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Promoting urban carpooling: A social cost approach based on the eastern Lyon case study

Promouvoir le covoiturage urbain : une approche par coût social à partir du cas de l'Est lyonnais

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This paper investigates the impacts of a rise in fuel prices and of a dedicated lane for carpoolers on the social cost of transportation. The analysis is based on a zoning covering the eastern Lyon area, where transport supply is characterized, and a modal choice model is applied to traffic flows across origin-destination pairs (ODs). The social cost includes consumers' generalized costs, externalities, and the expenses and revenues of public authorities and private operators. Four transport modes are considered: solo driver, carpool driver, carpool passenger, and public transport. Our results show that consumer's costs explain the majority of the social cost. Values commonly used for externalities barely impact the social cost and traffic reduction measures impact public and private revenues more than they reduce externalities. Moreover, results illustrate significant variations at the geographical scale, depending on the ODs where the scenarios are applied. These results suggest implementing daily-carpooling incentives should be decided conscientiously considering local travel patterns.

Keywords: social cost analysis, transport policies, carpooling, daily mobility

Cet article analyse les impacts d'une hausse du prix des carburants et d'une voie réservée au covoiturage sur le coût social total des déplacements. L'étude repose sur un zonage situé dans l'est lyonnais, pour lequel l'offre de transport est caractérisée et sur un modèle de choix modal appliqué sur les flux entre les couples origine-destination. Il comprend les coûts généralisés supportés par les usagers, les externalités, ainsi que les dépenses et recettes des acteurs publics et privés. Quatre modes de transport sont considérés : conducteur solo, conducteur covoiturage, passager covoiturage et transport en commun. Les résultats montrent que les coûts supportés par les usagers représentent la majeure partie du coût social total. Les valeurs couramment utilisées pour monétariser les externalités ont un impact limité sur le coût social, et les mesures de réduction du trafic affectent davantage les recettes publiques et privées qu'elles ne réduisent les externalités. Par ailleurs, les résultats révèlent de fortes variations selon les zones géographiques concernées. Ces éléments soulignent l'importance d'adapter les politiques d'incitation au covoiturage aux dynamiques locales de déplacement.

Mots-clés : analyse des coûts sociaux, politiques de transport, covoiturage, mobilité quotidienne

JEL Codes: D61, D62, L92, L98

Introduction

The sustainability and efficiency of transportation systems have become critical concerns due to widespread use of individual motorized vehicles. Solo driving accounts for the vast majority of car commuting trips. In France, the most recent national survey (SDES, 2021) shows that 88% of car commuting trips¹ are made alone.

By improving the occupancy rate of vehicles, carpooling is often cited as a solution to reduce traffic nuisances in daily mobility, such as pollution or greenhouse gas emissions (Caulfield, 2009; Shaheen *et al.*, 2018), congestion—averaging 138 hours in 2021 for an average driver in Paris (INRIX, 2022)—and parking issues—40m² per car (Héran & Ravalet, 2008).

Recent studies highlight the complexity of carpooling practices. In low-density areas, carpooling is often driven by economic motives and social solidarity, while it is adopted in urban areas more due to positive perceptions of collaborative economies (Pigalle & Aguiléra, 2021). Incentives also play a crucial role in promoting carpooling, with financial and non-financial measures (e.g., time saving, trust-building) proving effective. Psychological incentives particularly influence women's participation, both as drivers (Bulteau *et al.*, 2021) and as preferred travel partners on digital platforms due to perceived safety and trust (Farajallah *et al.*, 2019; Le Goff *et al.*, 2025).

However, several individual-level barriers to carpooling remain. Behavioral obstacles such as lack of trust (Ter Huurne *et al.*, 2017), scheduling difficulties (Furuhata *et al.*, 2013), and the perceived loss of autonomy (Vincent, 2008) hinder its widespread adoption. Moreover, carpooling can compete with public transport rather than solo driving, especially in urban areas, raising concerns about its actual environmental benefits (Aguiléra & Pigalle, 2021). While digital platforms like BlaBlaCar have expanded access to carpooling (Shaheen *et al.*, 2017), their impact remains limited for short-distance commutes². Sustaining carpooling initiatives is also challenging due to their dependence on informal networks or associative efforts and limited long-term public support. Additionally, carpooling often involves longer travel times and logistical uncertainties, which reduce its attractiveness. Infrastructure such as high-occupancy vehicle (HOV) lanes

1 |Trips shorter than 80 kilometers for professional purposes.

2 |Carpooling is difficult to measure precisely due to the large share of informal trips not recorded by platforms according to the French National Observatory of Daily Carpooling (Observatoire national du covoiturage au quotidien, 2022). As a rough estimate, however, it remains a marginal practice: according to the Forum Vies Mobiles (2023), daily carpooling through platforms accounts for less than 0.05% of distances traveled by car.

and restrictions on solo driving are considered necessary to enhance its viability (Crozet, 2022).

At the collective level, carpooling policies may lead to unintended rebound effects (Coulombel *et al.*, 2019). For instance, lower kilometric costs could increase the attractiveness of car use, potentially shifting demand away from public transport. It could also increase trip distances or induce new travel demand, raising the number of vehicle kilometers and associated external costs.

To measure potential impacts of several scenarios on carpooling usage, we employ a cost-benefits analysis (CBA) framework which is widely used in transport economics. Most of the time, CBA evaluates transport policies by quantifying three cost categories: infrastructure and operational expenditures, user costs (time, reliability, accessibility), and externalities (CO₂ and pollutant emissions, noise, accidents, congestion). They make it possible to estimate the efficiency of policy measures and select the best ones. Many applications of CBA can be found in the literature: Wang *et al.* (2015) look at cordon toll and bus frequency in Madrid, Sisiopiku *et al.* (2010) study HOV lanes and Monchambert & Proost (2019) analyze congestion delays for rail network. Other examples are Koning *et al.* (2018) who investigate policies aimed at decarbonizing road freight transport or Proost (2024) who incorporates slot allocation costs for congested airports.³

The main objective of this paper is to evaluate how carpooling incentives or external shocks affect collective welfare. We therefore test how consumer costs, external costs, and public and private profits vary across two main scenarios, including time savings for carpoolers and the rise in fuel prices for cars. As such, we test both a time and a monetary scenario that positively impact carpooling through a direct incentive for carpoolers and a constraint on drivers.

