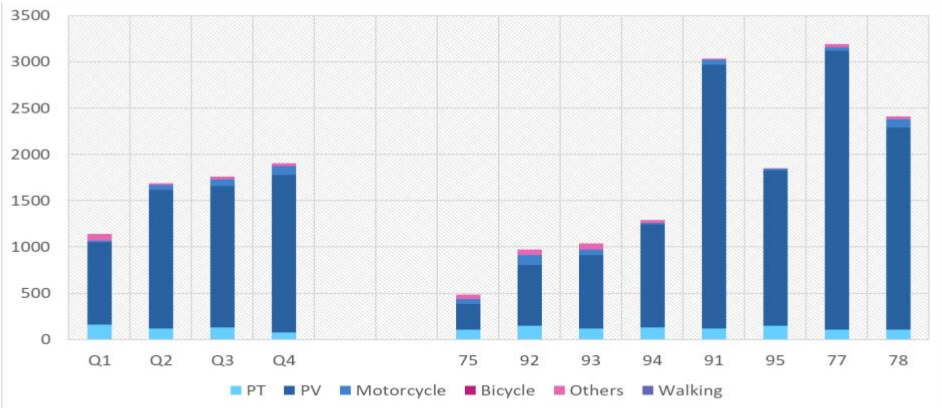


In figure 5, we show the transport burden representing the percentage of household travel expenses with respect to the household income. As expected, the highest budget share is observed in the 1st quartile due to its low income relative to the others. The transport budget share decreases progressively with the quartiles. It is also observed that, as one moves away from the city center, the transport burden increases for all quartiles, which is due to the car dependency.

4.1.3. CO_2 Emission Cost

Since CO_2 emissions are highly correlated with vehicles travelled distances, the same upward trend of increase with the distance from Paris and with the income is observed.

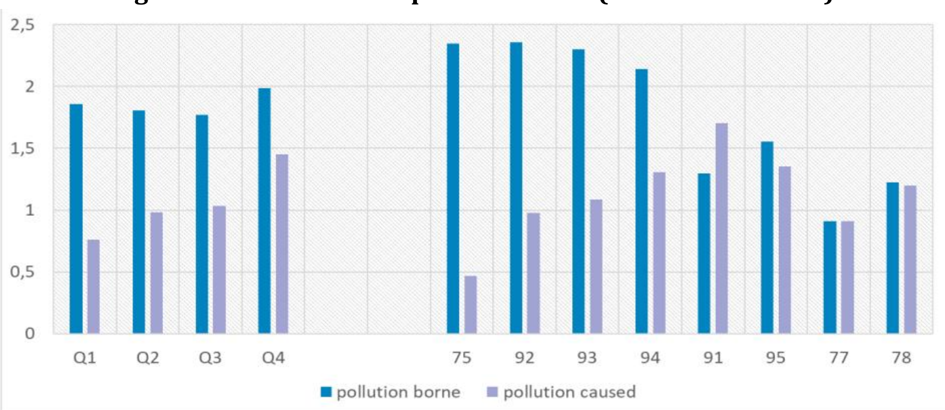
Figure 6. CO_2 emissions (gCO_2) per household member



4.1.4. Air Pollution Costs

Since air pollution costs are related to the density of the travelled area in addition to the kilometers travelled and the mode used, the distribution of air pollution costs caused by households does not have the same shape as that of travelled distances (Figure 7). The average pollution caused cost is lower than the pollution borne that is almost equal between quartiles. This is because freight transport, that is included in the pollution borne, and not included in the pollution caused, represents 55% of the air pollution in the IdF (Coulombel et al. 2018).

Figure 7. Distribution of pollution costs (borne and caused)



When comparing between departments, we note that the city center residents emit the lowest, because of their reliance on public transport. As far as we move away from the city center, the pollution caused cost increases. Regarding the pollution borne, as expected, the peak value is shown in the Paris city center, that is the most congested area.

