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Carpooling for daily trips : individual behavior and challenges for public policies

Alix-Dorian Le Goff

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Carpooling for daily trips.

Individual behavior and challenges for public policies.

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UNIVERSITÉ DE LYON UNIVERSITÉ LUMIÈRE LYON 2
ÉCOLE DOCTORALE SCIENCES ÉCONOMIQUES ET DE GESTION

**CARPOOLING FOR DAILY TRIPS:
INDIVIDUAL BEHAVIOR AND
CHALLENGES FOR PUBLIC POLICIES**

A THESIS PRESENTED BY
ALIX LE GOFF

IN FULFILLMENT OF THE REQUIEREMENTS FOR THE DEGREE OF
DOCTOR IN SCIENCES

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Foreword

This thesis focuses on the determinants of behaviors leading to the practice of carpooling in daily mobility, as well as the issues associated with this practice at the collective scale. This thesis manuscript consists of three research articles which constitute its chapters. This explains the potential redundancy between chapters, particularly in data presentation, as well as the use of terms like "paper" or "article".

The first chapter of the thesis is a peer-reviewed article published in *Transport Policy* (doi.org/10.1016/j.tranpol.2021.10.001), co-written by Guillaume Monchambert and Charles Raux. The second chapter is a work in progress co-authored by Guillaume Monchambert and Martin Koning. The third chapter is also a work in progress co-written by Guillaume Monchambert and Martin Koning, as well as Clément Marchal and Jean-Baptiste Ray, who also provided data for the realization of this chapter.

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Abstract

This thesis focuses on the determinants of behaviors leading to the practice of carpooling in daily mobility, as well as the issues associated with this practice at the collective scale. This study is mainly based on the results of a stated preference survey built up at the beginning of the thesis in order to better understand individuals' transport mode choices. The thesis is structured in three chapters. The first chapter deals with individual preferences for carpooling in daily mobility, with a particular focus on solo-driving commuters. The second chapter looks specifically at the role played by different ways of organizing carpooling, such as the presence of a carpooling platform, or the profile of the potential carpooler. This chapter also proposes a preliminary analysis of these effects and of carpooling incentives at community level. The third chapter assesses the impact of exogenous economic shocks or incentives on daily carpooling, through an analysis of the social cost of the trips. The results in Chapter I show that time seems to be valued higher in carpooling than in solo driving, and that individuals are more likely to carpool as drivers than as passengers. This indicates that the number of drivers is unlikely to fall, refuting the hypothesis that more carpooling would automatically lead to lower road traffic and emissions. The findings of Chapter II suggest that carpooling platforms appear to be effective in reducing the perceived risk of carpooling, even more for passengers than for drivers. Women are also more sensitive to their potential carpooler's gender, with a preference for carpooling in the company of another woman (excluding relatives). The ideal situation from the community's point of view would be for passengers to be paid and drivers to pay to carpool, which goes against what seems acceptable at the individual level for drivers. Chapter III is based on transport supply data from the eastern part of Lyon (France). It shows that the costs of trips carried at the individual level are much higher than those of private companies, public authorities and traffic externalities. In addition, the exogenous shocks and incentives tested had highly differentiated impacts at the spatial level, with cases where carpooling incentives could lead to negative environmental outcomes. This suggests that the local context and potential spatial inequalities should be carefully considered before implementing a daily carpooling policy.

Keywords: Daily carpooling, individual preferences, mode choice, cost-benefit analysis, public policies

Résumé

Cette thèse s'intéresse aux déterminants des comportements menant à la pratique du covoiturage dans la mobilité quotidienne, ainsi qu'aux enjeux associés à cette pratique à l'échelle collective. Ce travail repose principalement sur les résultats d'une enquête de préférence déclarées construite au commencement du travail de thèse afin de comprendre au mieux les choix de mode de transports des individus. La thèse s'articule en trois chapitres. Le premier chapitre traite des préférences individuelles pour le covoiturage dans la mobilité quotidienne avec un focus particulier sur les « autosolistes » utilisant leur voiture quotidiennement pour aller au travail. Le second chapitre s'intéresse particulièrement au rôle que joue les différentes manières d'organiser le covoiturage, comme la présence d'une plateforme de mise en relation, ou le profil du covoitureur potentiel. Ce chapitre propose également une première analyse de ces effets et d'incitations au covoiturage au niveau de la collectivité. Le troisième chapitre propose une évaluation des impacts d'incitations ou de chocs économiques exogènes sur la pratique du covoiturage grâce à une analyse du cout social des déplacements. Les résultats du Chapitre I montrent que le temps semble être valorisé plus fortement en covoiturage qu'en « autosolisme » et que les individus sont plus susceptibles de passer au covoiturage en tant que conducteurs qu'en tant que passagers. Cela indique que le nombre de conducteurs est assez peu susceptible de baisser, réfutant ainsi l'hypothèse que plus de covoiturage conduirait automatiquement à une baisse du trafic routier et des émissions. Les conclusions du Chapitre II indiquent que les plateformes de covoiturage semblent bien efficaces pour réduire l'appréhension à passer à la pratique, et ce d'autant plus pour les passagers que les conducteurs. Les femmes sont également plus sensibles au genre de leur covoitureur potentiel, avec une préférence pour covoiturer en compagnie d'une autre femme (hors proches). La situation idéale du point de vue de la collectivité devrait être une solution où les passagers sont payés et les conducteurs payent pour covoiturer, ce qui va à l'encontre de ce qui semble acceptable au niveau individuel pour les conducteurs. Le Chapitre III repose sur des données d'offres de transport du cas de l'est de Lyon (France). Il indique que les coûts des trajets portés à l'échelle individuelle sont bien supérieurs à ceux des entreprises privées, des autorités publiques ainsi qu'aux coûts des externalités du trafic. En outre, les incitations et chocs exogènes testés ont eu des impacts très différenciés au niveau spatial, avec des cas où l'incitation au covoiturage pouvait mener à des impacts environnementaux négatifs. Cela suggère donc de bien considérer le contexte local et les potentielles inégalités spatiales avant l'application d'une politique de covoiturage quotidien.

Mots clés : Covoiturage quotidien, préférences individuelles, choix de mode, analyse cout bénéfiques, politiques publiques

INTRODUCTION

Carpooling is a genuine success story in France, and is now a mainstream mode of travel for long-distance trips. Created just 15 years ago, the BlaBlaCar carpooling platform counts millions of users nowadays. Its success is such that 60% of 18-35 years-old in France are now registered¹. However, carpooling is still struggling to find a place on the daily commute despite the fact that the majority of car trips (99%) and distances (68%) are made for short distance trips (SDES, 2021). More than 18 million French people drive to work (INSEE, 2021), for an average distance of 13.3 km (SDES, 2021). The annual cost of these trips for a single driver is estimated at around €2,000 on average², providing a strong incentive to share the expenses. Carpooling therefore has a substantial development potential for daily trips.

Motivations for this thesis

In this context, public authorities in France are seeking to promote carpooling at local level. One example is the Lyon metropolitan area, which is experimenting since December 2020 two high-occupancy-vehicle (HOV) lanes on its main north-south road. Contrary to North America – where first opened in the 1970's – or some places in Europe – where these facilities were created a few before 2000 (e.g. Madrid, Leeds, Linz), the Lyon's HOV is brand new to the population and one of the very first in the country. The reserved lane in the northern part of the city is 6 kilometers long, and the southern one is 4 kilometers long, and is also shared with public transport.

¹ <https://blog.blablacar.fr/newsroom/news/blablacar-franchit-la-barre-des-100-millions-de-membres>

² Considering 220 working days a year, 2 trips per working day of 13,3 km on average (SDES, 2021) and a price per kilometer of 0,335€/km (ADETEC, 2019).

My thesis, funded by the Auvergne Rhône Alpes Region³, began ahead of this implementation. At the same time, in 2018, the SystemX technology research institute and the Lyon metropolitan area also launched the "Lyon Covoiturage Experimentation" project (i.e. Lyon Carpooling Experimentation, LCE). It brings together several industrial (freeway companies, carpooling platforms, urban planners, digital specialists), institutional and academic partners, including Transport, Urban Planning and Economics Laboratory (LAET), where I carried out the thesis. The aim of this project is to improve traffic flow on Lyon's main north-south road, on which the HOV-lane will be installed, by improving occupancy rates (close to 1.05 during rush hours on this route) and optimizing transport organization to encourage changes in behavior⁴. The project partners met regularly over a period of three years to share their expertise and discuss the respective progress of their work. In our case, we were able to present upstream the main empirical material used in this thesis, i.e. our stated preference experiment to better understand mobility behavior through the study of transport mode choices. The feedback we received proved useful, as detailed in the section of this manuscript dedicated to the design of our survey.

Carpooling benefits

Carpooling is logically seen by local authorities as a solution for reducing the numerous local nuisances caused by road traffic, being mainly solo-driver cars. Among them, congestion is a major issue in many cities. The time lost in congestion by the inhabitants of large urban areas is close or exceeds 100 hours per year on average, even after the COVID period. In the case of Lyon, this time lost represents 92 hours per year (INRIX, 2022). Moreover, congestion issues are not limited to road traffic. The abundance of cars can also become problematic

³ The administrative region of Lyon

⁴ <https://www.irt-systemx.fr/en/projets/lce/>

considering parking issues. Héran & Ravallet (2008) shows a car requires on average 40m² for parking. Hence, more cars mean a higher demand for parking infrastructures or higher parking times. Furthermore, one can also mention the various pollutions brought by road traffic. Concerning air pollutants, for example, particulate matter resulting from the combustion of fossil fuels would kill 10 million people each year in the world following Vohra et al. (2021) findings. Road traffic also causes direct externalities through accidents. According to the World Health Organization (2022), road traffic crashes cost most countries 3% of their GDP and causes 1.3 million death per year. Another pollution brought by road traffic is noise. This one is valued in France at 147 billion euros by the French Environment and Energy Management Agency (ADEME, 2021), of which more than half is generated by road traffic. Moreover, from a global perspective, car traffic has a non-negligible impact on greenhouse gas emissions, around 8% of the CO₂ emissions worldwide⁵ (Tiseo, 2022). In France, this number is higher as private cars represent around 16% of the domestic emissions⁶ (Ministère de la Transition Écologique, 2020).

Despite the negative externalities mentioned above, travel remains a necessity for most of the population nowadays. And car has many advantages over competing modes: fast, flexible, secure, effortless. One of the policies to be implemented for both keeping some of these advantages and limiting the car externalities is to fill them better since occupation rates are very close to 1 for commuting trips (ENTD, 2008), and hence, promote carpooling. As a part of the sharing economy, carpooling can allow to reduce the car production and hence mitigate its indirect environmental impacts, provided some of current car owners accept to become future passengers or to share their vehicle. Increasing vehicle occupancy can also

⁵ Worldwide, the transport sector represents 20.2% of CO₂ emissions and passenger cars represent 39% of these.

⁶ In France, the transport sector represents 31% of greenhouse gas emissions. Among these 31%, private cars represent 51%. These values are higher than those worldwide, mainly due to the fact that France produces a very low-carbon electrical energy, which increases the share of CO₂ emitted by sectors using fossil fuels, such as transportation.

reduce the externalities mentioned above if it results in a decrease in traffic as presented by Chan & Shaheen (2012). It can also increase road capacity without requiring a new costly infrastructure, since most of the time roads already exist. Indeed, if the vehicle flow remains unchanged, more occupied vehicles imply a higher passenger flow.

If carpooling can reduce collective costs, it can also be beneficial for individuals. In France, 15% of the household budget is spent on transportation (Ministère de la Transition Écologique, 2021). Therefore, sharing travel costs can significantly reduce these expenses. In addition to offering a new transportation option to non-motorized people, carpooling can also allow a greater adaptability of trips than public transportation. Both from a spatial perspective – with the possibility to connect sparsely populated area – and from a time perspective – making some connections possible at hours not covered by public transportation.

Ridesharing, Carsharing or Carpooling? What we do (and don't)

There are many ways to share the use of a car. Some typologies have already been proposed (see e.g. Furuhata et al., 2013). Here we rely in part on the one proposed by Chan & Shaheen (2012) by considering both what we will call “organization”, i.e. if carpooling is planned ahead or not, and how individuals are brought together to carpool and their links i.e. whether carpooling is carried out informally with friends or colleagues or via a carpool operator. The forms of interest of sharing cars in this thesis are those where this use is shared during the trip, where the car is therefore occupied by at least two individuals who share a trip, what we will call here "ridesharing". Other forms of shared use of a car exist like “carsharing”. It can be defined as the share of the car between several users, who use the vehicle occasionally, mostly for short time periods but not necessarily with several occupants and will hence not be the focus here. These different ways to share cars with examples of actors in the French market are displayed in Figure 1.

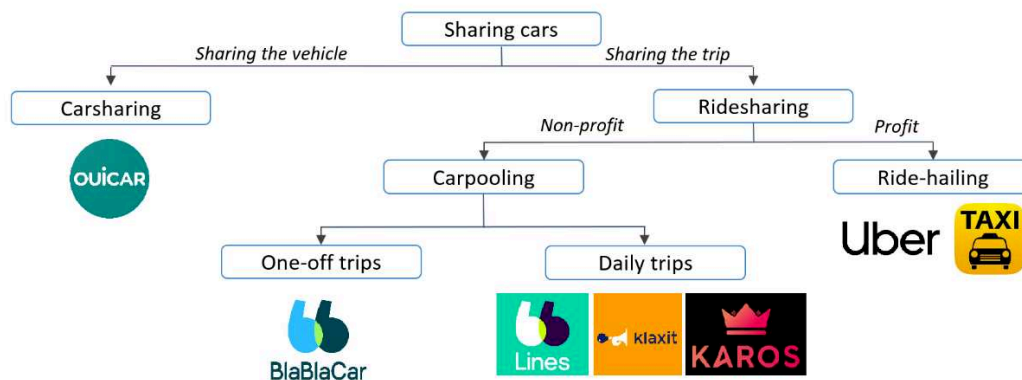


Figure 1 : Different ways to share cars and examples of French industry operators

Ridesharing can be classified into two types. On the one hand, there's a for-profit rideshare, in which the driver has no interest in making the journey alone, so his or her only interest is in making a profit on the ride. This is the case with taxis, for example, or ride-hailing services such as Uber. On the other hand, we find a rideshare form where the driver's primary aim is not profit. This time, the driver has an interest realizing the trip, even if he or she is alone. It's important to note that, although this is a non-profit rideshare, a monetary exchange may take place. Its purpose is here to refund part of the driver's expenses for the journey, such as fuel or tolls, as defined by French law⁷. It is this non-profit rideshare that we will be the focus of this thesis and which we will refer to in this manuscript as “carpooling”.