In recent years, French public authorities have been trying to democratize the practice of carpooling for commuting trips. For example, a law was passed in 2015 to enable companies to facilitate carpooling for their employees.⁴ Locally, public authorities are also setting up reserved parking lots or matchmaking platforms, as well as reductions in motorway tolls for carpoolers. This is coupled with a tax exemption for employees who

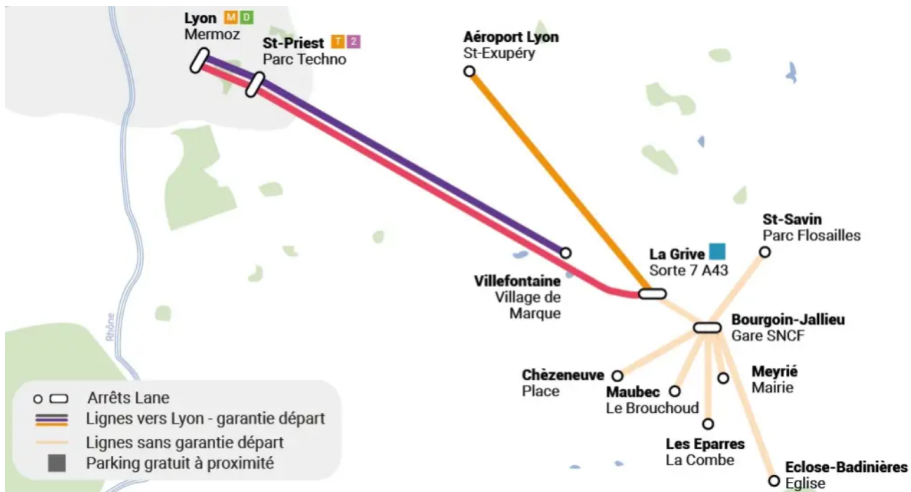
3 |It is also possible to adapt CBA to a transportation mode—e.g. Litman (2025) and Gössling *et al.* (2019) quantify health co-benefits from increased active mobility—or to innovative services—e.g. Becker *et al.* (2020) evaluate willingness to pay for Mobility as a Service (Maas).

4 |https://www.legifrance.gouv.fr/jorf/article_jo/JORFARTI000031044948

organize carpooling to work⁵ and the Mobility Orientation Law⁶ that allows local authorities to set up reserved lanes or stations for carpooling. While HOV lanes are common in North America, the only reserved lanes in France (prior to 2020) were bus lanes.

Since the French citizens commute more with public transport than with carpooling, the start-up Ecov created a service similar to public transport. Carpooling lines are proposed, with predefined stops and station commodities where passengers can check in and wait for their carpoolers as they would do with high-frequency public transportation. One of these routes—called LANE—connects the city of Lyon (1.4 million inhabitants) with Bourgoin (50,000 inhabitants), located 50 kilometers to the southeast along a major highway (Figure 1). With this service, passengers are guaranteed to find a driver within 20 minutes.⁷ Drivers are informed of waiting passengers via traffic signs upstream of the stop. Each passenger transported earns them €2, regardless of distance.

Figure 1: The LANE service between Lyon and Bourgoin-Jallieu (Ecov)



This paper analyzes the impacts of such a service, along with various incentive levels and price configurations, from both an individual and collective point of view.

The cost components of this study are derived from transport supplies and flows obtained for 6,287 different origin-destination pairs (ODs) in the eastern Lyon area. We then estimate modal shares using a modal choice

5 | <https://www.ecologie.gouv.fr/covoiturage-en-france-avantages-et-reglementation-en-vigueur>

6 | <https://www.senat.fr/petite-loi-ameli/2018-2019/369.html>

7 | If the 20-minute delay is exceeded, the start-up will pay a taxi to get them to their destination.

model calibrated on a stated preference survey realized in 2019 among 2,515 commuters of the Lyon area (see details in Le Goff *et al.*, 2022). Once modal shares are obtained, we infer the four components of social cost (consumer cost, externalities, and public and private revenues). This allows us to compare social costs and analyze the spatial heterogeneity of policy effects between ODs.

Results indicate that consumers' costs constitute the main component of the social cost. Externalities appear to have a limited impact in our simulations. Traffic reduction measures also appear to impact public and private revenues more than they reduce external costs, leading to higher social costs. Moreover, results indicate significant variations depending on the trips where the policies are applied.

The next section presents our modelling strategy. In section 3, we describe the data used and scenarios tested. Results are then reported and discussed in section 4 before we conclude in the final section.

1. Modelling strategy

1.1. Social cost function

The social cost (SC) is made up of four main aggregates: generalized costs for travelers, external costs, the public authorities' deficit and private companies' deficit⁸,

$$SC = \sum_k \sum_j GC_{kj} + EC_{kj} + PuD_{kj} + PrD_{kj} \quad (1)$$

Where k stands for the OD pair and j for the transport mode. We consider four modes: solo driver (SD), carpool driver (CD), carpool passenger (CP) and public transport (PT).

The travel generalized cost (GC_{kj}) has two main components. The first one is the monetary cost of the trip. This includes gasoline expenditures, tolls and fees for SD, CD and CP, as well as PT fares. The second part of GC_{kj} is the valuation of the time spent in transportation. Since the value of time (VoT) varies depending on the stages of the trip and on the mode (Wardman *et al.*, 2016), we consider in-vehicle, waiting, detour, and access/egress travel times.