Values in the inner ring are almost equal to the Paris value, but those in the outer ring are much lower; while the residents of Paris and the inner suburbs bear a cost 3 to 2 times higher than the cost they emit, those of the outer suburbs borne a cost smaller or slightly higher than the one they emit.

4.1.5. Private Costs

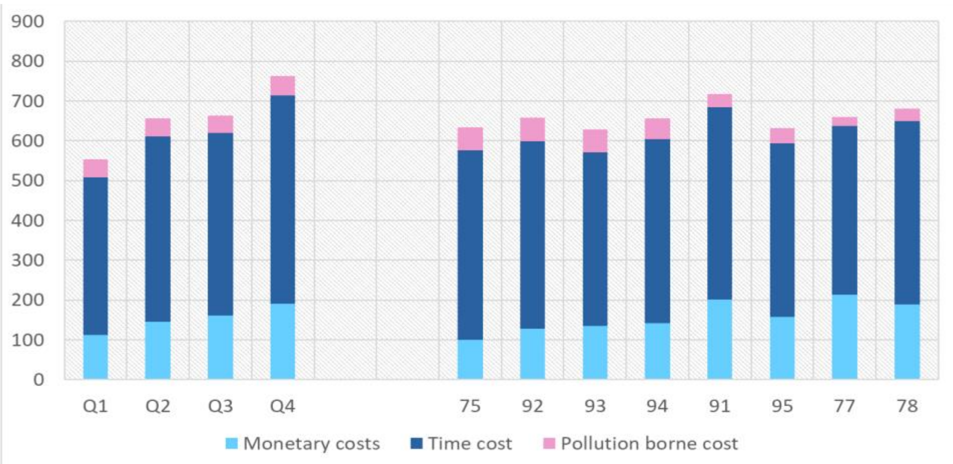
Comparing between departments, we note that costs are offset between them. Private costs values are close between departments, except for the 91th department that recorded the highest time cost and a high monetary cost.

Regarding the distribution between quartiles, we notice that the shape of the distribution remains always the same: the costs increase with the increase of the income.

4.2. Gini Index Comparison

Figure 8 gives us a first idea of the existing inequalities in terms of transport costs. However, the purpose of looking at the inequality is to better detect the vulnerable and to build on it to better target future projects. The graphs present averages by departure or quartile, without showing the existing heterogeneity in the same sub-population, which can greatly bias the results. In what follows, we show the Gini index between the total population, and also between the different sub-populations.

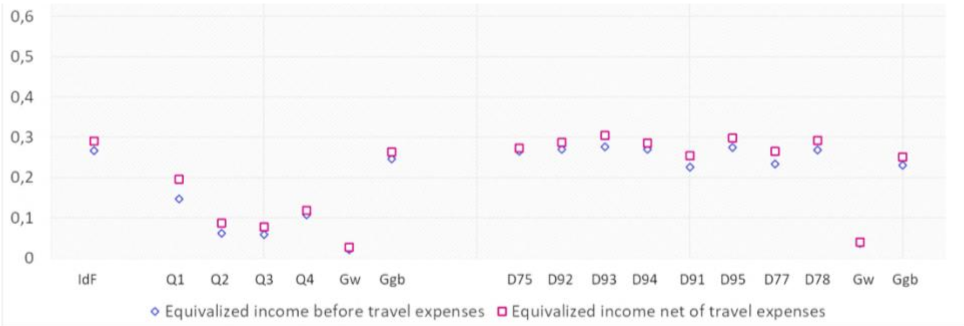
Figure 8. Monthly private costs (€) per household member



4.2.1. Income Inequality

In a first step, we compute the Gini index to the IdF households equivalized income, before and after deducting the monetary costs (per unit of consumption). The Gini index is 0.2672 and 0.2901, before and after considering the monetary costs respectively, which means that transport costs are increasing inequality in the IdF region.