Heterogeneities in carpooling uses

Carpooling may be used for several distinct purposes. It can be used for vacations or weekends, generally for long, one-off journeys. It may also be a response to a particular event bringing together several thousand people in the same place (festivals, concerts, sport events). In this case, the use is also punctual, but can be used for short distances. Lastly, carpooling can also be used for daily trips. This involves work-related trips, usually during the day at peak

⁷ https://www.legifrance.gouv.fr/codes/article_lc/LEGIARTI000039784386.

hours, or other daily trips purposes such as shopping or leisure trips, mainly at the end of the day, on a more or less occasional basis. Last but not least, the use with the highest potential in daily trips, due to its frequency, are commuting trips.

In addition, the way in which carpoolers are matched up can also vary and influence the practice. From this point of view, there are two main carpooling families: organized and real-time carpooling. On the one hand we find “organized carpooling”, in which carpoolers contact each other in advance of the trip and arrange to define the meeting and drop-off points for the journey, as well as the times, enabling them to choose the spatial and temporal conditions that are most convenient for everyone. However, once these locations and times have been defined, this type of carpooling becomes very inflexible and looks similar to a train service. This type of carpooling can be carried out informally, for example within the family, friends or professional circle. It can also be carried out via a third-party platform, on an application or the Internet.

On the other hand, we find “real-time” carpooling, mainly used for short distances. Here, carpoolers meet literally at the carpooling departure place, i.e. the location where driver and passenger start sharing the trip. The advantage of this type of carpooling is that there's no detour for the driver, and extra flexibility for the passenger, whose only constraint is to be at a stopping point where the drivers can pick them up. This type of carpooling can also be carried out informally, in this case it is called hitchhiking. Passengers and drivers can also meet at defined stops on a carpool lane, this form of carpooling is similar to the use of a subway or a bus for the passenger. There are also intermediary examples of these two situations, where individuals meet at informally defined stops like in Washington D.C., which is called “slugging” (Cui et al., 2022). Figure 2 below summarizes the different forms of ridesharing and carpooling studied in this thesis.

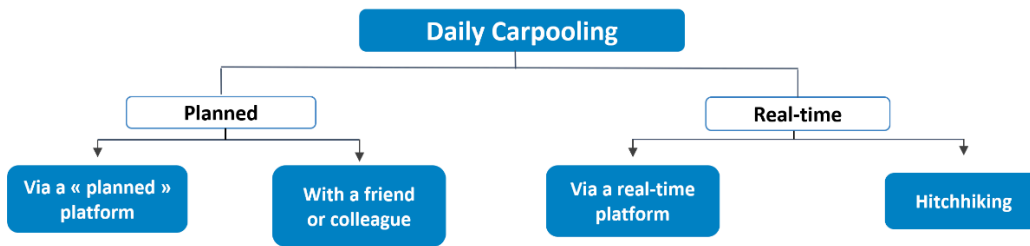


Figure 2 : Different ways to use carpooling for daily trips

Carpooling for daily trips

Sharing car costs leads carpooling to be competitive. This is especially the case in France for long distance trips (see e.g. Monchambert, 2020), where the online platform Blablacar became the carpooling world leader. It often offers way cheaper trips than train with a better spatial and time flexibility. This carpooling for occasional trips has become a mainstream mode of transportation and has been analyzed through several papers (see e.g., Shaheen, 2017; Farajallah et al., 2019).

However, contrary to long distance trips, carpooling remains a relatively unused mode for commuting trips as evidenced by the occupancy rates already mentioned for commuting trips, close to 1.1 individual per vehicle. There are several explanations for this apparently inefficient use of cars. While carpooling is very competitive over long distances, this is less true for daily journeys, which are mostly over short distances. In France, they face stiff competition from public transport in densely populated areas. The latter are massively subsidized and offer a cheap option for these trips.

Moreover, the way carpoolers are matched up may also explain the delay in carpooling development on daily commutes. Indeed, a 15-minute detour seems to be a little disadvantage on a one-off 5-hour journey. On the other hand, for a daily trip of 30 minutes, this same detour

has a proportionally greater impact. This constraint is particularly penalizing as the trip is repeated daily. This illustrates that daily trips have stronger spatial and temporal constraints, making it more difficult for carpooling to be efficient. Furuhashi et al. (2013) also show that organized carpooling for daily trips can very easily lead to unoptimized spatial and/or time matching between individuals.

Furthermore, carpooling faces behavioral barriers. Li et al (2007), for example, showed that solo drivers do not switch to carpooling mainly due to fear of the unknown. The desire for independence and flexibility are also cited in Li et al.'s paper as key factors preventing carpooling. Indeed, everyday life may involve unexpected events, which explain this desire for flexibility. In a study carried out to understand the impact of the relationship between carpoolers, Chaube et al. (2010) asked individuals on a university campus whether they would be willing to carpool to the campus. An overwhelming majority would have no problem carpooling with someone close to them, while a very large majority would refuse to carpool with someone they do not know. This underlines the importance of this factor in the individuals' willingness to carpool.

Real-time carpooling may provide a partial solution to the problem of flexibility. Nonetheless, the fact of meeting a carpooler at the moment of boarding does not reduce the perceived risk. In fact, the effect is the opposite, particularly for hitchhiking (Chester & Smith, 2001).

There are a number of ways to overcome the obstacles mentioned above. As an example, carpooling platforms can represent a third party in which both passengers and drivers trust and facilitate payment, that is what Witkowski et al. (2011) call "escrow mechanism". Furthermore, their development through internet and mobile apps can help reaching an important number of users. Besides, platforms can also influence trust via a "social network effect". For example, offering a rating system for carpoolers affects their reputation and therefore encourages more

virtuous behavior during the journey, while providing information for future carpoolers (Furuhata et al., 2013).

Several monetary incentives can also play a key role in triggering the carpooling practices. Among these is the return guarantee system which, as its name suggests, ensures passenger return trip when carpooling is impossible, by covering expenses of the bus or taxi cab. While this guarantee appears to be very costly, it is, in practice, rarely used (ADEME, 2015). Other systems, such as the "reverse toll" system introduced in Rotterdam in 2014, or the "parking cash-out" system (Shoup, 1997), reward individuals for abandoning their personal vehicle, and show interesting results in terms of traffic reduction, but do not quantify the impact on carpooling.

Finally, carpooling can also be facilitated when dedicated facilities are provided. Such as High-Occupancy-Vehicle (HOV) lanes or free parking lots, even though the latter incentive seems to not be the most efficient (Hess, 2001). HOV-lanes are the main incentive infrastructure, allowing time savings for commuters who choose to carpool. They have been created for over 50 years in North America. Their ability to increase occupancy rates is well documented (see e.g., Schijns & Eng, 2006; Ugolik et al. 1996; Wellander et al., 2001). Other benefits of these lanes on traffic such as their ability to increase passenger flow or reduce the number of lane transfers are also mentioned in the literature such as the "smoothing" and "compacting" effects (Menendez & Daganzo, 2007; Daganzo & Cassidy, 2008).

Research objectives

Few papers quantify the impact of factors mentioned above on the choice to carpool. This has partially been done in Switzerland by Ciari & Axhausen (2012) to measure carpooling values of time (VoTs) and to compare them with those of usual modes of transport, i.e., public transport and car as a solo driver. However, it is known that from one country to another these values can be significantly different, as described very well by the meta-analysis of Wardman et al. (2016). Moreover, a VoT can fluctuate within a same transport mode depending on its level of perceived comfort (Bouscasse & de Lapparent, 2019), or on the trips stage as Wardman et al.'s meta-analysis shows. Waiting or walking times are e.g. valued higher than in-vehicle time. Carpooling trips also include detour time that, to my knowledge, is not valued in the literature. This valuation of time parameters is essential in order to understand individual preferences.

Furthermore, individual choices cannot be reduced to VoTs on their own, and the impact of other influencing factors must be considered. Chan & Shaheen (2012) advances carpooling with someone unknown before is perceived as a risk. This is also confirmed by the findings of Chaube et al. (2010) who highlights the influence of the relationship between carpoolers on their willingness to carpool. Therefore, platforms have the potential to create a reassuring third party to reduce this perceived risk (Ter Huurne et al., 2017). If the literature mentions these determinants, only few papers try to monetarily quantify their impact. Yet, the effects of these elements potentially play a substantial role in the estimation of preferences, modal shift and hence of collective gains from carpooling incentives.

Finally, analysis to assess the relationship between costs and benefits for the community are widely studied in the transport economics literature. This type of analysis can be carried out on a transportation mode – e.g. public transport (Litman, 2015) – a combination of modes – e.g.

MaaS (Becker et al. 2020) – an infrastructure – such as an HOV-lane (Sisiopiku et al., 2010) – or to evaluate policy impacts – e.g. Wang et al. (2015) with the potential effect of cordon tolls or higher bus frequency on accessibility. However, the impact of a carpooling incentive may depend on the local context e.g. the current transport supply. It is therefore necessary to apply this method to local data to get an idea of the impacts of different incentive measures on a defined spatial zoning. If one wants to deal with the case of the Lyon’s region, one will therefore have to use the appropriate local data, i.e. also data corresponding to local individual preferences.

This thesis aims to fill some of the gaps discussed previously. Research objectives of this work are the following:

Research Objective 1: Understanding individual choice mechanisms towards carpooling for daily trips.

To this end, we estimate VoTs and other impactful variables such as the valuation of the way carpooling is organized or the impact of the carpooler’s individual characteristics. These valuations are made for carpooling both as a driver and as a passenger, considering the heterogeneity of preferences in the population. This will allow to estimate modal switch and traffic reduction potential of different incentive measures.

Research Objective 2: Assessing the impact of carpooling incentive policies or exogeneous economic shocks for the community.

This is done through a welfare analysis, looking at four stakeholders of daily trips total social cost: travelers – for which preferences have been analyzed and valued – private operators, public authorities and environmental externalities. Several scenarios of promoting carpooling policies, change in fuel prices or the introduction of a new carpooling platform are simulated,

allowing to understand observing among stakeholders benefit most from each scenario tested. Furthermore, by considering spatial disparities in a given zoning, we are able to observe heterogeneous effects of a single measure.

To achieve these research objectives, we are going to study individuals' behaviors in the Lyon region. We design a stated preferences survey that adapts to respondents' usual travel patterns. We then communicate via social networks and through our partners in the LCE project to disseminate the survey widely at local level, and ensure that it runs correctly online before collecting and cleaning the resulting data. Details of the survey are presented in the next section.

The preferences survey as the starting point of the thesis

Survey conception and methodological choices

This work started before the implementation the new HOV-lane in Lyon – opened to the traffic in December 2021 – it was all the more challenging because this infrastructure was new in France. The idea was to understand *ex-ante* how individuals would react to this infrastructure that will change the transportation supply. Therefore, a methodology adapted to a hypothetical situation was needed, since it was necessary to propose to individuals a situation that did not exist yet. This adapted methodology is none other than the stated preferences (SP) survey.

The aim of this survey was to better understand people's transportation mode choices for their daily trips, in the presence of a carpooling alternative, by measuring the effect of different variables on these choices, such as price, travel time, reliability and comfort. The initial idea was therefore to provide as detailed a description as possible of the trip in the two usual motorized modes of transport in France, car and public transport, in addition to two

carpooling alternatives, as driver and as passenger.

Detailing all travel conditions in these four modes is a relatively complex task, requiring a very large number of parameters to be included. In addition, this potentially high number of parameters would make the choice situations more complex, which could be detrimental to the estimation of these parameters. We therefore decided – after back and forth between LCE project partners, my thesis supervisors and myself – to restrict ourselves to a very precise description of the trip (departure and arrival times, travel time, detour, access, egress and possible waiting times and connections), a monetary variable, and finally three characteristics of the potential carpooler: the way in which the connection was made – informal or via a platform – his or her gender and age.

To collect this data efficiently, it was important to target our respondents. Our aim was to place the respondent in the context of a trip he could do with the proposed modes in the survey. We were interested in respondents for whom carpooling was a credible alternative for their usual trip. As a consequence, only respondents whose usual trip meets the following criteria were kept in the survey:

- a travel time between 15 and 90 minutes
- having a driving license
- traveling during rush hours (between 6 and 10 am or between 4 and 8 pm, excluding Saturday and Sunday)

On the one hand, we consider carpooling is not a credible alternative for very short distance trips (<15 minutes by car), because even a short waiting time (for the passenger) or detour time (for the driver) would proportionally lengthen the trip a lot. On the other hand, we consider long trips (>90 minutes) as outside the study scope since the time gain procured by the

HOV-lane can be considered as proportionally too marginal regarding the decision to carpool. Furthermore, the average commuting time by car in Lyon area, which is around 30 minutes, is way below this threshold (SYTRAL, 2016).

To make respondents state what they would do in a real situation, alternatives were kept realistic by using the information on their usual trip collected earlier. First, we differentiated between individuals who are able to drive – i.e. with a driver's license and an available car – and those who are not. The latter were placed in a different choice experiment, in which driving modes were not available. Second, the time attributes levels of the alternatives had to vary around the initial values of this usual trip. Furthermore, as it is a new policy in France, the HOV-lane was presented to the respondents before the choice tasks through an information screen (see Appendices). In this survey, we wanted to test how the organization impacts individuals' choices by proposing carpooling alternatives either planned or in real-time to the respondents. Consequently, they were also informed about how carpooling is organized with an information screen before the choice experiment begins (see Appendices). A summary of this protocol is displayed in the Figure 3 below.

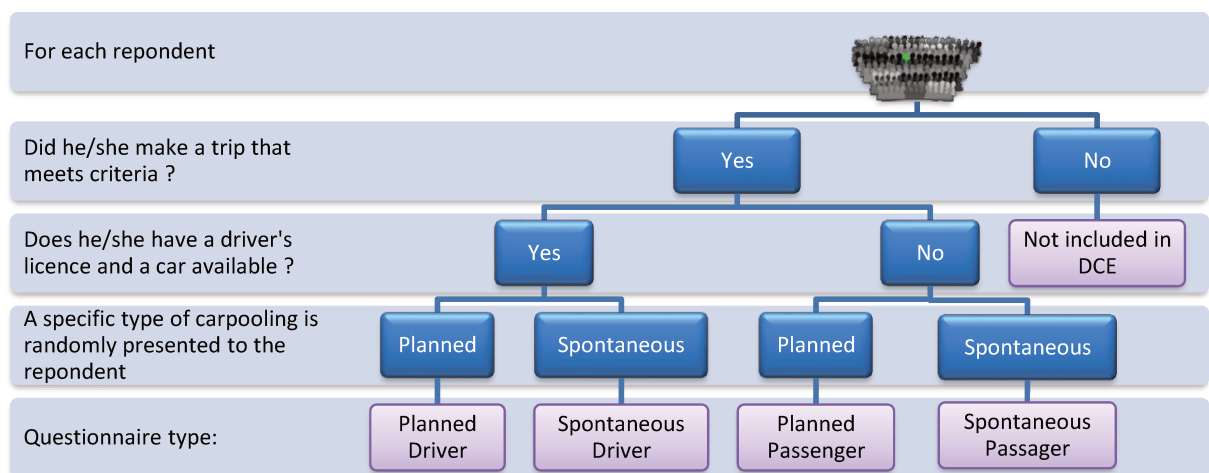


Figure 3 : Data sampling and survey protocol

Survey design

To build the survey design, I used the Ngene software (ChoiceMetrics, 2012) to get balanced choice tasks and to extract as much information as possible from the trade-offs made by respondents. For that, prior information about parameters have been used from de Palma & Fontan (2000) and Quinet (2013).