The external costs (EC_{kj}) also contain several elements. First, we focus on the sanitary and material damages related to local pollution (NO_x , PM_{10} ,

⁸ | We use deficits rather than profits to avoid negative components in the equation as the analysis is conducted in terms of costs.

NH_3 , SO_2). We also consider climate change, accident and noise costs. For the sake of simplicity, we deliberately assume that PT do not generate any external cost.⁹

The public authorities' deficit (PuD_{kj}) is affected by wear and tear costs on non-tolled roads, i.e. the non-highway network. Other public costs come from subsidies provided to the private firm that operates the carpool platform. By contrast, public finance incomes originate from fuel and corporate taxes on highway companies. Since the PT supply is assumed to remain constant, operating costs are invariant and only the differences in revenues from PT fares are computed. Our analysis accounts for the opportunity cost of public funds that expresses individuals' losses in satisfaction due to the fact that taxes must be raised to fund changes in PuD_{kj} .

The last component of SC is made up of the private firms' deficit (PrD_{kj}). The earnings of the highway manager come from tolls paid by SD and CD and expenses from the road wear costs as well as taxes paid on profits. Regarding the carpooling service provider, it is assumed that operational costs are covered by public subsidies. In fact, monetary transfers between CP and CD are strictly equal, so that the platform does not earn any profit.

In addition to estimating SC, we also estimate CO_2 abatement costs with respect to the benchmark situation:

$$AC = \frac{\Delta GC + \Delta EC^* + \Delta PuD + \Delta PrD}{\Delta \text{CO}_2} \quad (2)$$

Note that ΔEC^* in the numerator does not include the valuation of CO_2 changes.

1.2. Empirical approach

For the benchmark situation, we first define transport supplies in terms of distances, travel times, and costs for every OD in the zoning, as well as for all modes. This information then serves as input to a modal choice model to estimate the flows for each mode and each OD. Given the assumed transport supplies and VoTs as well as other parameters found in literature, these modal shares then allow us to obtain the different components of SC. This whole process is duplicated for the different scenarios under study, considering their impacts on the initial transport supply (hence on modal shares and cost components).

Instead of using kilometric monetary values, as done for external costs of noise and accidents, we instead estimate the quantity of local

9 | This is consistent with our working assumption of constant PT supply.

pollutants and CO₂ emitted according to the Computer Program to calculate Emissions from Road Transport (COPERT) framework (see EMEP/EEA, 2019). To do so, we make assumptions on vehicles' speeds and fleet structures. Estimated emissions are then translated into monetary equivalents by using cost factors proposed by the European Commission handbook (Essen *et al.*, 2020).

1.3. Scenarios

The benchmark situation for which SC is first computed corresponds to the current LANE supply over the Lyon-Bourgoin axis. Carpooling trips are done in real time with a numeric platform that connects CP and CD. Meeting points are materialized at LANE stations, CP pay CD €2 for their journey, the platform making no margin on this transaction.

We focus here on two illustrative cases:

- The “HOV” scenario which simulates the implementation of an HOV lane. It affects the travel times of the three car modes. It is considered that the HOV lane is implemented on every highway section of the trip. This scenario implies time gains for carpoolers (equivalent to a speed gain of around 10km/h) and time losses for SD (equivalent to a speed loss of around 5km/h).¹⁰
- The “Fuel Price +” scenario simulates an increase in fuel prices from €1.7/L to €2.5/L only for car modes. Since taxes on gasoline are assumed to be proportional to prices before tax, this scenario implies increases in public earnings.

2. Data

2.1. Transport supplies

The benchmark transport supplies and flows on each OD are based on the MOBPRO database (INSEE, 2019). Only home-work trips originating in or going to the Rhône department (the French administrative region between the region and commune level) where the city of Lyon is located were selected. Some city territories are disaggregated according to a 1-km grid to gain precision. The zoning is presented on Figure 2.

Distances are calculated following the car trip from OD, considering the potential detour to carpool and PT stations. Toll costs and travel times (for

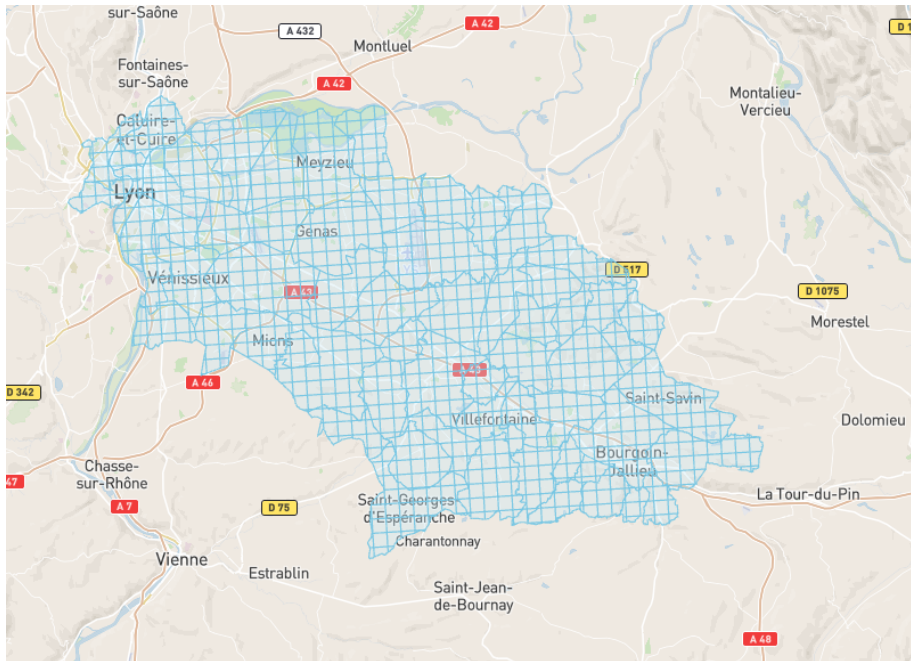
10 | Travel time variabilities are also reduced—for CD and CP—or raised—for SD—by the same amount.

peak and off-peak periods), at the OD level, are estimated via open-source API calls (from averages over Tuesdays in December 2021, excluding school vacations). Waiting times depend on the mode:

- 5 minutes for PT, assuming travelers arrive at the stop shortly before their departures.
- 7 minutes for CP, considering the 4-minute average waiting time in peak hours and 3 additional minutes to account for what passengers consider a “usual maximum time” (by contrast, CD do not wait).