Figure 9. Decomposed Gini index for equivalized income before and after monetary costs



Then, we decompose the income Gini index between quartiles and between departments (Figure 9). The inequality between quartiles (gross contribution of the between-inequality) contributes to 92% of the total inequality, and the inter-group inequality contributes only to 8% of the total inequality, we note that quartile 1 and 4 have higher within-group inequalities than quartiles 2 and 3, which is obvious because of the unbounded interval of each of these quartiles. When monetary costs are added, we observe an inequality increase within and between quartiles (8.68% increase in total inequality). Contribution of the intra and inter inequality remains almost the same: a slight increase of the contribution of the inequality within quartiles (2%) is observed Regarding the decomposition between departments, inequalities within departments contribute to 14% of total inequality.

After considering travel monetary costs, inequalities within and between departments increase.

4.2.2. Costs inequalities

Decomposition per subpopulation

Now, to complete the graphs already presented, we apply Gini of these costs to see the inter-group inequalities and to obtain a wider picture than the single averages (Figure 10 and 11).

Figure 10. Gini index values for travel costs (per individual per household)-decomposition per quartiles

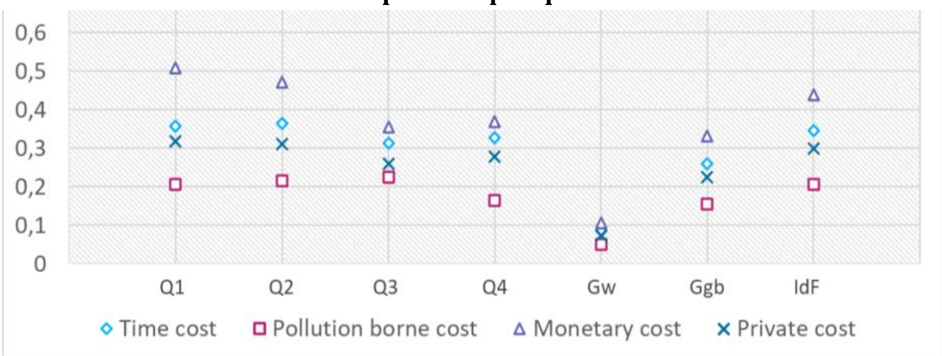
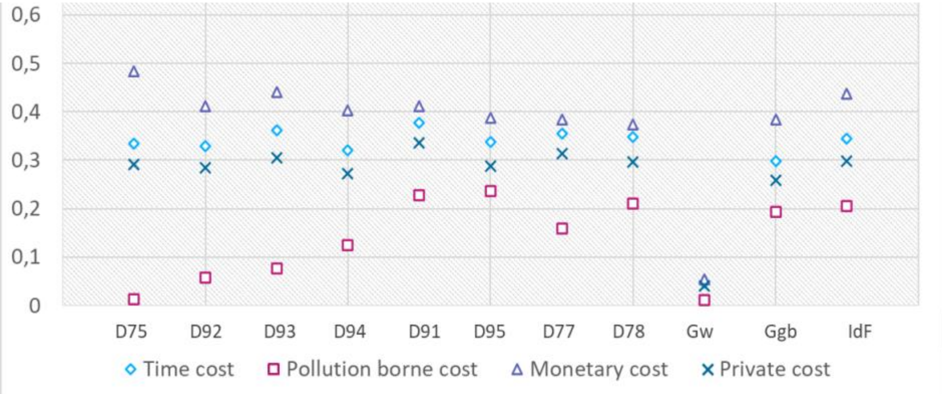


Figure 11. Gini index values for travel costs (per individual per household)-decomposition per departments



In line with the graphs shown before, monetary costs present the highest inequality at quartiles and departments levels as well at the IdF level. Time cost comes second, and the pollution cost comes third. Adding the three components together, private cost inequality decreases compared to time and monetary costs, which means that time cost and pollution costs offset monetary cost for a large group. Between-quartiles inequality is contributing by almost 75% to overall inequality, and within inequality is contributing by 25%. Regarding departments decomposition, between-departments inequality contributes to 86% to overall inequality, and within inequality contributes to 14%. The same applies to all components.