It was then necessary to transform Ngene's outputs to provide respondents with the clearest possible choice screen. This required a lot of back-and-forth with the company responsible for putting the survey online⁸, with explanations of the expected output for each choice situation coupled with the parameters of the trip mentioned by the respondent. They were also in charge of the final visual rendering, which we discussed at length with them to present the transport supplies in the style of an internet trip simulator, detailing each of the parameters. Examples of Ngene output screens and the final version displayed to respondents are shown in the Figure 4 and Figure 5 below.

⁸ Inkidata, a survey institute based in Lyon (<https://inkidata.fr/>)

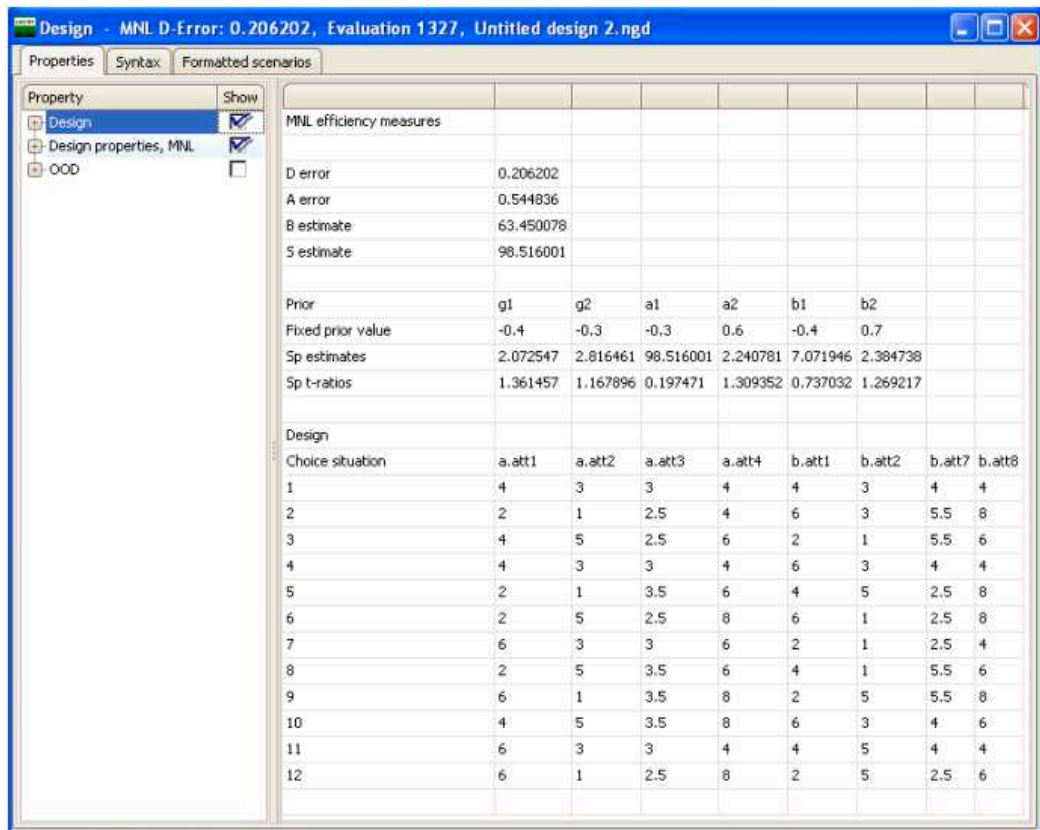


Figure 4 : Example of a Ngene output with 1 line corresponding to 1 choice task

Mode	Driver Alone	Driver in a Carpool	Passenger in a Carpool	Public Transport
Trip Characteristics	<p>Start : 7:20</p> <p>🚗 Drive Alone: Between 30 and 40 min</p> <p>Arrival: Between 7:50 and 8:00</p>	<p>Start : 7:30</p> <p>Join the station: no detour ⌚ 5 min</p> <p>Wait: ⌚ 5 min</p> <p>🚗 Carpool : Between 25 and 40 min</p> <p>Join your destination: 🚶 5 min walk</p> <p>Arrival : Between 8:15 and 8:30</p>	<p>Start : 7:35</p> <p>Join the station: 🚶 5 min walk ⌚ 5 min</p> <p>Wait: ⌚ 5 min</p> <p>🚗 Carpool : Between 30 and 40 min</p> <p>Join your destination: 🚶 5 min walk</p> <p>Arrival : Between 8:20 and 8:30</p>	<p>Start : 7:30</p> <p>Join the station: 🚗 10 min by car ⌚ 5 min</p> <p>Wait: ⌚ 5 min</p> <p>🚗 Public Transport: Between 25 and 40 min</p> <p>Join your destination: 🚶 5 min walk</p> <p>Arrival : Between 8:15 and 8:30</p>
Monetary aspects	You pay your usual transportation costs	You pay your usual transportation costs Carpooling makes you earn 1€	You save on your usual transportation costs Carpooling costs you 1€	You save on your usual transportation costs Public Transport costs you 0,80€
Carpooler's profile		Your passenger: 🚶 45 years old, Hitchhiker	Your driver: 🚶 25 years old, Referenced on the carpool platform	
Which mode do you choose ?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 5 : Example of a choice screen of the stated preferences survey

The survey was organized in three main parts. The first one collects the respondent's individual information and the characteristics of its usual trip; this information being needed to extract information only from the sample of interest. The second part is the discrete choice experiment on its own. Respondents face 10 choice screens in which each alternative is labelled and characterized by their associated attributes. Furthermore, the order of columns has been randomized for each screen to avoid the left right bias as recommended by Hess & Rose (2009).

Finally, five questions were asked to evaluate the respondents' sensitivities to environmental consequences of the solo driving practice. Indeed, incentivizing carpooling involves psychological and social dimensions which go beyond self-interest, this latter dimension being covered through our SP design. The environment or the level of congestion in the city may be seen as "commons" which deserve specific behavioral adaptations.

Regarding the potential of motivational factors towards pro-environmental behavior, the literature offers two main theories: the theory of planned behavior (TPB; Ajzen, 1991) and the norm-activation theory (NAT; Schwartz, 1977). These two theories are applied and compared by Wall et al. (2007) to explain drivers' intentions to reduce or maintain their car use for commuting. The authors show that a combination of TPB and NAT constructs has a superior power of explanation when compared to the two theories separated. Following Wall et al. conclusions, a set of five statements was built (presented on a Likert scale) which cover the basic constructs of both theories: 1) Car traffic is a major source of pollution and congestion. 2) I am satisfied with my daily trip choices. 3) I can or could easily change the way I travel daily. 4) The opinion of people who matter to me is important for the way I travel daily. 5) I feel personally responsible for contributing to reduce pollution and congestion.

Survey collection

In order to collect a large amount of data and reduce survey costs, we decided to carry out the entire survey online. We chose to carry out the data collection with a company specialized in online survey management, and after a call for tenders we selected a Lyon-based company called Inkidata. We also worked with them on the layout of the survey, as previously mentioned. Concerning the distribution of the survey link, we took advantage of our partnership with the members of the LCE project. As a result, highway companies, local authorities, the University of Lyon, and a carpool company allowed us to spread a web-link of the survey to many inhabitants in the Lyon area. The call message for the survey was developed in partnership with the Lyon metropolitan authority's communication service. It specified that it was about daily mobility and not specifically about carpooling to avoid strategic or selection bias.⁹

Importantly, there was a financial incentive to answer the survey as respondents had a chance to win a 100€ voucher. A wide part of the sample came thanks to the dissemination of the survey to electronic tolling motorway subscribers. Finally, a database containing 4,845 respondents who fully completed the survey was collected. More information on this dataset will be proposed in the following chapters of this thesis. Above all, this large number of respondents was achieved thanks to the support of all the LCE project stakeholders mentioned above. I therefore take this opportunity to warmly thank all the companies and people who contributed to the creation and dissemination of this survey, of which the results have been fundamental to the further development of the thesis work.

⁹ The call message for the survey was: "We are interested in your daily journeys! Help researchers at the University of Lyon to better understand your travels! Take this online survey in 15 minutes and try to win vouchers!"

Thesis outline

This thesis proposes an analysis of carpooling in daily trips, on both individual and collective levels. The manuscript is divided into three chapters. Each chapter is written in the format of a scientific paper, of which the first (Chapter I) has already been published in a peer-reviewed international journal, the two remainders being in final preparation before their submission.

Chapter I: Evaluating solo driving commuters' switch to carpool potential. Co-authored by Guillaume Monchambert and Charles Raux (doi.org/10.1016/j.tranpol.2021.10.001).

The first chapter deals with the question of individual preferences towards mobility choices. More specifically, it aims to understand the reactions of current driving commuters to a new carpooling supply. One of the most common ways of measuring preferences in transport economics are VoTs. As Ciari & Axhausen (2012) suggest, VoTs in carpooling may differ from the one of solo drivers. Moreover, Wardmann et al. (2016) clearly showed that VoTs may differ depending on the local context – with different valuation between European countries – and may also differ depending on the stage of the trip. These heterogeneities in VoTs are measured in this chapter through analysis of modal choices between the four modes of transport presented in the stated preference survey described above.

Our results suggest that carpooling VoTs are higher than those of solo drivers and that the potential shift from solo drivers to carpooling would be more likely towards the driver mode rather than the passenger mode. This result suggests that carpooling passengers could be a scarce resource in the current population of solo drivers and if one wants to make carpooling efficient, passengers will have to be found elsewhere.

Chapter II: Impacts of organization and carpooler on willingness to carpool and welfare.

Co-authored by Guillaume Monchambert and Martin Koning.

This chapter also deals with individual preferences using the same stated preferences survey, but on another level. Its objective is to measure the impact of carpooling organizational variables that have already been mentioned in the literature; whether it is the impact of a matchmaking platform (Montero, 2019), of the potential carpooler met on this platform (Farajallah et al., 2019), or more generally the type of relationship with this potential carpooler (Chaube et al, 2010). This chapter therefore deals with the effects of the conditions under which carpooling is carried out, as well as the relationship between individual characteristics of the respondent and of its potential carpooler. In addition, this chapter also briefly discusses the impact that some carpooling incentives could have at the community level by proposing a social welfare analysis.

Our results show that platforms seem efficient to build trust and raise the individual willingness to carpool, with an even stronger effect for passenger than for drivers. Women are more easily accepted as carpoolers than men and more sensible than men to their carpooler's gender. Finally, our results indicate that drivers should pay passengers in order to make carpooling optimal from a welfare perspective, which is the opposite of the current carpooling practice.

Chapter III: Social cost analysis of carpool incentives and spatial heterogeneities. Co-authored by Guillaume Monchambert, Martin Koning, Clément Marchal and Jean-Baptiste Ray.

This chapter addresses the question of the impact of carpooling incentives or exogenous shocks to transport supply on the total social cost of transport over a given area. The costs for

the community are measure through four components: travelers' costs, external costs, private companies' costs (net or earning) and public authorities' costs (net or earning). Costs are calculated using reference values used in transport socio-economic analysis, mainly with values taken from the Quinet report (2014) and the handbook on external costs of transport (European commission, 2020). We use local data from the eastern Lyon region with 6,287 different origin-destination (O-D). These data were obtained in collaboration with Ecov – a carpooling start-up operating in the area – which estimated the transport supplies for the 4 modes of transport studied in our stated preferences survey, on which a modal choice model is calibrated. Once modal choices estimated, we obtain the vehicle flows for each O-D that allows us to calculate their associated transport social costs. We then test the impact of several measures simulating new carpooling supply through scenarios that modify carpool organization, with the implementation of a real-time carpooling service. Other scenarios are also testing new carpooling supplies with modified times, such as a “HOV-lane” or a “Closer carpooling stations” scenario. Finally, we also create scenarios testing the impact of new carpooling and fuel prices on the total social cost of transport.

Our results underline the high impact of travelers' costs within the total social cost and conversely, the low impact of environmental costs in welfare analysis. Furthermore, our results indicate that public authorities benefit from private cars' traffic through taxes and that it outweighs the value of negative externalities produced. Moreover, we find a significant spatial heterogeneity of policy impacts, suggesting that the local context and the question of spatial equality must be considered carefully before implementing a daily carpooling policy.

Finally, the last section of the thesis concludes with a review of its main results, limitations and potential future research.

Appendices

Appendix A. Example of information screens before choice tasks in the SP survey

Reserved lane presentation screen



The Grand Lyon is considering a new layout: a **reserved lane** to **carpools** and **buses**.

It allows users to avoid potential traffic jams on other lanes.

It can be used when there are 2 or more occupants in your car.



An example of reserved lane to carpools and buses

How to answer this survey ?

For this trip for which you wish to arrive at 8:30 A.M.

- Several transport modes are presented
- You observe their different characteristics
- You choose your preferred alternative

Transport mode	Carpool passenger	Public Transport
Trip Characteristics	Departure: 7h50 Carpool: between 20 et 30 min Reach destination: 10 min walk Arrival: entre 8h20 et 8h30	Departure: 7:45 PT: between 25 et 40 min Reach destination: 5 min walk Arrival: between 8:15 and 8:30
Monetary aspects	This trip costs you 1€	This trip costs you 0,80€
Carpooler's profile	25 years old Met via platform	
What do you choose?	<input type="radio"/>	<input type="radio"/>

Appendix B. Lyon's HOV-lane map



Notes: Only the highway crossing Lyon from north to south is shown on this map. Sections with reserved lanes are shown in blue. Source: Grand Lyon.

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CHAPTER I.