Fuel prices are calculated from the distance via an average ratio (MTE, 2019)¹¹ and an initial price of €1.7/L. PT fares are equal to €0.8/trip.

Figure 2: Zoning considered in the survey (source: authors)



11 |We use values from the French Ministry of Ecological Transition (MTE). The kilometric value is calculated with the cost and the average vehicle fleet of the year 2021, by extrapolation from the 2015 and 2030 values. The value obtained is 0.0878 €/km.

2.2. Modal choices

In order to estimate modal shares, we assume that individuals choose the transport alternative that provides with them the highest utility (Walker & Ben Akiva, 2002),

$$U_{ik} = ASC_k + \beta_{tt_k} * TT_{ik} + \beta_{tv_k} * TV_{ik} + \beta_{at_k} * AT_{ik} + \beta_{wt_k} * WT_{ik} + \beta_{dt_k} * DT_{ik} + \beta_{cost} * Cost_{ik} + \beta_{cont_k} * Con_{ik} \quad (3)$$

Where U_{ik} represents the deterministic part of the individual utility in OD i for mode k . Each mode is considered to have its own value for alternative specific constant (ASC), in vehicle travel time (TT) and travel time variability (TV), which is considered in this study as the difference between the “empty-road” travel time and the peak-period travel time. Variables AT, WT and DT stand for access/egress, waiting and detour times respectively. Cost represents the monetary cost (net of earnings for CD) of the alternative and Con the number of connections in the trip.

We rely on data from a survey conducted in 2019 on 2,515 commuters in the Lyon region (see Le Goff *et al.*, 2022) in order to estimate the parameters shown in equation (3). As detailed in Le Goff (2023), our econometric model behaves consistently and exhibits expected signs for marginal disutilities (the different β s).¹²

By crossing, for each OD and each mode, the transport supply with this choice model, we predict modal shares. Since the number of CD found at this step often exceeds the number of CP, we assume that the effective CD share is limited by passengers and that the surplus of drivers (those who do not find a passenger) finish their trip as SD.

2.3. Data filtering and model calibration

In order to calibrate this behavioral model, we use data from MOBPRO (INSEE, 2019) and we compare modal shares observed between private cars and PT for some ODs in this database to those given by our econometric model. The latter globally underestimated PT shares. This led us to test by regression if the predictors for the different components of utility function were correctly estimated. Doing so, we raised the impact of transfers on our utilities, lowered the travel time variability for trips to the city center and adjusted the PT constant to obtain modal shares very close those observed in the MOBPRO census.

12 | This model also includes a “platform effect” (see Le Goff, 2023), which has a positive influence on the utilities of carpooling modes, and which is included in the reference scenario here.

The initial database contained slightly less than 300,000 different ODs. We first removed the ODs in which the number of flows was critically low—such as 1-km squares with no habitations and/or jobs. We then removed two thirds of the ODs, but we conserve 98% of the total flows in the database. In a second data filtering, we decided to remove any OD in which the carpool supplies could not be estimated. Thus, we can apply our model to the remaining ODs. The final database contains 6,287 ODs. Descriptive statistics of the transport supplies for an average OD in this final setting are presented in Table 1. They underline how heterogeneous the PT supply is across the ODs, with important standard deviations.

Table 1: Descriptive statistics of an average trip

	Mean	Sd
Road distance	35 km	5.5
Of which highways	25 km	5.9
Car travel time	28 min	4.9
PT travel time	37 min	13.8
#PT transfers	0.8	0.5
Access Carpool station	5 min	2.6
Access PT station	13 min	5.9

Notes: Values are weighted by flows and rounded.

2.4. Cost structures

We briefly present the different values used to calculate the social cost. Again, more details can be found in Le Goff (2023)¹³.

Starting with VoTs, we do not use those that can be found using our econometric modelling but rather “official” ones. Quinet (2014) thus recommends that on-board values vary depending on the mode and the distance. Considering an average distance of 35 km, we find 9.9€/h for private cars and 11.1€/h for PT. In practice, VoTs were adjusted for each OD and each mode. Also, we assume that VoTs for CD and CP are identical to the one for SD. Therefore, the time spent alone on the trip (before the carpooler is picked up), during the detour and the time effectively carpoled (i.e., when both driver and passenger share the car) are grouped together and multiplied by the on-board VoT.

When considering other stages of the trip, Quinet (2014) recommends formulas that directly depend on the on-board VoT for each mode. For the

13 |All monetary values from the literature are expressed in €₂₀₁₆.

connections, it is advised to double the benchmark VoT. In terms of waiting and access/egress times, it is considered that they should be valued the same way as connection times, i.e. twice the VoT. Detour time is not mentioned in the report and will be valued the same as the value of in-vehicle travel time.¹⁴

To calculate emissions due to local pollutants and CO₂ based on the COPERT approach, we consider that the vehicle fleet is split into five main categories: petrol eu3 (2% of the fleet), petrol eu6 (21%), diesel eu3 (6%), diesel eu6 (70%) and, finally, electric vehicles (1%).¹⁵ The values for pollutants considered in this study are considered in Table 2.¹⁶ External costs of noise and accidents are valued thanks to Bergerot et al. (2021). For noise, the value for highways is 0.006€/vkm and 0.034€/vkm for urban roads. Accidents are valued on all roads at 0.031€/vkm.