Decomposition per source

We decompose here private cost inequality between its components. Using Shapley and Lerman decomposition, applied to same Gini formula of covariance, we got almost the same results: private costs inequality in the IdF region is 0.297. Time cost, monetary costs and pollution borne inequalities contribute to private cost inequality by 78%, 21% and 0% respectively, based on Lerman decomposition, however both methods gave similar results (Table 2).

Table 2. Gini index of private cost decomposition

Distribution of transport costs (household costs/household size) (Monetary, time and pollution borne costs)										
Decomposition method		**Source α (Time cost)**			**Source ϒ (Monetary Costs)**			**Source ρ (Pollution Borne Costs)**		
		G	*S*	*C*	*G*	*S*	*C*	*G*	*S*	*C*
Lerman & Yitzhaki	0.292	0.442	71%	0.228 (78%)	0.367	22%	0.062 (21%)	0.197	7%	0.0012 (0.4%)
Shapley	0.292	0.442		0.244 (84%)	0.367		0.052 (18%)	0.197		0 (0%)

Note: "G" stands for Gini, "S" for budget share, and "C" for the contribution to the total Gini index as mentioned in equation (4).

This decomposition shows that time cost contributes to private inequality by 3.6 times the monetary cost, mainly because time cost has a very large share of the total budget (71%).

5. DISCUSSION AND CONCLUSION

This paper has investigated inequalities with respect to transport costs across income quartiles (vertical equity), and between geographical zones (horizontal equity). The study is based on a multi-factor approach: travel costs are broken down into monetary costs (including variable costs and fixed costs), time costs, and external costs (including air pollution and CO_2 emissions). We find first that travel monetary costs are regressive (Venter 2011), and they are the most unequally distributed dimension. Time costs contribute 3.6 times more to the private costs' inequality because of their high budget share. Pollution costs are almost equally distributed. Considering that they only account for 5.5% of the total private costs, this leads to an approximately null contribution to private cost inequality. Private cost inequality is lower than monetary cost and time cost inequality, which means that the various costs are indeed compensating each other.

Using the decomposed Gini between subpopulations, we find similar results regarding vertical and horizontal equity: while there exist some inequalities within subgroups (income quartile or departments), inter-group inequalities are much more significant.

Based on the breakdown of costs by mode, it is clear that as one moves away from the center of Paris, the use of the car becomes more and more frequent. More precisely, travel distance strongly increases with distance to the city center, especially so for car. This implies that monetary costs also strongly increase with distance from the center, which makes the residents of the periphery the ones who face the highest expenses. Comparing the transport burden between departments and quartiles, the highest values are recorded at the first quartiles and mainly at the outer suburbs, which makes these people more and more sensitive to changes of car prices and fuel prices. CO_2 emissions, which are directly related to fuel consumption, are more important for residents of the outer suburbs. On the other hand, one advantage for the residents of the outer suburbs is their exposure to air pollution, which is almost half of the pollution suffered by Parisians, while the former are the ones responsible for 50% the total air pollution in the Paris region. Finally, the travel time distribution is rather random across departments, although with significant changes in travel time per mode (with more use of the car in the periphery).

Regarding disparities between income quartiles, travel time increases with income, with a remarkable difference in travel time by car: quartile 4 spends by car 1.7 times the time spent by quartile 1. Travel time by other modes is almost equal across quartiles. Similarly, the mean daily distance varies between quartiles, especially so for car travel, quartile 1 travelling half the distance travelled by quartile 4. While travel expenses do increase with income as a result of the increase in car operating cost (longer distances and more energy consuming vehicles) and car ownership, the transport burden decreases as the income elasticity of transport expenses is lower than one, implying that low-income households face the greatest financial burdens. Finally, pollution borne is roughly the same across quartiles, while pollution caused is lower for low-income households. When expenditures, time and pollution borne are added together, each component increases with income, implying the increase of the private cost with income.