Evaluating commuters switch to carpool potential

1. Introduction

Traffic congestion is still a major issue in large cities around the world. France is no exception to this observation. According to INRIX (2019), the drivers in Paris, Marseille, Lyon and Toulouse – the four largest cities in the country – respectively lost on average 237, 140, 141 and 130 hours in road congestion in 2018. Most of this traffic congestion appears during morning and evening peak hours.

Promoting carpool is seen as a cost-effective way to moderate road congestion while avoiding costly investments in road expansion and to reduce harmful gas emissions. The current rate of car occupancy is low in France, since it amounts especially at 1.08 for commuting trips (ENTD, 2008). Similar results are found in UK (1.14, Department for Transport, 2019), USA (1.13, Santos et al., 2011) or Australia (below 1.1 in major cities, Loader, 2012). It implies that there is a large unused transport capacity during peak hours.

Local policy makers in France are currently considering different kinds of policies to promote carpool for commuting trips. The cities of Lyon and Grenoble are experimenting high occupancy vehicles (HOV)-lanes in 2021. These lanes are expected to offer shorter travel time and improved reliability for carpoolers compared to solo drivers. Despite several similar experimentations in Europe - like in Madrid, Spain or in Trondheim, Norway (Schijns & Eng, 2006) – there are few quantitative studies detailing preferences towards carpooling for commuting trips. This gap in the empirical literature motivated this research.

We address the following research question: what are the preferences of current solo drivers towards carpooling as a driver and as a passenger for a commuting trip? We especially

test the presence of heterogeneity in preferences, both across modes and individuals, and measure it. By addressing these questions, we also tackle the potential behavioral responses of current solo drivers to a new carpooling supply. We answer these questions by estimating end-to-end VoTT and their distributions for commuting trips as a solo driver, a carpool driver, a carpool passenger, and a public transport passenger. To this aim, a discrete choice experiment survey was conducted on a sample of 1556 solo driving commuters in the city of Lyon. To our knowledge, we are the first to empirically measure solo driver values of time for carpool commuting trips.

A strong average preference for solo driving is identified through our results. However, the individual heterogeneity in these preferences must be considered. This heterogeneity can be described by distinguishing four behavioral patterns: reluctant to mode change, preferring the three alternative modes over solo driver, preferring public transport and preferring driver modes whether solo or carpool. The simulations performed suggest that despite travel time gains due to HOV-lane or monetary subsidies, few current solo drivers would switch to carpool as passenger.

The rest of the paper is organized as follows. Section 2 reviews the previous literature on the topic. Section 3 presents the survey design, data sampling and summary statistics. Section 4 shows the methodological framework and the empirical strategy used to estimate values of travel time. Section 5 presents the results, which are discussed in Section 6. Section 7 concludes.

2. Literature Review

Previous qualitative studies showed preferences toward carpooling for commuting trips are not a clear-cut case. On the one hand, individuals often consider carpooling as a risky mode (Chan & Shaheen, 2012). The desire of independency or flexibility are also reasons raised from solo drivers to stay alone in their car (Li et al., 2007). On the other hand, in a French survey (ADEME, 2015), carpoolers often cite friendliness, ecology or a reduced stress and fatigue as reasons why they choose this mode. Economic criterion is also found to be a crucial determinant of the modal choice. Indeed, the economic gain or loss is seemingly an essential attribute in the transport modal choice. Sharing the costs makes carpooling economically competitive compared to solo driving or other travel modes at least on long distances (Shaheen et al., 2017; Monchambert, 2020).

Values of travel time (VoTT) are known to differ between modes and individuals. Wardman et al. (2016) distinguished “mode used VoTT” – relative to individual characteristics – and “mode valued VoTT” – relative to mode characteristics such as comfort, privacy, security, or externalities due to environment. Previous surveys showed that travel time values are lower for public transport users – in bus and rail – than for car users (Shires & De Jong, 2009; Wardman et al., 2012; Quinet, 2013). Regarding carpooling VoTT, in a stated preferences survey in France, Blayac & Adjeroud (2018) compared VoTTs of bus and carpool users over long distances. They found that the value of time for carpool users is more than twice the one of bus users. Monchambert (2020), in a long-distance carpool survey, found that VoTTs in carpooling are higher than those as a solo driver, bus user and train user. Concerning VoTTs for carpool commuting trips, Ciari & Axhausen (2012) measured values in Switzerland for the same four modes as the present survey, but without precision about trip purpose. They found a substantial heterogeneity between value of public transport travel time and values for other modes, with a slightly higher value for carpool modes than for solo driving.

3. Survey Design and Data Sampling

3.1. Study context

This survey and its questionnaire were designed to observe how the inhabitants of the Lyon area (1.4M inhabitants) would react to the creation of a HOV-lane, a new infrastructure in France. Indeed, in 2021 the metropolitan authority of Lyon opened two HOV-lane sections on its main North-South axis. These lanes are 6 and 4-km long for the northern and the southern sections, respectively. The survey was conducted in spring 2019 and at this time the expected time savings for carpoolers were between 5 and 15 minutes during morning rush hours.

3.2. Survey design

The questionnaire is organized in three parts. The first part aims at collecting basic socio-demographic data and the respondent's usual trip characteristics. The second part is the stated choice experiment. It is a responsive experiment in the sense that the choices tasks proposed to the respondents depend on their trip characteristics. The third part is a questionnaire on attitudes.

3.2.1. Socio-demographic and trip characteristics

In this online survey, we first collect information on respondents' socio-economics variables (gender, age, income, professional position...) and on the characteristics of their "usual trip" i.e. the most frequent trip made by car or public transport during a workweek. These characteristics are used to responsively build the choice tasks in the second step of the survey.

Our aim is to place the respondent in the context of a trip he can do with the proposed modes in the survey. We are interested in respondents for whom carpooling is a credible alternative for their usual trip. Respondents whose usual trip meets the following criteria are

kept in the survey:

- a travel time between 15 and 90 minutes
- driving their car
- during rush hours (between 6 and 10 am or between 4 and 8 pm, excluding Saturday and Sunday)

On the one hand, we consider carpooling is not a credible alternative for very short distance trips (<15 minutes by car), because even a short waiting time (for the passenger) or detour time (for the driver) would proportionally lengthen the trip a lot. On the other hand, we consider long trips (>90 minutes) as outside the study scope since the time gain procured by the HOV-lane can be considered as proportionally too marginal regarding the decision to carpool. Furthermore, the average commuting time by car in Lyon area, which is around 30 minutes, is way below this threshold (SYTRAL, 2016).

As it is a new policy in France, the HOV-lane and the carpooling organization are presented to the respondents before the choice tasks through two screens.

3.2.2. Experimental Design

To make respondents state what they would do in an actual situation, alternatives are kept realistic by using the information on their usual trip collected earlier. The time attributes levels of the various alternatives vary around the initial values of this usual trip.

Since variation is needed between the exercises, a total of 60 different choice task patterns is created, split into 10 blocks. Then each respondent is allocated to a block and face six choice situations. In each of these choice screens, the respondent has the choice between four

alternatives (modes), presented in columns: Solo Driver, Carpool Driver, Carpool Passenger and Public Transport (see Appendix A). Following Hensher et al. (2015) recommendations, the attribute levels of the proposed alternatives are not such that any alternative dominates the others. Furthermore, the order of columns is randomized for each screen to avoid the left right bias as recommended by Hess & Rose (2009).

For a given trip, each alternative is labelled and characterized by different types of attributes:

- Trip attributes include several time variables (in-vehicle time and in the case of alternatives to solo driver mode, waiting, detour, access, and egress time), as well as the departure and arrival times.
- The monetary aspects include two attributes. The first is the cost (resp. gain) due to the use (resp. no use) of their personal car. The second attribute is a gain or cost for providing or using carpool services or public transport. Contrary to “slugs” in the USA (Burriss et al., 2012) carpoolers in France are used to a monetary exchange between the driver and the passengers. In this survey, we approximate this cost depending on the duration of the trip. The cost for Public Transport alternative is fixed to 0.8€ as it is the average cost for a subscriber in the city.
- In carpool alternatives, organization and matched carpooler’s profile are also presented to check for other attributes who could affect mode choice such as close relationship between driver and passenger and the impact of a carpool platform. These variables will be used as controls in this survey.

The Ngene software (ChoiceMetrics, 2012) is used with a D-efficient design (see Rose et al., 2008) to build balanced choice tasks and extract as much information as possible from the trade-offs made by respondents. For that, prior information about parameters have been

used from de Palma and Fontan (2000) and Quinet (2013). The mode attributes and levels used in the choice tasks are presented in Table 1.1.

Table 1.1: Trip attributes, levels in stated choice design and choice shares

Type	Attributes	Alternatives	Levels	Mean Value
Time				
Schedule early/late (in min)	Solo Driver	0, 30, 60 (earlier or later)		17 min (earlier) 12 min (later)
		Solo Driver	Min: $0.8 \times \text{usual_tt}$ Max: $1.9 \times \text{usual_tt}$	55 min
End-to-end travel Time (in min)	Carpool Driver	Min: $0.6 \times \text{usual_tt}$ Max: $1.5 \times \text{usual_tt} + 20$	50 min	
	Carpool Passenger	Min: $0.6 \times \text{usual_tt} + 10$ Max: $1.5 \times \text{usual_tt} + 50$	64 min	
	Public Transport	Min: $0.6 \times \text{usual_tt} + 10$ Max: $1.5 \times \text{usual_tt} + 35$	60 min	
Cost (in €)	Carpool Driver	Receives $(0, 0.02, 0.05, 0.1) \times \text{usual_tt}$		1.65 €
	Carpool Passenger	Pays $(0, 0.02, 0.05, 0.1) \times \text{usual_tt}$		2.00 €
	Public Transport	Pays 0.8		0.80 €
Carpool supply				
Carpooler matching	Carpool Driver and	With a relative, met by platform, with a hitchhiker		
Carpooler Gender	Carpool Passenger	Male, Female (not presented if relative)		
Carpooler Age		25, 45, 65 years old (not presented if relative)		

Notes: "usual_tt" is the usual travel time the respondent reports in the survey. Detailed attribute levels are provided in Appendices.

3.2.3. Attitude Questions

Finally, five questions are asked to evaluate the respondents' sensitivities to environmental consequences of the solo driving practice. Indeed, incentivizing carpooling involves psychological and social dimensions which go beyond self-interest, this latter dimension being covered through our DCE design. The environment or the level of congestion in the city may be seen as "commons" which deserve specific behavioral adaptations.

Regarding the potential of motivational factors towards pro-environmental behavior, the literature offers two main theories. The first one is based on self-perceived cost and benefits, with the theory of planned behavior (TPB; Ajzen, 1991). TPB aims at explaining behavioral

intentions (viewed as the immediate antecedent of actual behavior) by the attitudes (ATT), the perceived social pressure regarding this behavior (subjective norms, SN) and the perceived behavioral control (PBC). The other theory is based on moral and normative concerns with the norm-activation theory (NAT; Schwartz, 1977) and aims at explaining altruistic behavior. Feelings of obligation, stemming from perceived norms (PN), precede immediately behavior and are activated by the awareness of behavior consequences (AC) and beliefs about personal responsibility.

These two theories are applied and compared by Wall et al. (2007) to explain drivers' intentions to reduce or maintain their car use for commuting. The authors show that a combination of TPB and NAT constructs has a superior power of explanation when compared to the two theories separated. Following Wall et al. conclusions we build a set of five statements (presented on a Likert scale) which cover the basic constructs of both theories:

- 1: Car traffic is a major source of pollution and congestion (AC).
- 2: I am satisfied with my daily trip choices (ATT)
- 3: I can or could easily change the way I travel daily (PBC).
- 4: The opinion of people who matter to me is important for the way I travel on a daily basis (SN).
- 5: I feel personally responsible for contributing to reduce pollution and congestion (PN).

The answers to these statements have been transformed into continuous variables as follows: -2 if the respondent strongly disagreed, -1 if disagreed, +1 if agreed and +2 if strongly agreed with the statement. Neutral answers were coded as 0.

3.3. Data collection

A partnership with different motorway companies, local authorities, the University of Lyon, and a carpool company allowed us to spread a web-link of the survey to many inhabitants in the Lyon area. The call message for the survey specified that it was about daily mobility and not specifically about carpooling to avoid strategic or selection bias.¹⁰ There was a financial incentive to answer the survey as respondents had a chance to win a 100€ voucher. A wide part of the sample came thanks to the dissemination of the survey to electronic tolling motorway subscribers. Finally, a database containing around 3,300 respondents who fully completed the survey was collected.

In this paper our focus is on the potential change of daily commuters from solo-driving to carpooling when facing a HOV-lane. Thus, only respondents who declare a usual trip as solo drivers, at least several times a week and for work purpose are kept. This commuters' subset still represents an important part of our base sample, with 2,044 respondents.

Finally, an adhoc data filtering is applied as recommended by Hess et al. (2010). Since response times for each choice screen are available, 309 people who answered to a choice screen at least once in less than 6 seconds were excluded. This allows us to remove respondents who only came to win a voucher and answer the questionnaire as fast as they can without examining the choice sets. Also, 179 respondents who did not report income were excluded from the survey for a final sample of 1556 respondents and 9336 observations analyzed. Descriptive statistics of this final sample are presented in **Erreur ! Source du renvoi introuvable.** A comparison between socio-demographic characteristics of our sample and the targeted population (population in the first rows of **Erreur ! Source du renvoi introuvable.**) shows a fairly good

¹⁰ The call message for the survey was: "We are interested in your daily journeys! Help researchers at the University of Lyon to better understand your travels! Take this online survey in 15 minutes and try to win vouchers!"

representativeness of our sample.

Table 1.2: Sample characteristics

	Sample		Commuting Population in the area**		
	Mean	Sd	Mean	sd	
Individual					
Male	54.7%		54.8%		
Age (years)	44.6	10.4	41.1	11.6	
Income per month (€)*	2378	901			
Occupation					
Self-employed	3.9%		7.3%		
Senior Management/Professional	47.9%		18.5%		
Middle Management	12.1%		29.1%		
Clerical Staff	32.3%		22.8%		
Laborers	3.0%		21.7%		
Students	0.7%		Farmers	0.5%	
Reference trip					
Length (min.)	39.1	16.7			
Attitude statements (in the sample)					
	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S1 (“car traffic major source”)	2.1%	5.0%	8.5%	34.4%	50.0%
S2 (“satisfied with my choices”)	8.6%	25.1%	19.4%	30.9%	16.0%
S3 (“could change easily”)	19.5%	28.1%	16.3%	28.6%	7.5%
S4 (“opinion matter”)	25.8%	17.2%	31.2%	19.3%	6.6%
S5 (“personally responsible”)	5.5%	7.9%	22.8%	44.0%	19.8%
Choices					
	Solo Driver	Carpool Driver	Carpool Passenger	Public Transport	
	31%	38%	15%	16%	
Nb of individuals		1556			

*income variable is collected as categorical. Mean and standard deviation are calculated using the center of the classes selected by respondents. Income is not available in the census.