Table 2: Costs of local pollutants and CO₂ in France (€/kg)

	NOx (rural)	NOx (city)	PM10	SO2	NH3	CO2
Cost	14.8	27.2	24.7	13.9	15.4	0.1

Expenses for public finance and the highway company are the costs of road wear, valued at 0.008€/vkm by Bergerot et al. (2021). Public finance benefits from fuel taxes, approximated to 60% of the fuel cost defined in the transport supply, and from the corporate income tax (assumed at a 25% rate on highway companies' profits). Thanks to the toll grid of the highway company, we estimate by regression that the average toll is 0.11€/km. Finally, the operational cost of the carpool platform is covered by a public subsidy here estimated at 200,000€/year. Importantly, all expenses and revenues for public finance will be multiplied by 1.2 considering the opportunity cost of public funds, as recommended by Quinet (2014).

14 |For travel time variability, Quinet (2014) considers an adaptative valuation based on travel time distribution. Our assumptions (uniform distribution of travel times and constrained trips, see Le Goff [2023] for more details) lead to valuing variability at the same level as in-vehicle travel time.

15 |Traffic speeds are computed by crossing travel times and traveled distances.

16 |NOx values depend on whether pollutants are emitted in or outside the city. Since most of trips connect urban centers, we assume that 75% of the non-highway distances are on “urban” roads and 25% on “non-urban” roads. The distances travelled on highways are considered to be driven on “non-urban” roads. Knowing that the average toll is €0.11 per km driven on the highway and the level of the toll in the transport supply, for a given OD, we can approximate the distance on highways per OD (i.e., 9.1 km per € paid on average).

3. Results

3.1. Reference scenario

Table 3 displays the main components of social cost and their variations between the three scenarios. The first results indicate that, in the LANE benchmark situation, average trip costs are equal to €14.85 per capita to the community. The social cost is mainly driven by the level of the consumers' costs. Indeed, its absolute value is much larger than the other components of the social cost. A detail of each social cost component is provided in the Appendix. Another important result in this table is the negative sign of public and private deficits, meaning public authorities and private companies earn more than they spend in our simulations.

Considering the modal shares, it should be noted that the low number of CPs limits the number of CDs. In the reference case, the model predicts a CD modal share of 38.5% which is limited by the lower CP's share of 10%. The 28.5% of CDs "in excess" is then assumed to make their trip as drivers and hence consider that the surplus of CDs becomes SDs, who consequently become the predominant transport mode, used by over 60% of individuals. All in all, the car occupancy rate in the benchmark is 1.14 individuals per vehicle.

Table 3: Social costs for different scenarios

	Reference	HOV	Fuel Price +
Average social cost (in €/trip)	14.85	15.00	15.32
Consumer cost	16.75	16.83	17.90
External costs	1.69	1.65	1.63
Public deficit	-2.22	-2.15	-2.90
Private deficit	-1.37	-1.33	-1.32
Modal Shares			
SD	62.3% (33.8%)	57.7% (28.6%)	59.1% (32.8%)
CD	10.0% (38.5%)	12.8% (41.9%)	11.0% (37.3%)
CP	10.0%	12.8%	11.0%
PT	17.7%	16.7%	18.9%
CO ₂ abatement cost (in €/t)	/	2739	4019
Car.km	26.1	25.5	25.3
Occupancy rate	1.14	1.18	1.16

Note: Modal shares between parentheses are those calculated by our modal choice model. Effective modal shares are displayed in the table considering the surplus of carpool drivers (which is limited by the carpool passenger modal share) become solo drivers, e.g. the solo driver effective modal share in the reference scenario is 33.8%+(38.5%-10.0%) = 62.3%.

The social costs and its components are displayed in €/trip. From the MOBPRO dataset and after our filtering process, we get 1,994 trips over the 6,287 ODs.

3.2. HOV and fuel price increase scenarios

In our “HOV” scenario, the time saved by carpoolers and lost by SDs respectively results in an increase and a decrease of their associated modal shares, as expected. It is also important to note that this improvement in carpooling supply can create a modal shift from PT to the car. This results in a reduced number of car-kilometers—0.6 per trip made—which leads to reduced externalities. At the same time, it produces a lower private profit, which is here entirely borne by highway profits. Indeed, the number of cars on highways is lower in this scenario. Moreover, this reduced traffic also negatively affects the revenues from fuel taxes which leads to the observed decrease in the public finance balance. Overall, externalities and public and private expenses are linearly dependent on the number of car-kilometers, as detailed in the Appendix. Accidents are the main contributor of external costs, followed by CO₂ emissions and noise. Similarly, public and private revenues increase with traffic through fuel taxes and tolls.

Unexpectedly, the consumers’ costs seem to be barely affected by the changes of the HOV scenario. This result is due to the opposite effect that (positively) affects carpoolers and (negatively) SDs. Furthermore, even though the time loss of SDs is smaller than the time gain of carpoolers, the global effect on consumers is negative. The explanation comes from the SD modal share which is much higher than the carpoolers’ one. The detailed consumer cost in the Appendix (Table 8) gives more details to explain this phenomenon. First, the cost of the mode with the highest modal share (SD) is increased. Second, the HOV lane is an incentive to switch to carpool, which is a mode with higher total cost than SD, despite the time gain for travelers. Furthermore, the low modal share of CPs implies the same modal share for CDs, despite a very attractive time cost. The time gain then affects a much smaller number of individuals than the time lost incurred to SDs.

The social cost of the HOV scenario is slightly superior to the one of the reference scenario. This increase is also mainly due to the reduction of both private companies and public authorities’ revenues. This indicates that the externalities caused by traffic are more than offset by the various revenues it generates—here mainly through fuel taxes and highway tolls. This counter-intuitive result, which increases the social cost when lowering the externalities, may be explained by their low valuation. This is partly what indicates the €2,739 CO₂ abatement cost, which is the cost of a ton of CO₂ that would make both HOV and LANE scenarios equal in terms of social cost, and is far above the current value for a ton of CO₂.