In short, inequalities in transportation costs are very marked between departments, despite the relatively balanced distribution of high and low-income households within the Paris region. Because of the low public transport accessibility, residents of the outer suburbs rely on their private cars to get around. While high-income households are able to cope with the high expenses, households in the 1st and 2nd quartile face the highest financial burden among all other segments; a similar result was found by Nicolas et al. (2012) in the case of Marseille, Lille and Bordeaux.

With this inequitable scenario, and the use of cars by the richest and by the most disadvantaged, the implementation of a more equitable policy is rather complicated. The uniform increase in fuel prices or the flat carbon taxes aiming to attenuate the environmental emissions of cars, will affect mainly the richest living in all the Paris region and the poorest living in the peripheries. But this increase, representing a modest budget for the rich, will highly affect the poor who already suffer from huge transportation expenses compared to the rest of the IdF residents (Berri et al. 2014).

A more equitable solution would be to implement targeted subsidies to these households after implementing fuel price increases, or to implement a progressive carbon tax. Encouraging the development of sectors in the outer suburbs, and providing it an accessibility comparable to that of Paris, will reduce the use of cars without imposing additional costs on this segment.

Our results are subject to a certain number of caveats. First, housing costs were not considered in the analysis, while these could party offset the greatest transport costs in the outer suburbs. Regarding this point however, Coulombel and Leurent (2013) found that households in the Paris region tend to consider each expense item – housing and transport – separately, meaning that there is no such (or very limited) compensation. Another limit of the analysis is that we were not able to precisely take into account transport subsidies and tax rebatements as these were not detailed, as well to count the public transport taxes paid by households to deduct the real costs paid. Lastly, trip frequency and trip purposes could be considered in future works: household living in deprived areas and having a budget constraint are forced to limit discretionary trips, thus risking social exclusion, while other households, living in the center, can travel longer and more frequently with lower or equal costs.

REFERENCES

Abdelwahab Bilal, Matthew Palm, Amer Shalaby, Steven Farber. 2021. Evaluating the equity implications of ridehailing through a multi-modal accessibility framework. *Journal of Transport Geography* 95.

ADETEC. 2020. « Le cout réel de la voiture en 2018 et son évolution depuis 2008 », on line.

Berri, Akli, Stéphanie Vincent Lyk-Jensen, Ismir Mulalic, Theodoros Zachariadis. 2014. « Household Transport Consumption Inequalities and Redistributive Effects of Taxes: A Repeated Cross-Sectional Evaluation for France, Denmark and Cyprus ». *Transport Policy* 36: 206‑216.

Bittencourt, Tainá A., Mariana Giannotti. 2021. « The Unequal Impacts of Time, Cost and Transfer Accessibility on Cities, Classes and Races ». *Cities* 116.

Bocarejo S., Juan Pablo, Daniel Ricardo Oviedo H. 2012. « Transport Accessibility and Social Inequities: A Tool for Identification of Mobility Needs and Evaluation of Transport Investments ». *Journal of Transport Geography* 24: 142‑154.

Cascajo, Rocío, Lourdes Diaz Olvera, Andrés Monzon, Didier Plat, Jean-Baptiste Ray. 2018. « Impacts of the Economic Crisis on Household Transport Expenditure and Public Transport Policy: Evidence from the Spanish Case ». *Transport Policy* 65: 40‑50.

Commissariat général à la stratégie et à la prospective. 2013. « Évaluation socioéconomique des investissements publics ».

INSEE, Comparateur de territoire 2019, on line: https://www.insee.fr/fr/statistiques/1405599?geo=DEP-75+DEP-92+DEP-93+DEP-94+DEP-91+DEP-95+DEP-77+DEP-78.

Chantreuil, Frédéric, Trannoy, Alain. 1999. « Inequality Decomposition Values: The Trade-off Between Marginality and Consistency ». THEMA. DP 99-24.

Coulombel, Nicolas, Laetitia Dablanc, Mathieu Gardrat, Martin Koning. 2018. « The environmental social cost of urban road freight: Evidence from the Paris region ». *Transportation Research Part D*: D63: 514-532.