** source: MOBPRO, a national census that aim to survey the professional mobility over territories (INSEE, 2019), solo driver data from départements of Ain, Isère, Loire and Rhône which intersect the Lyon urban area.

4. Methodology

4.1. Econometric Models

Three model types are used to analyze the discrete choice data: a multinomial logit (MNL) which is the usual base model, a mixed logit (MXL) and a latent class logit (LCL).

These two last models provide two different functional forms of heterogeneity in preferences for some attributes, which relieve the IIA assumption (McFadden & Train, 2000) and consider the panel structure of the data (Lancsar et al., 2017). The MXL model considers and analyzes heterogeneity through “random parameters” estimates. These estimates then vary following a parametric distribution. Contrary to the MXL, the LCL model does not need any assumption on distribution of preferences in the population. It builds a typology of preferences, considering as many types of behavior as latent classes. However, the number of classes is chosen by the analyst, which is in a way another assumption. We retain the number of classes whose model has the lowest AIC (Louviere et al. 2000, chap.10).

Concerning the parametrization of individual heterogeneity, we let intercepts and time estimates vary across respondents. Preferences can thus vary according to time spent in the mode, reflecting for example perceived comfort (time estimates), or a pure preference for the mode, due for instance to past experiences (intercepts). Other estimates remain fixed across all classes just like in the MNL model.

Furthermore, the analyst can define latent class parameters to explain the class allocation probability of individuals (see Hess & Palma, 2020). Hence, we tried to use respondents’ socio-economic characteristics and the attitude statements answers as explanators of the classes.

4.2. Utility Specifications

A willingness to pay (WTP) space utility specification is used (Train & Weeks, 2005; Daly et al, 2012). This expression of the utility is a re-parametrization obtained by multiplying the cost coefficient estimate by time coefficients. It allows for a direct interpretation of time estimates as values of time.

Utilities for the four alternatives are presented below:

$$\begin{aligned}
V_{sd} &= \beta_{cost}(Cost_{sd} + \beta_{TTsd}TT_{sd} + \beta_{earl}SchedEarly + \beta_{late}SchedLate) + \beta_{Zsd}Z \\
V_{cpd} &= \beta_{cost}(Cost_{cpd} + \beta_{TTcpd}TT_{cpd}) + \beta_{Zcpd}Z + \beta_{Xcpd}X_{cpd} \\
V_{cpp} &= \beta_{cost}(Cost_{cpp} + \beta_{TTcpp}TT_{cpp}) + \beta_{Zcpp}Z + \beta_{Xcpp}X_{cpp} \\
V_{pt} &= \beta_{cost}(Cost_{pt} + \beta_{TTpt}TT_{pt}) + \beta_{Zpt}Z
\end{aligned} \tag{1}$$

β_{0k} is the Alternative Specific Constants (ASCs) associated with mode k , with β_{0sd} normalized to zero (solo driver chosen as the reference alternative), β_{cost} is the cost coefficient, β_{ttk} the Value of Travel Time (VoTT) of mode k , Z the respondent individual variables and X the carpool organization variables.

β_Z and β_X are vectors of estimates for Z and X respectively. β_{0ds} and β_{Zds} are fixed to 0 as references. At this point, let's recall that we expect heterogeneity across individuals, but that we also expect individual preferences to vary across modes, due for example to differences in comfort or safety. Therefore, one ASC and one VoTT coefficient per mode are estimated.

Focusing on the Solo Driver cost function, leaving earlier or later is considered as an option to avoid road congestion. Considering the HOV-lane will reduce congestion for other modes, schedule delay is only considered for Solo Driver. The idea is to observe if respondents are ready to delay their trip rather than switching to carpool modes or public transport. *SchedEarly* and *SchedLate* are schedule delay time variables. β_{earl} and β_{late} are their respective estimates. The *Cost* variable is measured as the difference between the cost of the alternative and the cost of the Solo Driver situation (reference).

In the MXL, travel time random parameters are defined as follows for mode k :

$$\beta_{ttk} = \exp(\mu_{\beta_{TTk}} + \sigma_{\beta_{TTk}} * \zeta_{\beta_{TTk}}) \quad (2)$$

where μ and σ are the estimated parameters of the lognormal distribution and ξ follow standard normal distribution across individuals.

Correlations are introduced between travel time random parameters, particularly because VoTT is correlated with unobserved respondent idiosyncrasies (see Appendix B). The VoTTs of an individual are hence expected to be correlated with each other.

5. Results

5.1. MNL and MXL estimates

Coefficients in Equations (1) have been estimated with the *Apollo* package built by Hess & Palma (2019) for the R software. Full estimation results are displayed in the Appendices while an extract is shown in Table 1.3. The MXL models has been estimated with 2,000 Modified Latin Hypercube Sampling (MLHS) draws (Halton draws are not advised for more than five random coefficients, see Bhat, 2003). In these models, the alternative-specific constants are assumed to be normally distributed. It is assumed that VoTTs are positive and correlated with the distribution of incomes, which justifies the choice of lognormal distributions.

Table 1.3: Estimations results of MNL and MXL models

Attribute	Alternative	MNL1	MNL2	MXL1	MXL2	MXL3
Alternative-Specific Constants (ASCs)	Carpool Driv.	-0.483***	0.240*	-1.038***	-0.845**	-0.015
(Reference: Solo Driver)	Carpool Pass.	-0.638***	0.025	-1.082***	-1.079**	-0.295
	Pub. Transport	-1.054***	-0.286*	-2.186***	-0.917*	-0.886*
ASCs	Carpool Driv.			2.350***	1.413***	1.508***
Standard deviation (σ_{ASC})	Carpool Pass.			2.494***	0.092	0.686***
	Pub. Transport			2.864***	1.503***	2.122***
Travel time ($\mu\beta_{tt}$ in MXL)	Solo Driver		0.336***		-0.630***	-0.777***
	Carpool Driv.		0.502***		-0.730***	-0.666***
	Carpool Pass.	0.576***	0.462***	-1.095***	-0.841***	-0.732***
	Pub. Transport		0.481***		-0.548***	-0.588***
Travel time	Solo Driver				0.891***	1.254***
Standard deviation ($\sigma\beta_{tt}$)	Carpool Driv.				0.260***	0.674***
	Carpool Pass.			0.776***	0.233***	0.004
	Pub. Transport				0.275***	0.019
Schedule early	Solo Driver	0.299***	0.190***	0.175***	0.170***	0.166***
Schedule late	Solo Driver	0.072***	0.052***	0.050***	0.056***	0.033*
Cost	All	-0.072***	-0.100***	-0.199***	-0.163***	-0.167***
Carpool organization controls (Z)		Yes	Yes	Yes	Yes	Yes
Respondent individual controls (X)		Yes	Yes	Yes	Yes	Yes
Correlation between random param.		/	/	No	No	Yes
Nb of individuals		1556	1556	1556	1556	1556
Nb of observations		9336	9336	9336	9336	9336
Nb of parameters		24	27	28	34	40
LL (final)		-11004.1	-10917.5	-9137.3	-8808.2	-8625.2
Adj.Rho-squared (0)		0.148	0.154	0.292	0.317	0.331
AIC		22056	21889	18331	17684	17330
BIC		22228	22082	18531	17927	17616

Notes: Values for MXLs are the “ μ ” parameters of normal and lognormal functions. See detailed results in appendices. P-values: 1 () 0.1 (‘) 0.05 (*) 0.01 (**) 0.001 (***) 0.

5.1.1. General comments on models

The MNL1 and MXL1 suppose no difference between VoTTs of the four modes. The MNL2, MXL2 and MXL3, which consider “mode-valued” heterogeneity, outperform these models with higher Rho-squared and lower AIC and BIC. It shows with consistency across models that time is valued differently in solo driver compared to its alternatives. The Akaike

Information Criterion (AIC) and the Bayesian Information Criterion (BIC) confirm that using random coefficients produces a better goodness of fit, indicating with consistency over the three MXL the presence of individual heterogeneity. The best fit is found for MXL3, indicating correlations between time parameters estimated.

5.1.2. *Constants*

A positive (resp. negative) mode k ASC implies a relative preference (resp. depreciation) for mode k over the solo driver mode (reference alternative). The Public Transport ASCs are significantly negative in every model which means that all other variables equaling zero, there is on average a preference for Solo Driver mode over Public Transport.

Despite the means of ASC for Carpool Driver and Carpool Passenger are zero in the MXL3 model, there is a strong heterogeneity in “pure” preferences for modes across individuals. Indeed, the standard deviations of the ASC are high, 1.51 for Carpool Driver, 0.69 for Carpool Passenger and even 2.12 for Public Transport.

5.1.3. *Values of time*

The MNL2 results show directly VoTTs in €/minute, that can be multiplied by 60 to give results in €/h. Solo Driver, Carpool Driver, Carpool Passenger and Public Transport VoTTs are respectively equal to 20€/h, 30€/h, 28€/h and 29€/h. In the MXL3, due to specificities of the lognormal distribution, $\exp(\mu)$ is the median of the lognormal distribution. Consequently, MXL3 gives median VoTTs for Solo Driver, Carpool Driver, Carpool Passenger and Public Transport respectively equal to 28€/h, 31€/h, 29€/h and 33€/h.

Table 1.4 below displays the VoTT for all modes estimated through MNL2 and MXL3. The lower Solo Driver VoTT given by the MNL2 suggest a preference for this mode. The three alternatives to this mode show VoTTs between 40% and 50% higher than solo driver VoTT.

Since the respondents are currently solo drivers, this is not surprising to find Solo Driver VoTT as the lowest.

Table 1.4: Values of Time in MNL and MXL models

Model	MNL2	MXL3
Mode		Med [1Q;3Q]
Solo Driver	20	28 [12 ; 64]
Carpool Driver	30	31 [18 ; 60]
Carpool Passenger	28	29 [14 ; 59]
PubT	29	33 [19 ; 59]

Notes: Values for MXL3 are the median, 1st and 3rd quartile values of the estimated lognormal distribution.

5.1.4. Schedule delay

Schedule delay is presented only with solo driving mode in the survey. In all models, the cost of arriving at destination one minute earlier than the preferred arrival time (0.19€/minute in MNL2, 0.17€/minute in MXL3) is found to be higher than the cost of arriving one minute later (0.05€/minute in MNL2, 0.03€/minute in MXL3). This is an unexpected result discussed in the next section. Our results also suggest that the value of the schedule delay early is around 36% of the Solo Driver VoTT.¹¹

5.1.5. Cost

As expected, the cost coefficient sign is negative in both specifications. The value of the estimated coefficient in MXL3 implies that all other things being equal, a one euro increase in the price of a mode decreases the odds of choosing this mode over other modes by 15.4%.¹²

¹¹ $0.166 / \exp(-0.777) = 0.361$

¹² $\exp(-0.167) - 1 = -0.154$

5.2. LCL model

We also estimate coefficients in Equations (1) with a LCL model. The LCL model with the lowest AIC, presented here in Table 1.5, has four classes. We use the five “attitude statements” as latent class membership covariates. We also tested individual socio-economic variables (gender, age, and income) as latent class membership covariates, but the goodness-of-fit was lower (see Appendices).

Table 1.5: Estimations results of LCL model

Attribute	Alternative	LCL			
		Class A	Class B	Class C	Class D
Alternative Specific Constants (Reference: Solo Driver)	CpDriver	-3.042 ***	2.103 ***	-2.659 ***	1.100 ***
	CpPassger	-5.531 ***	2.554 ***	-1.832 **	-1.068 **
	PubTrsprt	-4.396 ***	2.507 ***	0.997 **	-1.659 **
Travel Time	SDriver	0.280 ***	0.454 ***	0.443 ***	0.208 ***
	CpDriver	0.432 ***	0.719 ***	0.290 ***	0.313 ***
	CpPassger	0.113	0.620 ***	0.278 ***	0.185 ***
	PubTrsprt	0.237 **	0.714 ***	0.400 ***	0.293 ***
Scheduled early	SDriver		0.193 ***		
Scheduled late	SDriver		-0.017		
Cost	All		-0.132 ***		
Latent Class Allocation Variables					
	Average Latent Class Allocation Probability	0.20	0.35	0.12	0.32
	S1 (“car traffic major source”)	0	0.263 **	0.353 **	0.161 .
	S2 (“satisfied with my choices”)	0	-0.679 ***	-0.966 ***	-0.285 ***
	S3 (“could change easily”)	0	0.661 ***	0.891 ***	0.499 ***
	S4 (“opinion matter”)	0	0.091	-0.116	0.138 *
	S5 (“personally responsible”)	0	0.206 *	0.045	0.155 .
Carpool organization controls (Z)			Yes		
Respondent Individual characteristics controls (X)			Yes		
Nb of individuals			1556		
Nb of observations			9336		
Nb of parameters			66		
LL(final)			-8560		
Adj.Rho-square			0.334		
AIC			17252		
BIC			17723		

Notes: This table reports LCL estimates of coefficients in Equations (1).

P-values: 1 () 0.1 (‘) 0.05 (*) 0.01 (**) 0.001 (***) 0. See Appendices for more detailed results.

The adjusted Rho-squared of the LCL is 0.33. The LCL model outperforms the MNL with lower information criterions (AIC and BIC). Since their structures are not nested, MXL and LCL are not directly comparable. However, they present similar goodness of fit.

5.2.1. Latent class probability and covariates

The sample average probability of belonging to Class A is 20%, 35% for Class B, 12% for Class C and 32% for Class D. We find that individuals who agree with the statements S2 (“I am satisfied with my daily trip choices”) and disagree with statement S3 (“I can or could easily change the way I travel on a daily basis”) have a higher probability of belonging to Class A. On the contrary, individuals who disagree with S2 and agree with S3 are more likely to belong to Class B and even more to class C. Individuals who agree with S4 (“The opinion of people who matter to me is important for the way I travel on a daily basis”) are more likely to be in Class D. Finally, we can observe a tendency for class B (and more slightly for class D) to declare more often they feel personally responsible to reduce traffic, and that it is a major source of pollution (Statements 1 and 5).

5.2.2. Mode preferences

To understand how mode preferences differ between the classes, it is important to consider both ASCs and VoTTs. Therefore, we build up in Table 1.6 generalized costs for a 40-minute trip which is the average length of respondents’ current trip (see **Erreur ! Source du renvoi introuvable.**).