(100€/t—Essen *et al.*, 2020). In both scenarios, CO₂ abatement costs are very high, underlining the difficulty in making these scenarios economically efficient, showing a contradiction between the social cost indicator and the aim of promoting carpooling.

The “Fuel Price +” scenario also induces higher modal shares for passenger modes than in the LANE situation, as a direct consequence of the higher costs for driving modes. The observed increase in consumers’ cost is also intuitive. It should be noted that this scenario leads to the largest decrease in car-kilometers and external costs from all scenarios tested. Consequently, private profits are also lower. However, public authorities’ revenues become higher than in the reference situation. Even though the drivers’ modal shares are slightly lower, public authorities’ revenues are increased for each car remaining on the road since fuel is still taxed at the same rate, which consequently increases revenues per car-kilometer.

3.3. Spatial heterogeneity

We now focus on the spatial diversity in our data. Indeed, all ODs can be affected differently by the measures we simulated. Figure 3 and Table 4 below present three ODs with very different characteristics that illustrate this phenomenon. The first OD selected (OD#1) connects the center of Bourgoin to the center of Lyon. The PT supply is excellent and its market share is therefore important. The OD#2 connects a village north of Bourgoin to Lyon. In this OD, access to PT is more complicated and the trip requires a connection. A significant part of the trip by car is made off the highway and the market share of carpooling is low. Finally, the OD#3, which connects Bourgoin to the southeastern suburbs of Lyon, has a PT supply requiring two connections with a very high travel time, and its market share is almost zero. On the other hand, access to the carpooling stations is easy and almost the entire trip is made on the highway. The dedicated lane will therefore have its full effect on an OD like this one.

Figure 3: The three ODs selected (source: authors)

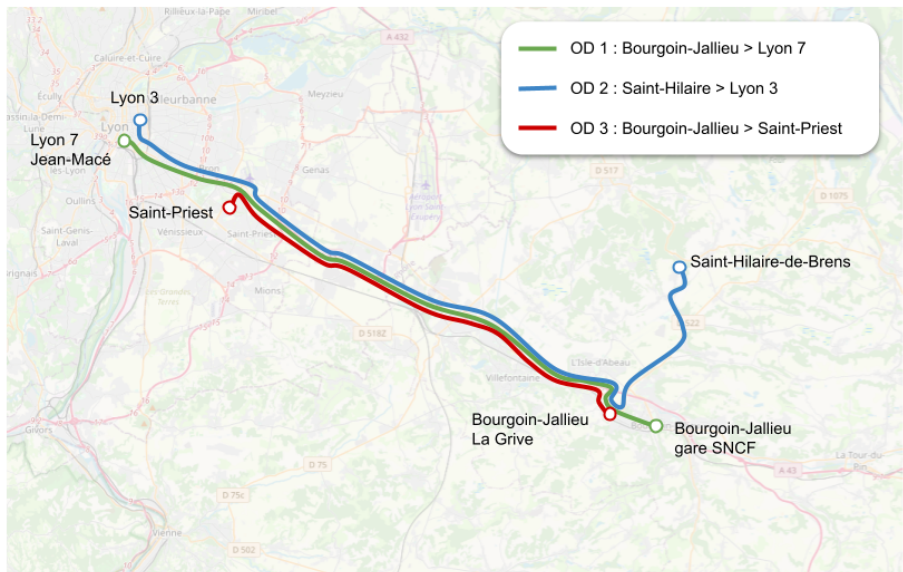


Table 4: Descriptive statistics of the 3 selected ODs

	OD#1	OD#2	OD#3
Road distance	44 km	45 km	31 km
Of which highways	35 km	19 km	30 km
Car travel time	33 min	45 min	19 min
PT travel time	27 min	95 min	71 min
#PT transfers	0	1	2
Access Carpool station	8 min	16 min	1 min
Access PT station	12 min	16 min	2 min
Initial social cost	17.68	21.35	10.76
Consumer's cost	18.94	22.24	13.18
Externalities	0.36	2.96	1.53
Public deficit	-1.29	-2.66	-2.18
Private deficit	-0.33	-1.19	-1.76
Initial Modal Shares	17.68	21.35	10.76
SD	7.4%	45.1%	41.7%
CD	4.9%	36.7%	34.9%
CP	2.0%	12.1%	22.7%
PT	85.7%	6%	0.6%

Table 5: HOV and FP+ scenarios applied to the three selected ODs

	HOV			FP+		
	OD#1	OD#2	OD#3	OD#1	OD#2	OD#3
Average social cost	+0,05	+0,14	-0,19	+0,10	+0,70	+0,39
Consumer cost	+0,06	+0,10	-0,33	+0,22	+1,79	+1,04
Externalities	+0,02	-0,04	-0,11	-0,05	-0,08	-0,03
Public deficit	-0,01	+0,06	+0,14	-0,11	-1,05	-0,66
Private deficit	-0,02	+0,03	+0,11	+0,05	+0,03	+0,04
Modal Shares						
SD	-1.1 p.p.	-4.9 p.p.	-8.9 p.p.	-1.0 p.p.	-1.1 p.p.	-0.9 p.p.
CD	+1.7 p.p.	+3.1 p.p.	+4.1 p.p.	-0.9 p.p.	-1.2 p.p.	-1.0 p.p.
CP	+1.1 p.p.	+2.1 p.p.	+4.9 p.p.	+0.0 p.p.	+1.5 p.p.	+1.8 p.p.
PT	-1.7 p.p.	-0.3 p.p.	-0.1 p.p.	+1.9 p.p.	+0.8 p.p.	+0.1 p.p.