Coulombel, Nicolas, Fabien Leurent. 2013. « Les ménages arbitrent-ils entre coût du logement et coût du transport : une réponse dans le cas francilien ». *Economie et Statistique* 457‑458: 57‑75.

Dagum, Camilo. 1997. « A New Approach to the Decomposition of the Gini Income Inequality Ratio ». *Empirical Economics* 22: 515‑531.

di Ciommo, Floridea. 2018. « How the Inaccessibility Index Can Improve Transport Planning and Investment ». Documents de travail du Forum international des transports, 2018/08, Éditions OCDE, Paris.

El-Geneidy, Ahmed, David Levinson, Ehab Diab, Genevieve Boisjoly, David Verbich, Charis Loong. 2016. « The Cost of Equity: Assessing Transit Accessibility and Social Disparity Using Total Travel Cost ». *Transportation Research Part A: Policy and Practice* 91: 302‑316.

Fourrey, Kevin. 2019. « Décomposition des indices d'inégalité et impact des politiques publiques ». Normandie Université.

Gandelman, Néstor, Tomás Serebrisky, Ancor Suárez-Alemán. 2019. « Household Spending on Transport in Latin America and the Caribbean: A Dimension of Transport Affordability in the Region ». *Journal of Transport Geography* 79.

Gebremeskel, Eleni, Mintesnot Woldeamanuel, Berhanu Woldetensae. 2022. « Transport Vulnerability: Measuring Travel Time and Expenditure Budget in Addis Ababa ». *Research in Transportation Economics*.

Golub, Aaron, Karel Martens. 2014. « Using Principles of Justice to Assess the Modal Equity of Regional Transportation Plans ». *Journal of Transport Geography* 41: 10‑20.

Guo, Yujie, Zhiwei Chen, Amy Stuart, Xiaopeng Li, Yu Zhang. 2020. « A Systematic Overview of Transportation Equity in Terms of Accessibility, Traffic Emissions, and Safety Outcomes: From Conventional to Emerging Technologies ». *Transportation Research Interdisciplinary Perspectives* 4.

Iglesias, Vicente, Francisca Giraldez, Ignacio Tiznado-Aitken, Juan Carlos Muñoz. 2019. « How Uneven Is the Urban Mobility Playing Field? Inequalities among Socioeconomic Groups in Santiago De Chile ». Transportation Research Record: *Journal of the Transportation Research Board* 2673 (11): 59‑70.

Jin, Tanhua, Long Cheng, Kailai Wang, Jun Cao, Haosheng Huang, Frank Witlox. 2022. « Examining Equity in Accessibility to Multi-Tier Healthcare Services across Different Income Households Using Estimated Travel Time ». *Transport Policy* 121: 1‑13.

Lerman, Yitzhaki. 1984. « A Note on the Calculation and Interpretation of the Gini Index ». *Economics Letters* 15: 363‑368.

Leroutier, Marion, Philippe Quirion. 2022. « Air Pollution and CO2 from Daily Mobility: Who Emits and Why? Evidence from Paris ». *Energy Economics* 109.

Lucas, Karen, Karel Martens. 2019. « 19- Conclusions ». In *Measuring Transport Equity,* Elsevier.

Lucas, Karen, Giulio Mattioli, Ersilia Verlinghieri, Alvaro Guzman. 2016. « Transport Poverty and Its Adverse Social Consequences ». *Proceedings of the Institution of Civil Engineers - Transport* 169 (6): 353‑365.

Mueller, Natalie, David Rojas-Rueda, Haneen Khreis, Marta Cirach, Carles Milà, Ana Espinosa, Maria Foraster, al. 2018. « Socioeconomic Inequalities in Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment Study for Bradford, UK ». *Environment International* 121: 931‑941.

Nicolas, Jean-Pierre, Nicolas Pelé. 2017. « Measuring Trends in Household Expenditures for Daily Mobility. The Case in Lyon, France, between 1995 and 2015 ». *Transport Policy* 59: 82‑92.