Class A preferences are clearly drive by the ASC with high negative values that prevent any switching from the solo driver mode. On the contrary, class B has positive ASCs, indicating an interest for alternative modes but the difference between the generalized costs of the different modes is smaller. The VoTTs of all modes are quite high compared to other classes, suggesting this class has a higher opportunity cost of time. Class C clearly rejects carpool alternatives, with

a preference for Public Transport and finally, class D prefers driving modes.

Table 1.6 : Generalized costs for a 40-minute trip in each mode and class in LCL

	Class A	Class B	Class C	Class D
Solo Driver	11€	18€	18€	8€
Carpool Driver	40€	13€	32€	4€
Carpool Passenger	47€	6€	25€	15€
Public Transport	43€	10€	8€	24€

Notes: the generalized cost is obtained dividing the ASC by the cost estimate and adding the mode-specific value of 40 minutes for each mode.

5.3. Elasticities

We compute direct modal share elasticities to travel time by using Hensher et al.'s (2015) formula. The elasticity of the probability to choose alternative j with respect to a marginal change in attribute k in the alternative j is:

$$E_{X_{jk}}^{P_j} = \frac{\partial V_j}{\partial X_{jk}} X_{jk} (1 - P_j)$$

Note that the elasticity is then sensitive to modal share, P_j and to end-to-end travel time X_{jk} .

Table 1.7: Direct share elasticities to end-to-end travel time

Alternative	MNL2	MXL3	LCL
Solo Driver	-1.15	-0.86	-0.78
Carpool Driver	-1.34	-1.30	-1.16
Carpool Passenger	-1.72	-1.88	-1.59
Public Transport	-2.06	-2.17	-2.01

Notes: These elasticities are calculated on the survey data. They can be interpreted as follows: an increase of 1% solo driver travel time would decrease the probability to choose the solo driver mode by 0.78% according to LCL results.

Results are presented in Table 1.7 below. In all models, time elasticity is the lowest for the Solo Driver mode, then increasing for Carpool Driver, Carpool Passenger and finally Public

Transport. The direct elasticities ranking is the same across models, showing some robustness. Moreover, elasticities are calculated locally and are therefore sensitive to the modal shares and travel times of our sample (see Table 1.1 and **Erreur ! Source du renvoi introuvable.**). This strengthens the validity of the elasticity ranking as Carpool Driver has a higher modal share and lower end-to-end travel time than Solo Driver and still has a higher elasticity.

6. Discussion

6.1. Main results

6.1.1. Heterogeneity of preferences

In our study, MXL3 and LCL models clearly outperforms the MNL2, the pseudo-R-squared being more than twice larger than the MNL2 one. This proves that the heterogeneity of individual preferences is meaningful. Moreover, in the MXL3 model, the combination of the standard deviation and correlation estimates that are statistically significant shows that both the ASC and the VoTT are highly distributed across the population. This heterogeneity in preferences towards transport modes may recover several aspects. It can be related to mode-specific features (like service quality or comfort), to individual characteristics (age, income, gender), or to personal attitudes (environmental concerns, social norms). A sharpened public policy should consequently consider this high heterogeneity.

The LCL model allows a different approach to estimate preferences heterogeneity, distinguishing as many preferences profiles in the sample as the number of classes. We consider simultaneously VoTTs and ASCs to understand mode preferences of each class. As an example, in Class A, the Carpool Passenger's VoTT is not significant, but the Carpool Passenger constant is very high with a negative impact on the alternative. This reveals a strong aversion for this

mode in Class A. The four following profiles are identified with the same logic:

- Reluctant to change from solo driving (Class A, 20% of the sample)
- Preferring the three alternative modes over solo driver (Class B, 35%)
- Preferring public transport (Class C, 12%)
- Preferring driver modes whether solo or carpool (Class D, 32%)

The ranking of elasticities found in Table 1.7 – with higher elasticities for alternatives to solo driver – implies that the modal shift towards carpooling and public transport will be greater if one reduces the (end-to-end) travel times of these modes rather than increasing the solo driver's travel time.

6.1.2. *Values of time*

The VoTT ratios go from 40% to 50% higher VoTTs for carpool modes compared to the solo driver VoTT. They are slightly higher than those Ciari & Axhausen (2012) found with Swiss data (their ratios are between 20% and 30% higher for carpool modes VoTTs). It could be explained by differences between the two samples. Ours is composed of current commuting solo drivers, expected to have a stronger preference for solo driving over other modes compared to a whole population representative sample, as in Ciari & Axhausen (2012). Consequently, they could proportionally value lower the Solo Driver travel time compared to a sample including other mode users.

VoTTs estimated in this survey are higher than what Wardman et al. (2016) and Shires & De Jong (2009) reported for commuting by car in France, respectively 11.8€₂₀₁₉/h and 15.4€₂₀₁₉/h. Several reasons may explain this. First, our sample is composed only of currently solo drivers, who may have higher incomes than the whole population and hence higher values of time. Another explanation could be that the values we find can be considered from a willingness to accept (WTA) perspective since the exercises challenge what solo drivers are

willing to accept to switch to another mode (see also Monchambert, 2020). In the VoTT field, De Borger & Fosgerau (2008) found an important gap between WTP and WTA with a 1 to 4 factor.

When analyzing the distributions of MXL3-derived VoTTs, we see that the interquartile ranges are overlapping. This is an unexpected result since our sample contains only solo drivers. One would have expected the distribution of the solo driver VoTT to be at lower ranges. This suggests that the current choice of solo driving by some respondents is constrained by the weak quality of alternative supplies because with equivalent travel times, they would choose alternative modes more often.

The schedule late delay is valued lower than schedule early delay. This result is unexpected and opposite to what is found in the literature. It could be due to the way we introduced schedule delay in the survey, that may have been unclear. Respondents could have only observed that their departure time was later than usual and hence thought their total travel time was lower, thinking all the alternatives were arriving on time. Respondents may also have a lot of flexibility and no time constraints they cannot override. However, the scheduled early value is found around 36% of the Solo Driver VoTT. This result is consistent with what was found in de Palma & Fontan (2000) in Paris, around 35%.

6.2. Policy implications

6.2.1. Carpool passenger is the scarce resource

The analysis of preferences allows to predict properly modal shares and the impact of new measures on demand. This is an opportunity to test the effects of a HOV-lane and a subsidy for carpooling passengers. Therefore, modal shares need to be estimated on a reference situation. This reference situation is calibrated to give modal shares close to those observed (in France,

the car occupancy rate for commuting trips is 1.08, ADEME, 2015).

Table 1.8: Market shares with the implementation of new measures

Measure	Alternative	MNL2	MXL3	LCL
<i>(i) Reference situation</i>	Solo Driver	76%	65%	73%
	Carpool Driver	16%	23%	19%
	Carpool Passenger	5%	8%	6%
	Public Transport	3%	4%	2%
<i>(ii) HOV-Lane 5 min time savings</i>	Solo Driver	-5pp	-3pp	-5pp
	Carpool Driver	+3pp	+3pp	+4pp
	Carpool Passenger	+1pp	+0pp	+1pp
	Public Transport	+1pp	+0pp	+1pp
<i>(iii) HOV-Lane 15 min time savings</i>	Solo Driver	-15pp	-11pp	-17pp
	Carpool Driver	+10pp	+9pp	+12pp
	Carpool Passenger	+3pp	+1pp	+3pp
	Public Transport	+2pp	+1pp	+2pp
<i>(iv) Subsidy 1.5€ subsidy for Carpool Passenger</i>	Solo Driver	-1pp	-1pp	-1pp
	Carpool Driver	-0pp	-1pp	-0pp
	Carpool Passenger	+1pp	+1pp	+1pp
	Public Transport	-0pp	-0pp	-0pp
<i>(v) Subsidy 3€ subsidy for Carpool Passenger</i>	Solo Driver	-1pp	-1pp	-2pp
	Carpool Driver	-0pp	-1pp	-1pp
	Carpool Passenger	+2pp	+3pp	+3pp
	Public Transport	-0pp	-0pp	-0pp

Notes: values in the reference situation are the initial modal shares. Values in HOV-lane and subsidy scenarios indicates gains or losses in percentage points compared to the reference situation

Thus, the transport supply of the four modes is calibrated based on the current travel time of the respondent. The solo driving alternative has an end-to-end travel time equal to the respondent's current situation. A few minutes are added to the carpool trips as a driver and as a passenger to represent the potential time lost to find or wait for the carpooler. Public transport trips are assumed to be 50% longer than the solo driver trip. Modal shares obtained in this situation are displayed in the first lines of **Erreur ! Source du renvoi introuvable.** Two levels for each measure have been tested. A 5-minute and a 15-minute time gain with the HOV-lane, a 1.5€ and a 3€ subsidy. time gain with the HOV-lane, a 1.5€ and a 3€ subsidy.

The reference situation (*i*) modal shares are slightly different between the models. However, these shares are of the same order of magnitude and reflect the current situation on the routes potentially affected by a HOV-lane. In the reference situation, the scarce resource for carpooling is the passenger. Indeed, even if carpool drivers would like to carpool, they are limited by the low number of potential passengers. According to the MXL3, out of 100 current drivers, only one-third (8/23) of drivers willing to carpool can find a carpool passenger. Furthermore, 96% of people choose to commute by car (solo driver + carpool modes modal shares) and only 8% will be able to do it as carpool passengers. Hence, the vehicle occupation rate would be 1.09 (on 100 individuals 96 are commuting in $96 - 8 = 88$ cars, thus an occupation rate of $96/88 = 1.09$), very close to what is observed today.

The estimation of modal shares varies across the models. Indeed, the MXL3 model estimates a lower modal share for the solo driver. It is also less sensitive to time savings and more sensitive to subsidies than other models. The important result of these predictions is that the modal share of the Carpool Passenger remains very low despite the implementation of measures to increase this share.

We study the effects of a HOV-lane, which allows a time saving of 5 (*ii*) or 15 minutes (*iii*) for carpooling and public transport modes. Scenario (*ii*) implies a potential decrease in the solo driver modal share of between 3 and 5 percentage points. However, the variation in the effective share of carpoolers is marginal because few switchers go towards the scarce resource, carpool passenger.

Scenario (*iii*) is hardly more successful. Indeed, according to the MXL3 (and LCL), of the solo drivers leaving this mode, 82% (71%)¹³ become potential carpool drivers and only 9% (18%) become carpool passenger. The time saving does not seem to overcome the scarcity of the carpool passenger resource.

Scenarios (*iv*) and (*v*) consist of the allocation of a subsidy of €1.5 and €3 respectively to carpool passengers.¹⁴ These subsidies result in a slight increase in the modal share of carpool and passenger (+1 pp in scenario (*iv*) and between +2 and +3 pp in scenario (*v*)). The 3€ subsidy is expected to decrease the total share of drivers (solo and carpool) from 88 to 85%. As the drivers' average distance travelled in Lyon's area is around 26km (SYTRAL, 2016), it implies that the subsidy would cost 0.4€ per veh.km saved.¹⁵ This is way higher than the average external cost of a car, estimated at around 0.12€/veh.km by Van Essen et al. (2019). The main reason for this inefficiency is that around 70% of subsidized passengers would have chosen to be passengers even in the absence of subsidy (8% in reference situation, +3pp with the 3€ subsidy).

¹³ 9 out of 11 (82%) people who leave solo driver mode choose the carpool driver mode.

¹⁴ As a comparison, in 2018, public transport in Lyon was subsidized at around €1.30 per trip (Crozet et al., 2019).

¹⁵ A rough back-of the envelope calculation gives 3 drivers less, each travelling on average 26km. Considering a scenario in which 11 passengers are paid 3€, we obtained a marginal cost of veh.km saved of $(3 \times 11) / (3 \times 26) \approx 0.4$.

These simulations show that the measures tested do not seem to be effective solutions to the scarcity of carpool passengers. This result should be qualified because our sample only contains solo drivers. Carpool passengers may come from other modes (public transport, bicycle) or from the induced demand. However, in this case, the implementation of the carpool lane would not cause a decrease of vehicular traffic. Our recommendation to the public authorities is to be cautious about the modal origin of carpool passengers, who are the scarce resource of the system. There are several potential rebound effects on modal shift or trip distance that could mitigate positive effects of carpooling on traffic and pollution reductions (Coulombel et al., 2019).

6.2.2. *Latent class attitudes*

Following the results and typology identified with the LCL model, we find that attitudes are better correlates of carpool behavior than socio-demographics. These attitudes could be a tool to identify and target the profiles of individuals likely to switch to carpooling.

Respondents the most likely to switch to Carpool Driver are those associated with class D, which represent an important part of the sample (32%, see Table 1.5). This class values the opinions of others more highly. As shown in Table 1.6, the two driver alternatives generalized costs remains very close since end-to-end travel times are similar (8 € for solo driving, 4 € for carpool driving). This means the HOV-lane time gain should at least compensate the Carpool Driver time loss due, for example to a possible detour, in order to keep end-to-end travel durations equal.

If one wants to promote carpooling to reduce car traffic, some drivers will have to switch to passengers. It is even more crucial given the results obtained from simulations, indicating passengers will be the scarce resource. Following the typology obtained from the LCL,

individuals most likely to switch to Passenger Carpool are those associated with class B, which represents 35% of the sample. Linking the classes to the attitudes is consistent since these classes contain more respondents thinking car traffic is a major source of pollution and unsatisfied with their current journey choice (i.e. solo driving). It appears more useful to target this class with the message that carpooling makes people pollute less. This class has similar generalized costs for all alternatives. It seems difficult to guarantee a shorter end-to-end travel time when carpooling as a passenger than as a driver. However, it is necessary to guarantee quality and reliability of service to encourage them to switch to carpool passengers. Since the financial incentive on its own seems of limited effectiveness, the combination of several incentives or other incentives should be explored. The potential of nudging or psychological interventions combined to monetary incentives looks promising (Hilton et al, 2014; Raux et al, 2020).

6.3. Limitations of the study

6.3.1. Difficulty in considering a new supply

The first limitation of the survey comes from the limitations of the stated choice method. It is assumed that the hypothetical choice of respondents and their choice in a real situation would be the same. The difficulty of projecting oneself into the future and face this new HOV-lane could also bias the results. This hypothetical bias tends to lead to higher WTP.

6.3.2. External validity

As we only surveyed solo drivers, this sample does not reflect the entire population of a territory that could use carpooling to commute. In our case, it could be that some current public transport users switch to carpooling after the introduction of a HOV-lane.

Another limitation is the focus on end-to-end travel time values. This choice has been made to ensure comparability with VoTTs found in the literature. Nonetheless, it does not consider the various components that are part of a carpool trip. As Wardman et al. (2016) shows for public transport, access, waiting and detour times could be valued differently than in-vehicle time. Assessing these components could provide a more accurate understanding of individual preferences.