Note: Social cost values in this table display the differences at the individual level between the scenario and the reference situation, e.g. the HOV scenario increases the average social cost for an average individual in OD#1 by €0.05.

Modal share values indicate the evolution of modal shares in percentage point compared to the reference situation in each OD. The sum of the four modal shifts may be different from 0 due to rounded values.

Table 5 displays results of the HOV-lane and the fuel price increase scenarios for the three chosen ODs, as compared to the reference LANE situation shown in Table 4. It shows a lot of heterogeneity in the simulations' impact. The HOV lane scenario is a clear gain from the social cost perspective in OD#3. As the trip is almost entirely done on highways, time savings make carpooling alternatives very attractive. It provides gains from both an externalities and consumer cost perspective that outweigh the lower revenues for public authorities and private companies. This HOV lane scenario is inefficient for both ODs #1 and #2 for different reasons. In OD#2, the HOV lane degrades the SD supply which represents a large majority of the modal share on this OD. The incentive towards carpool does not compensate for this loss. It allows for reduction in externalities but the loss for public authorities and private companies due to the decrease in car-kilometer outweighs it. In the OD#1, the HOV lane encourages people to switch to carpool whereas they are mostly using PT. This measure results in a loss even from the perspective of externalities, considering the PT supply remains constant. Only public authorities and private companies benefit from this measure due to more people using their car and the highway.

Concerning the fuel price increase scenario, here again the three ODs are impacted in different ways. OD#1 is barely affected as most of the demand uses PT and we assume public authorities do not raise the ticket

price. OD#2 is the most impacted OD as a large majority of the population use their car and the carpool alternatives are not attractive. The opposite occurs in OD#3 in which the carpool alternative offers an alternative to solo driving, so the increase in car cost can be mitigated.

3.4. Sensibility tests (VoTs & EV)

Results presented above are dependent on some of the values chosen to estimate the social cost. In this subsection, we present two alternative ways to reconsider some of our findings.

Another way to value the scenarios is to consider different VoTs than those described in the data section. Table 6 below displays results equivalent to the detailed consumer costs presented in the Appendix, considering VoTs obtained through our stated preference survey carried out in the Lyon area in 2019 (see Le Goff *et al.*, 2022 for more details).

Table 6: Consumer costs considering our VoTs

	Reference	HOV	Fuel Price +
Consumer cost	26.33	26.22	27.82
Time components			
SD	15.42	16.40	15.41
CD	17.61	14.16	17.58
CP	35.17	31.62	35.22
PT	41.33	41.08	41.66
Toll cost	2.71	2.71	2.71
Fuel cost	3.09	3.09	4.54

Our VoTs are overall higher (i.e., 23.4€/h for SDs and 30.6€/h for CDs versus around 10€/h for a 35-km trip in Quinet, 2014) and this affects even more carpooling trips as our carpool values are higher than SD values for in-vehicle travel time. Consequently, the impact of time gain incentives is stronger with our values. As the reduction of travel time for carpoolers is more impactful on consumer’s cost with our values, the HOV scenario has a lower consumer cost than the reference situation, whereas it was the opposite with values from the literature used previously.¹⁷

17 |Consideration is currently being given to lowering values of time used for project evaluations in France (IGEDD, 2023). Lowering theses values would, in our framework, reverse the results presented in Table 6. Therefore, such policy choice could make it more difficult to adopt projects aimed at improving trip times such as dedicated lanes.

We also tested a scenario in which all cars were electric ones (see Table 7). In this scenario, cars emit no more local pollutant, except particulate matter that is divided by 2 (a significant part of particulate matter is emitted through braking and tire friction). Noise cost also has been divided by 2. Regarding the monetary cost linked to energy, we assume using an electric car divide by 3 the energy bill paid by drivers. Importantly, public finance still profits from the same proportion in taxes (60% of consumer's price).

Table 7: Social cost for the Electric Vehicles scenario

	Reference	Fuel Price +	EV
Average social cost (in €/trip)	14.85	15.32	13.71
Consumer cost	16.75	17.90	15.01
External costs	1.69	1.63	1.07
Public deficit	-2.22	-2.90	-0.95
Private deficit	-1.37	-1.32	-1.42
Modal Shares			
SD	62.3% (33.8%)	59.1% (32.8%)	66.7% (35.3%)
CD	10.0% (38.5%)	11.0% (37.3%)	8.7% (40.1%)
CP	10.0%	11.0%	8.7%
PT	17.7%	18.9%	15.9%
CO ₂ abatement cost (in €/t)	/	4019	-244
Car.km	26.1	25.3	27.3
Occupancy rate	1.14	1.16	1.11

Note: The social costs and their components are displayed in €/trip.

Results in modal shares are completely the opposite of the “Fuel Price +” scenario, as expected with a reduction of car monetary cost. Car kilometer and occupancy rate respectively rise and fall following the same mechanisms as those previously described. As this scenario implies an important decrease in car cost, consumer cost decreases significantly, which more than offsets the loss in public revenues from fuel tax. This result, added to reduction of associated external costs, allows a lower social cost, which implies a negative abatement cost. Nonetheless, it is important to note that such a scenario would also increase congestion, which is not included in this analysis.

To summarize our results, we find with values from the literature that the social cost is mainly driven by consumer costs. The values given to externalities seems too low to be impactful on the social cost and outweigh the public and private revenues from traffic—excluding major fleet changes.

As an illustration, the reference scenario here is the one with the lowest social cost, even though it is the scenario with the lowest car occupancy rate and the highest number of car-kilometers. However, these results can vary depending on assumptions made. This concerns values used for the externalities, although they would have to be increased substantially if one wants climate impact of the transport supplies to be reduced. This also concerns the values of travel times which can have a significant impact on the consumers' costs, which themselves play a serious role in the social cost. Finally, scenarios tested show an important spatial heterogeneity in their respective impacts. Carpooling incentives should consequently be applied, or not, according to the local context.