Nicolas, Jean-Pierre, Florian Vanco, Damien Verry. 2012. « Mobilité quotidienne et vulnérabilité des ménages ». *Revue d'Économie Régionale & Urbaine* (1): 19‑44.

Pereira, Rafael H. M., Tim Schwanen, David Banister. 2017. « Distributive Justice and Equity in Transportation ». *Transport Reviews* 37 (2): 170‑191.

Poulhès, Alexis, Laurent Proulhac. 2022. « Exposed to NO2 in the Center, NOx Polluters in the Periphery: Evidence from the Paris Region ». *Science of The Total Environment* 821.

Sastre, Mercedes, Alain Trannoy. 2002. « Shapley Inequality Decomposition by Factor Components: Some Methodological Issues ». *Journal of Economics* 9: 51‑89.

Souche, Stéphanie, Aurelie Mercier, Nicolas Ovtracht. 2016. « The Impacts of Urban Pricing on Social and Spatial Inequalities: The Case Study of Lyon (France) ». *Urban Studies* 53 (2): 373‑399.

Valenzuela-Levi, Nicolás. 2021. « The Rich and Mobility: A New Look into the Impacts of Income Inequality on Household Transport Expenditures ». *Transport Policy* 100: 161‑171.

Venter, Christoffel. 2011. « Transport Expenditure and Affordability: The Cost of Being Mobile ». *Development Southern Africa* 28 (1): 121‑140.

Zuurbier, Moniek, Gerard Hoek, Marieke Oldenwening, Virissa Lenters, Kees Meliefste, Peter van den Hazel, Bert Brunekreef. 2010. « Commuters' Exposure to Particulate Matter Air Pollution Is Affected by Mode of Transport, Fuel Type, and Route ». *Environmental Health Perspectives* 118 (6): 783‑789.

À quel point les coûts de transport sont-ils inégaux pour les ménages ? Le cas de l'Ile-de France

Résumé - Cet article étudie la distribution des coûts de transport subis par les ménages franciliens en fonction du niveau de revenu et du lieu de résidence, à partir de l'enquête globale de transport 2018. Les coûts considérés sont : les coûts monétaires, les coûts en temps, les coûts liés à la pollution de l'air (en distinguant la pollution émise et celle subie par les ménages) et les coûts liés aux émissions de CO_2. Nous étudions la distribution de chaque dimension seule, ainsi que la relation entre elles. Les inégalités de coûts sont étudiées en comparant les moyennes arithmétiques et l'indice de Gini. La décomposition de Gini par sous-population (quartiles de revenu et départements) et par composantes des coûts privés est appliquée. Les résultats montrent que les coûts monétaires sont régressifs et représentent la dimension la plus inégalement répartie entre les groupes de revenus et les départements, avec les ménages à bas revenu, résidant dans les banlieues extérieures (ménages dépendants de la voiture) confrontés aux taux d'effort les plus élevés. Le coût du temps est aléatoirement réparti entre les départements, mais il dépend du revenu des ménages. La pollution supportée par les habitants des banlieues est la plus faible et presque égale entre les quartiles de revenus. Les coûts sont compensés entre eux puisque le coût privé total (la somme des coûts monétaires, du temps et de la pollution) a un indice de Gini plus faible. Les inégalités de coûts au sein des quartiles de revenus et des départements sont importantes, mais contribuent peu à l'inégalité globale par rapport aux inégalités entre eux. Le coût du temps contribue à 75 % des inégalités de coûts privés en raison de sa part importante dans les coûts, et les coûts monétaires ne contribuent qu'à 25 %. Ces résultats soulignent l'importance cruciale de la prise en compte de l'équité dans la conception des politiques afin d'épargner les personnes défavorisées en matière de transport et d'empêcher l'accroissement des inégalités.

Mots-clés

Équité
Effets redistributifs
Coûts de déplacement
Indice de Gini