Furthermore, this sample is not representative of the whole French population. It remains more representative of solo driving commuters even if some of the occupations are under- (laborers) or over-represented (senior management). However, HOV-lanes are mainly installed on the outskirts of dense urban areas. The populations that can benefit from these infrastructures may also be different from all commuting solo drivers of the city. It will therefore be necessary to pay attention to the target population before generalizing the results of this study.

7. Conclusion

This paper has estimated preferences for four different modes for commuting trips in a context of prioritizing carpool through HOV-lanes: solo driver, public transport and carpool as a driver and as a passenger. A stated choice survey conducted on a 1556-respondent sample allowed us to understand modal choices through different types of models measuring heterogeneity in preferences across modes and individuals.

Our results suggest an average preference for the solo driving mode compared to carpool or public transport among solo drivers. Nonetheless, the respondents react heterogeneously in their mode choice behavior. The latent-class analysis reveals these heterogeneities are explained better by the attitude statements than by socio-economic variables. Besides, it also allows a

typology of currently commuting solo drivers that identifies four behavioral patterns: individuals reluctant to mode change, those preferring the three alternative modes over solo driver, the ones preferring public transport and the last preferring driver modes whether solo or in carpool. This typology could be used to target profiles likely to switch to carpooling as a driver and as a passenger. Moreover, knowing the preferences for carpooling provides a basis for calculating benefits in cost-benefits analysis. It could also be valuable for future studies on shared autonomous vehicles.

Moreover, our results clearly indicate that if one wants to decrease cars traffic by stimulating carpooling for commuting trips, the passengers will be the scarce resource. Indeed, the behavioral pattern most likely to switch to carpool passenger is also appealed by other alternative modes. Incentives will therefore have to be targeted on car commuters ready to switch and strengthened to make the passenger mode as attractive as possible.

Finally, we know carpool organization and individual social interactions may impact carpool choices. This raises the question of how impactful matching between individuals can be on the decision to carpool or not. Moreover, the different stages that compose end-to-end travel time can be valued differently, such as access to carpool meeting or waiting times. These effects on commuting mode choice will be explored through further research.

Appendices

Appendix A: An example of choice screen for a driver respondent with a 8:30 preferred arrival time

Mode	Driver Alone	Driver in a Carpool	Passenger in a Carpool	Public Transport
Trip Characteristics	Start : 7:20 Drive Alone: Between 30 and 40 min Arrival: Between 7:50 and 8:00	Start : 7:30 Join the station: no detour Wait: 5 min Carpool : Between 25 and 40 min Join your destination: 5 min walk Arrival : Between 8:15 and 8:30	Start : 7:35 Join the station: 5 min walk Wait: 5 min Carpool : Between 30 and 40 min Join your destination: 5 min walk Arrival : Between 8:20 and 8:30	Start : 7:30 Join the station: 10 min by car Wait: 5 min Public Transport: Between 25 and 40 min Join your destination: 5 min walk Arrival : Between 8:15 and 8:30
Monetary aspects	You pay your usual transportation costs	You pay your usual transportation costs Carpooling makes you earn 1€	You save on your usual transportation costs Carpooling costs you 1€	You save on your usual transportation costs Public Transport costs you 0,80€
Carpooler's profile		Your passenger: 45 years old, Hitchhiker	Your driver: 25 years old, Referenced on the carpool platform	
Which mode do you choose ?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Appendix B: Correlation estimates

The β_{ttk} estimates are assumed log-normally distributed with the following correlations:

$$\beta_{ttsd} = \exp(\mu_{\beta_{ttsd}} + \sigma_{\beta_{ttsd}} * \xi_{\beta_{ttsd}})$$

$$\beta_{ttcpd} = \exp(\mu_{\beta_{ttcpd}} + \sigma_{\beta_{ttcpd}} * \xi_{\beta_{ttcpd}} + \theta_{cpdsd} * \xi_{\beta_{ttsd}})$$

$$\beta_{ttcpp} = \exp(\mu_{\beta_{ttcpp}} + \sigma_{\beta_{ttcpp}} * \xi_{\beta_{ttcpp}} + \theta_{cppsd} * \xi_{\beta_{ttsd}} + \theta_{cppcpd} * \xi_{\beta_{ttcpd}})$$

$$\beta_{ttpt} = \exp(\mu_{\beta_{ttpt}} + \sigma_{\beta_{ttpt}} * \xi_{\beta_{ttpt}} + \theta_{ptsd} * \xi_{\beta_{ttsd}} + \theta_{ptcpd} * \xi_{\beta_{ttcpd}} + \theta_{ptcpp} * \xi_{\beta_{ttcpp}})$$

The θ parameters allow us to capture correlations between VoTT of the 4 modes. As an example, the parameter θ_{dcpsd} (used in the expression of β_{ttcpd}) is multiplied by $\xi_{\beta_{ttsd}}$, already used in the expression of β_{ttsd} .

Appendix C: LCL models tested with attitudes vs socio-economics

Class allocation variables	Attitudes	Socio-Economics
#parameters	66	51
LL	-8560	-8741
R ² -adj	0.334	0.321
AIC	17252	17584
BIC	17723	17948

Appendix D: Trip attributes and levels in stated choice design

Attributes	Alternatives	Levels
Time variables		
Schedule early/late	Solo Driver	0, 30, 60 minutes (earlier or later)
Access time	Passenger modes*	5 minutes walking (ref), 10 minutes by car, 20 minutes by car
Detour time	Carpool Driver	0, 5, 10 minutes
Waiting time	Passenger modes and Driver in Spontaneous Carpool	0, 5, 10 minutes
In-vehicle travel time	All	Solo Driver: (0.8, 1.1, 1.5) * usual_tt Other modes: (0.6, 0.9, 1.2) * usual_tt
Travel time variability	All	(0.1, 0.3, 0.5) * In-vehicle travel time
Egress time	Passenger modes	Carpool passenger: 5 min walking (ref), 10/20 min by Public Transport Public transport: 5 min walking
Cost (in €)	Carpool modes* and Public Transport	Carpool Driver: receives (0, 0.02, 0.05, 0.1) * usual_tt Carpool Passenger: pays (0, 0.02, 0.05, 0.1) * usual_tt Public transport: pays 0.8
Carpooler profile		
Carpooler matching	Carpool modes	Planned (with a relative or by platform), Spontaneous (with a hitchhiker or by platform)
Carpooler Gender		Male, Female (not presented if relative)
Carpooler Age		25, 45, 65 years old (not presented if relative)

Notes: Passenger modes: Carpool Passenger and Public Transport. Carpool modes: Carpool Driver and Carpool Passenger. "usual_tt" is the usual travel time the respondent reports in the survey

parameter θ_{dcps} (used in the expression of β_{ttcp}) is multiplied by $\xi_{\beta_{ttds}}$, already used in the expression of β_{ttds} .

Appendix E: Full estimation results of MNL and MXL models

Attribute	Alternative	MNL	MXL
Alternative-Specific	Carpool Driver	0.240*	-0.015
Constants (ASCs)	Carpool Passenger	0.025	-0.295
	Public Transport	-0.286*	-0.886*
ASCs	Carpool Driver		1.508***
Standard deviation (σ_{ASC})	Carpool Passenger		0.686***
	Public Transport		2.122***
Travel time ($\mu_{\beta_{tt}}$ in MXL)	Solo Driver	0.336***	-0.777***
	Carpool Driver	0.502***	-0.666***
	Carpool Passenger	0.462***	-0.732***
	Public Transport	0.481***	-0.588***
Travel time Standard deviation ($\sigma_{\beta_{tt}}$)	Solo Driver		1.254***
	Carpool Driver		0.674***
	Carpool Passenger		0.004
Travel time Correlation estimates (θ)	Public Transport		0.019
	Solo Driver / Carpool Driver		0.738***
	Solo Driver / Carpool Passenger		0.694***
	Solo Driver / Public Transport		0.629***
	Carpool Driver / Carpool Passenger		0.786***
	Carpool Driver / Public Transport		0.578***
Schedule early	Carpool Passenger / Public Transport		-0.048
	Solo Driver	0.190***	0.166***
Schedule late	Solo Driver	0.052***	0.033*
Cost	All	-0.100***	-0.167***
Male	Solo Driver		
	Carpool Driver	-0.213***	-0.362*
	Carpool Passenger	-0.391***	-0.596**
Age46+	Public Transport	-0.273***	-0.464*
	Carpool Driver	-0.459***	-0.700***
	Carpool Passenger	-0.502***	-0.598**
Income	Public Transport	-0.273***	-0.218
	Carpool Driver	0.185***	0.225 '
	Carpool Passenger	0.087*	0.058
Platform	Public Transport	0.213***	0.253 '
	Carpool Driver	0.109*	0.204**
Spontaneous	Carpool Passenger	0.233***	0.281**
	Carpool Driver	0.041	0.152
Carpooler Male	Carpool Passenger	-0.132 '	-0.159
	Carpool Driver	-0.218***	-0.427***
Carpooler25yo	Carpool Passenger	-0.260***	-0.387***
	Carpool Driver	0.003	0.030
Nb of individuals	Carpool Passenger	-0.033	-0.012
	Carpool Driver		
Nb of observations		1556	1556
		9336	9336

Nb of parameters	27	40
LL (final)	-10917.5	-8625.2
Adj.Rho-square (0)	0.154	0.331
AIC	21889	17330
BIC	22082	17616

Notes: Values for MXLs are the “ μ ” parameters of normal (for ASCs) and lognormal (for time) functions.

P-values: 1 () 0.1 (‘) 0.05 () 0.01 (**) 0.001 (***) 0.*

Appendix F: Estimations results of LCL model

Attribute	Alternative	LCL							
		Class A		Class B		Class C		Class D	
Alternative Specific Constants	CpDriver	-3.042	***	2.103	***	-2.659	***	1.100	***
	CpPassger	-5.531	***	2.554	***	-1.832	**	-1.068	**
	PubTrsprt	-4.396	***	2.507	***	0.997	**	-1.659	**
Travel Time	SDriver	0.280	***	0.454	***	0.443	***	0.208	***
	CpDriver	0.432	***	0.719	***	0.290	***	0.313	***
	CpPassger	0.113		0.620	***	0.278	***	0.185	***
	PubTrsprt	0.237	**	0.714	***	0.400	***	0.293	***
Scheduled early	SDriver			0.193	***				
Scheduled late	SDriver			-0.017					
Cost	All			-0.132	***				
Male	CpDriver			0.134					
	CpPassger			0.042					
	PubTrsprt			0.115					
Age46+	CpDriver			-0.135					
	CpPassger			-0.049					
	PubTrsprt			0.095					
Income	CpDriver			0.047					
	CpPassger			-0.134					
	PubTrsprt			0.095					
Platform	CpDriver			0.175	**				
	CpPassger			0.296	***				
Spontaneous	CpDriver			0.170					
	CpPassger			0.083					
CarpoolerMale	CpDriver			-0.351	***				
	CpPassger			-0.350	***				
Carpooler25yo	CpDriver			0.018					
	CpPassger			-0.071					
Latent Class Allocation Variables									
Average Latent Class AllocationProbability									
		0.20	0.35		0.12			0.32	
S1 (“car traffic major source”)		0	0.263	**	0.353	**		0.161	.
S2 (“satisfied with my choices”)		0	-0.679	***	-0.966	***		-0.285	***
S3 (“could change easily”)		0	0.661	***	0.891	***		0.499	***
S4 (“opinion matter”)		0	0.091		-0.116			0.138	*
S5 (“personally responsible”)		0	0.206	*	0.045			0.155	.
Nb of individuals					1556				
Nb of observations					9336				
Nb of parameters					66				
LL(final)					-8560				
Adj.Rho-square					0.334				
AIC					17252				
BIC					17723				

Notes: P-values: 1 () 0.1 (°) 0.05 (*) 0.01 (**) 0.001 (***) 0.

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CHAPTER II.

Impacts of organizational and carpoolers variable on choices and welfare

1. Introduction

Carpooling is often seen as an efficient and low-cost way to alleviate negative externalities of car traffic. Indeed, it allows to increase the occupancy rate of cars by filling empty seats (Shaheen et al., 2018).¹⁶ Thus, governments and local authorities are implementing measures to promote it. For example, the French government is offering a €100 subsidy to drivers who commit to carpooling, with the goal of tripling the modal share of carpooling for daily trips.¹⁷ Similarly, several countries have recently opened dedicated carpooling lanes: in Belgium in 2019¹⁸, in Switzerland in 2018, Israel in 2023¹⁹.

Several determinants influence the adoption of carpooling (Bulteau et al., 2019, Olson et al., 2019, Bachmann et al., 2018, Gheorghiu & Delhomme, 2018). One of the most predominant features is the perceived risk – or lack of trust – towards the individual with whom the carpooling is done (Delcampe, 2018, Olson et al., 2019). Indeed, for the driver, carpooling implies sharing his private space with an unknown person, and for the passenger, entering the private space of an unknown person and letting her take control of trip parameters, like speed or safety. These beliefs being highly subjective, a key ingredient for a successful carpool is the quality of matching between driver and passenger.

¹⁶ Note that this analysis is still debated. Carpooling reduces road traffic if carpool passengers use carpool instead of driving alone. However, a significant share of carpool passengers would have use public transport in the absence of carpool supply, and a non-negligible part of carpool drivers would have not made the trip in absence of the monetary reward earned when carpooling. The overall effect on traffic is not clearcut (see Wagner, 2016, or Finger et al., 2017).

¹⁷ https://www.lemonde.fr/en/economy/article/2022/12/14/french-government-presents-updated-plan-to-encourage-carpooling_6007720_19.html

¹⁸ <https://www.brusselstimes.com/56328/new-e411-carpool-lanes-only-on-walloon-side-weyts-belgium-overijse-wavre-arlon>

¹⁹ <https://www.jpost.com/israel-news/article-730018>

In this article, we investigate the effects of carpooling organization and individuals' idiosyncrasies on the propensity to carpool. Specifically, we test whether pre-planning, use of a platform, and socio-demographic similarities or differences between driver and passenger affect the likelihood of choosing this mode of transportation over solo driving and public transportation.

We answer these questions by using a stated choice experiment collected over 3,000 people in the Lyon's urban area. Interviewees are confronted with choice experiments presenting different transport modes for a trip close to their usual journey, including carpooling alternatives. Two types of carpool organization are presented. Each respondent face one of it and several carpooler profiles are presented in different transport modes choice situations. We estimate the utility functions of each transportation model with multinomial logit calibrated on our sample.