Conclusion

This paper presents an analysis of social cost changes by simulating two scenarios, one focused on time, the other one on money. The implementation of carpooling incentives or external shocks affecting the demand have been tested. The social costs are composed of four main components: consumer cost, externalities, public authorities' deficit, and private profits.

The results show that consumer cost constitutes the majority of the social cost with values commonly used. Values given to externalities seem too low to have an impact on the social cost and outweigh the public and private revenues from traffic. Hence, public authorities have diverging interests. One could expect them to implement measures to reduce negative externalities, and consequently to reduce traffic in this case. However, fuel taxes represent a significant source of revenues, which creates an interest in keeping high traffic levels. This contradiction leads us to question the CBA method used as taxes outweigh most of other factors, scenarios with a higher number of car-kilometers to be favored.

As an illustration of this contradiction, the reference scenario comes out as one of the best scenarios tested—from the social cost perspective—whereas it is the one with the lowest car occupancy rate and the highest number of car-kilometers. This result underlines the difficulty in making low-emission scenarios economically efficient considering the current values of externalities and stresses the contradiction between the government (which receives taxes), local entities (which fight against pollution and congestion), and global warming (at a world level).

Moreover, our results show a substantial spatial heterogeneity of policy impacts. As an example, incentive measures towards carpooling alternatives should not be implemented (and subsidized) where public transport supply

is already a good alternative to taking a car. On the other hand, deploying a carpooling alternative when a public transport alternative does not exist is an excellent measure to mitigate consumer cost when a negative exogenous shock happens, such as a fuel price increase.

Several hypotheses have been made in the calculations of this paper. Examples include the distribution of the vehicle fleet, the distribution of road types used (city/rural/highway), which may not perfectly reflect characteristics of trips made on each OD and which could lead to unprecise estimation of the social cost. We also did not consider the equity dimension in our analysis, which could affect our results in understanding the potential of carpooling as a solution for more equitable mobility. As with any hypothesis, these can be criticized and changed, which would of course affect results. Another limitation is that we only consider marginal costs of energy expenses, excluding fixed costs of vehicles' purchase and maintenance. Including these full monetary costs could significantly affect the estimated private and social costs of car use and the relative advantage of carpooling. We leave this issue for further research¹⁸. Furthermore, we did not consider the potential impact of our scenarios on congestion, which could also affect modal shares differently. The demand for trips from outside to inside the zoning studied was not considered, and could also affect traffic conditions. Therefore, the external validity of some of our results and conclusions may be biased. The results should be put in perspective with each other rather than being considered for the exact values found for each scenario.

This study tends to show that the decision to promote carpooling for daily trips should be made conscientiously considering local context. If one wants to reduce car traffic and externalities, carpool incentives can even lead to the opposite of the intended effects. However, improving carpooling supply can be interesting when it provides an additional transport solution for travelers and potentially greater resilience to external shocks. This is particularly the case where public transport supply is non-existent or inefficient. These results raise the question of potential impacts on demand outside the policy area, which could be explored in future research.

18 |If the "total cost of ownership" of electric vehicles would be lower than the one for thermic cars, the "rebound effect" found in Section 5.4, as well as the increase in the social cost, would be magnified (especially if one considers public subsidies to buy electric cars).

Appendix

Table 8: Social cost composition detail (in €/capita)

Scenario		Refence (LANE)	HOV	FP+
Modal Shares				
	SD	34% (63%)	29% (58%)	33% (59%)
	CD	39% (10%)	42% (13%)	37% (11%)
	CP	10%	13%	11%
	PT	18%	17%	19%
Social cost		14,85	15,00	15,32
Consumer cost				
TOTAL		16,75	16,83	17,90
Per mode	SD	9,44	9,08	9,78
	CD	1,22	1,37	1,50
	CP	2,41	2,89	2,66
	PT	3,69	3,48	3,96
At individual level				
SD	Total	15,23	15,80	16,67
	TT	4,66	4,96	4,65
	TV	4,74	5,05	4,73
	Cost	5,83	5,79	7,28
CD	Total	12,16	10,74	13,58
	TT	3,45	2,72	3,45
	TV	4,68	3,95	4,69
	DT	0,25	0,27	0,22
	Cost	3,78	3,80	5,22
CP	Total	24,09	22,69	24,14
	TT	3,45	2,72	3,45
	TV	4,68	3,95	4,69
	WT	1,76	1,76	1,76
	AT	1,90	1,92	1,91
	ET	6,79	6,81	6,80
	Con.	2,92	2,93	2,93

	Cost	2,60	2,61	2,60
PT	Total	20,87	20,80	20,94
	TT	6,84	6,80	6,89
	TV	1,93	1,91	1,94
	WT	1,41	1,41	1,41
	AT	4,75	4,74	4,75
	ET	3,75	3,75	3,75
	Con.	1,40	1,38	1,42
	Cost	0,80	0,80	0,80
Externalities				
	Total	1,69	1,65	1,63
	Loc. pollut.	0,18	0,17	0,17
	Noise	0,33	0,32	0,32
	Accid.	0,81	0,79	0,78
	CO ₂ (g)	3708	3651	3589
	Climate	0,37	0,37	0,36
Pub. Deficit				
	Total	-2,22	-2,15	-2,90
	Fuel Tax	-1,61	-1,57	-2,29
	Corp Tax	-0,55	-0,53	-0,53
	Road wear	0,08	0,08	0,08
	Income PT	-0,17	-0,16	-0,18
	Ptfm Subs.	0,03	0,03	0,03
Priv. Deficit				
	Total	-1,37	-1,33	-1,32
	Highway	-1,37	-1,33	-1,32
	Ptfm	0,00	0,00	0,00
Car.km		26,13	25,52	25,28
Occup. rate		1,14	1,18	1,16

Note: Values of consumer's cost are detailed by mode at the global level by multiplying effective modal share by consumer's cost at individual level.

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