Our results indicate that platforms raise the individual willingness to carpool. We also find platform's effect to be larger for passengers than for drivers. Other things being equal, we identify a clear gender effect: women are more easily accepted as carpoolers than men, and they also are more sensible than men to their carpooler's gender. By contrast, the age of the proposed carpooler does not affect carpooling choices. We illustrate these results with a stylized social welfare analysis which highlights a significant contradiction between what it would take to make carpooling beneficial from a welfare perspective – drivers should pay passengers – and what seems to be individually acceptable.

This paper relates and contributes to three strands of the literature. First, we focus on short-distance carpool whereas a vast majority of the specific literature was interested with long-distance trips (Farajallah et al., 2019, Monchambert, 2020). Second, in line with recent

development on platforms economics (Montero, 2019, Monchambert, 2023), we quantify the value of the platform for both sides of the market, i.e drivers and passengers. More specifically, our empirical strategy allows us to estimate willingness-to-pay measure for different types of carpool organization as well as different types of travelers. Third, we build on our estimate to propose a social welfare analysis of short-distance carpool schemes, consistently with a vast literature in transport economics which however has mostly focused on road or public transport pricing and infrastructure provision.

The rest of the paper is organized as follows. Section 2 presents the hypothesis tested in this paper. Section 3 presents the empirical material. Econometric specifications and results are displayed and discussed in Section 4. Welfare analysis is done in Section 5 before concluding in Section 6.

2. Hypotheses

Consider a situation in which an individual makes a choice between several available modes to make a trip. We are interested in the factors that may affect the probability of an individual choosing to carpool as a driver or as a passenger. Among these factors, we focus specifically on those related to the organization of carpooling and the characteristics of the matching between driver and passenger.

2.1. Trust and organization

We first detail the hypothesis about carpool “organization” which refers to the way carpooling is realized. The typology of carpooling organizations can be articulated around two distinctions: planned/real-time and with/without platform (ADEME, 2015). Planned carpooling consists of sharing a vehicle with people contacted beforehand, while real-time carpooling

consists of meeting carpoolers during the trip. Carpooling is organised with a platform when individuals use an internet carpooling platform that connects those with compatible journeys.

When these two dimensions are crossed, four types of organizations arise:

- planned in advance with someone met through a platform.
- planned in advance with someone not met through a platform, i.e. with someone known before the trip that we consider here as a relative (family, friend, colleague).
- in real-time via a platform.
- in real-time without a platform, i.e. hitchhiking.

Platform is expected to increase individuals' level of trust for several reasons. It sends signals about the profile of carpoolers and their carpooling experience. When there are many carpooling opportunities on offer, it allows individuals to screen and choose their preferred option. Platforms often include a secure banking service that guarantees payment. In general, therefore, the platform should help to reduce uncertainty (Ter Huurne et al., 2017).

Hypothesis 1: The presence of a platform increases the probability of choosing carpooling.

Planned carpooling is by far the most common form of carpooling in France. Half of carpools are made intra-family (ADEME, 2015) and the market-leading long-distance carpooling platform, BlaBlaCar, also organises planned trips (Shaheen et al., 2017). Consequently, only a small minority of trips are organized in real-time. Real-time carpooling is something unusual for individuals, which could lead to a situation perceived as riskier. Moreover, using focus groups, Deakin et al. (2010) showed real-time carpooling is perceived as less reliable than planned carpooling.

Hypothesis 2: Carpooling is preferred when planned ahead rather than organized in real time.

Sharing a car with an unknown person is perceived as a risk (Chan & Shaheen, 2012). Both drivers and passengers share this risk, but the driver knows the environment in which the carpooling takes place (his car), while the passenger does not. In addition to the risk previously

mentioned, passengers are also affected by their driver's driving style. They can have a feeling of absence of control on board which can also be stressful (see e.g. Dillen et al., 2020). If passengers are assumed to take more risks than drivers when carpooling and that platforms are ways to overcome perceived risks, then the platforms should have a larger effect on passengers.

Hypothesis 3: The positive effect of the presence of platform on carpooling choices is larger for passengers than for drivers.

As previously mentioned, carpooling may be perceived by individuals as a risk. Experimental economics have shown that males exhibit more confidence than females and that females appear more risk averse than males (Chaudhuri & Gangadharan, 2003; Borghans et al., 2009). If, as previously mentioned, platform effects are positively related to situations perceived as riskier, females should be more sensitive to them.

Hypothesis 4: The positive effect of the presence of platform on carpooling choice probability is larger for females than for males.

2.2. Matching

Whereas previous assumptions only focus on the characteristics of decision-makers, we should also acknowledge that carpooling choice is also affected by matching effects. It might thus be the case that idiosyncrasies of passengers and drivers interacts with each other and drive the decisional process. In this second part, we detail the hypothesis about the effects of the matching characteristics on the carpool choice. Matching during a carpooling trip is the proposed pairing between a driver and a passenger.

Chaube et al., 2010 have shown the relationship with the potential carpooler can highly change the willingness of individual to carpool for daily trips. A closer relationship leads to a

higher probability to accept to carpool. If carpooling with a stranger is perceived as riskier and women are more risk averse – as mentioned in hypothesis 4 – then female respondents should be more willing to carpool with a relative than male respondents.

Hypothesis 5: Females are more willing to carpool with a relative than males.

Age, or more precisely the age difference between the two individuals, is also a characteristic that can have an effect on the attractiveness of carpooling. People tend to have a more natural affinity for people of the same age (Buunk et al., 2002). It is then assumed that a carpooler of the same age is more easily accepted than a carpooler with a wide age difference.

Hypothesis 6: The likelihood of participating in carpooling is higher when the driver and passenger are of the same age.

Another carpooler's characteristic that could influence willingness to carpool is the carpooler's gender. A recent study from Farajallah et al. (2019) observed that women sell more seats and for higher prices than males on the Blablacar platform. This may result from several factors such as the perceived security to travel with a female carpooler. Indeed, more than three out of four road deaths involve men according to the French National Interministerial Observatory for Road Safety (ONISR, 2021). Carpooling with a male could also be perceived more dangerous as they tend to be more aggressive (see e.g. Björkqvist, 2018). Carpooling is therefore expected to be chosen more often when it is proposed with a woman.

Hypothesis 7: The likelihood of participating in carpooling is higher when a female is on the other side.

3. Data

We collected data from an online discrete choice experiment conducted in spring 2019 on inhabitants of the Lyon area. This experiment was built to understand how individuals would react to a new carpooling supply on their usual trip.

3.1. Survey design

On the first part of the questionnaire, we collect information on a usual trip of the respondent. They are asked to detail their most frequent trip made by car or public transport during the last 30 days. Respondents whose usual trip is susceptible to be carpoled are kept in the survey (see Le Goff et al., 2022 for more details on survey design). The time components of this trip are then used to create choice situations adapted to the respondent usual trip. This way, respondents face situations close to the reality of their daily life. The experiment seems more realistic and the hypothetical bias is reduced.

Before the choice situations start, respondents are randomly divided into two samples. The first one is assigned to a “planned ahead carpooling” experiment and the second one to a “real-time carpooling” experiment. For both samples, a screen detailing the carpooling organization is presented (see screens in Appendix A1). In the first sample, carpooling can be organized through dedicated platforms or informal with family, friends, or colleagues. The second sample faces choice tasks in which carpooling is done in real-time (or spontaneous), involving hitchhiking and so-called dynamic carpooling through digital apps.

Respondents then face six successive mode choice situations in which they choose their preferred alternative between four modes: solo driver, carpooling driver, carpooling passenger and public transport. These choice situations include different types of attributes. The first one is the time variables, in which the different stages of the trip are detailed. This includes departure time, access and egress time to a station for passenger modes, waiting time – which is also presented to carpooling drivers – as well as detour time and finally, the in-vehicle time in each mode (see Appendix A2 for an example of choice screen). Table 2.1 details attributes and levels used in the survey. The monetary cost of the alternative is also displayed. Finally, what we called carpooler profile – i.e. the way carpooler is met, its gender and age – is presented

in both driver and passenger carpooling alternatives. The carpooler profile presented may vary depending on whether respondents were assigned to the planned or spontaneous carpooling experiment. If they are in the planned sample, the proposed carpooler may be a relative or a person met by a carpooling platform. In the case of a relative, we consider gender and age do not impact the choice and these characteristics are consequently not presented. In the other case, and in spontaneous carpooling where the proposed carpooler is either registered on a platform or a hitchhiker, the age and gender characteristics of the carpooler are presented.

Table 2.1: Trip attributes and levels in stated choice design

Attributes	Alternatives	Levels
Time variables		
Schedule early/late	Solo Driver	0, 30, 60 minutes (earlier or later)
Access time	Passenger modes*	5 minutes walking (ref), 10 minutes by car, 20 minutes by car
Detour time	Carpooling Driver	0, 5, 10 minutes
Waiting time	Passenger modes and Driver in Spont. Carpool	0, 5, 10 minutes
In-vehicle travel time	All	Solo Driver: (0.8, 1.1, 1.5) * usual_tt Other modes: (0.6, 0.9, 1.2) *usual_tt
Travel time variability	All	(0.1, 0.3, 0.5) * In-vehicle travel time
Egress time	Passenger modes	Carpooling passenger: 5 min walking (ref), 10/20 min by Public Transport Public transport: 5 min walking
Cost (in €)	Carpooling modes* and Public Transport	Carpooling Driver: receives (0, 0.02, 0.05, 0.1) * usual_tt Carpooling Passenger: pays (0, 0.02, 0.05, 0.1) * usual_tt Public transport: pays 0.8
Carpooler profile		
Carpooler matching		Planned (with a relative or by platform), Spontaneous (with a hitchhiker or by platform)
Carpooler Gender		Male, Female (not presented if relative)
Carpooler Age		25, 45, 65 years old (not presented if relative)

Notes: Passenger modes: Carpooling Passenger and Public Transport. Carpooling modes: Carpooling Driver and Carpooling Passenger. "usual_tt" is the usual travel time the respondent reports in the first part of the survey

3.2. Data collection and descriptive statistics

The survey's web-link was widely spread to many inhabitants of the Lyon area. Participation in the survey was financially encouraged by a chance to win vouchers. The call message did not mention carpooling to avoid strategic or selection bias (see more details in Le Goff et al., 2022). The initial database contains 4,845 respondents.

Table 2.2: Sample characteristics

Variables	Mean	
	Sample	Population
Male	55.8%	54.8%
Age (years)	48.3 (13.6)	41.1 (11.6)
Income per month (€)	2361 (950)	
Occupation		
Self-employed	3.6%	3.2%
Senior Management	41.1%	14.7%
Middle Management	9.9%	12.2%
Clerical Staff	25.0%	23.7%
Blue collar workers	2.0%	9.6%
Farmers	0.1%	0.6%
Students	2.1%	11.5%
No activity	0.6%	\
Retired	15.7%	24.4%
Choices during the experiment		
Solo Driver	28%	
Carpooling Driver	34%	
Carpooling Passenger	15%	
Public Transport	23%	
Nb of individuals	3632	

Notes: Standard deviation between parenthesis. Income variable is collected as categorical. Mean and standard deviation are calculated using the center of the classes selected by respondents. Income is not available in the census. Population in the area data are from SYTRAL (2016), enquête ménage-déplacements, a public mobility survey in the Lyon urban area.

Adhoc data filtering recommended by Hess et al. (2010) is then applied. As response time for each choice situation is available, 734 respondents who answered a choice situation in less than 6 seconds were excluded. This way, those who answered as fast as possible to try to

win the voucher and did not examine the choice situations were removed. The 479 respondents who did not report their income were also excluded from the survey for a final sample of 3,632 respondents and 21,792 choice situations analyzed. Descriptive statistics of this sample are presented in Table 2.2 above. We compare our sample with the study population. Our sample is on average more male and older than the study population. We also observe that students and blue-collar workers are under-represented in our sample, while senior management is over-represented. The mode most often chosen during the discrete choice experiment is driver carpooling, followed by solo driver, public transport and then passenger carpooling. These choices depend on the screens that were offered to the sample and therefore do not reflect preferences.

Table 2.3: Reference trips characteristics

Variables	Mean
Length (min.)	43.2 (20.4)
Frequency	
Every working day	58%
Several times a week	27%
Several times a month	12%
Once a month	2%
Less	2%
Mode	
Driver (Alone)	69%
Carpool Driv.	12%
Carpool Pass.	2%
Pub. Transports	10%
Both car and PT	5%
Other	2%
Purpose	
Work	77%
Shopping	6%
Leisure	7%
Studies	2%
Accompaniment	2%
Other	6%

Notes: Standard deviation between parenthesis.

Table 2.3 displays the characteristics of the average reference trip of the sample. This average trip is around 43 minutes long. In more than half of our sample, this trip takes place every day, by a single person in a car, to get to work.

4. Econometric analysis

4.1. Empirical strategy

The usual methodology to estimate the effect of each variable in a stated preference survey considers that each alternative displayed has a specific utility function, composed with a systematic and a random part as in a random utility model (Walker & Ben Akiva, 2002). The respondent will then choose the alternative that provides the highest utility. Individual i using mode k with carpooler j experiments the following systematic utility:

$$V_{ijk} = ASC_k + \beta_C \times C_k + \beta_T \times Time_k + \beta_{orga_{ik}} \times Orga_{ik} + \beta_{match_{ijk}} \times Match_{ijk} + \beta_{Z_i} \times Z_i \quad (1)$$

Where k is a transport mode among solo driver, carpooling driver, carpooling passenger, and public transport.²⁰ ASC is the alternative-specific constant of the mode (with solo driver as the reference, $ASC_{SoloDriver} = 0$). $Cost$ is the price (or gain in the case of e.g. carpool driver²¹). $Time$ is a vector of the different temporal characteristics of the mode presented in the survey, $Orga$ is a vector of carpool organization variables, $Match$ a vector of matching variables and Z a vector of individual characteristics. $Orga$ and $Match$ are null for solo driver and public transport. ASC , β_C , β_T , β_{orga} , β_{match} and β_Z are coefficients or vector of coefficients to estimate.

The $Orga$ vector in Equation 1 defines the carpooling organization presented to the respondent during the choice experiment. Four types of organization were presented:

²⁰ Complete utility functions are available in Appendix A3.

²¹ The cost can also be negative in the case of a subsidy, as is the case in the simulation performed in the welfare analysis section

carpooling can be planned, with a relative or via a platform, or spontaneous with a hitchhiker or via a platform. This vector is hence as follows:

$$\beta_{orga_{ik}} \times Orga_{ik} = (\beta_{plat}, \beta_{spon}, \beta_{plat \times spon}) \times \begin{pmatrix} \mathbb{1}_{Platform} \\ \mathbb{1}_{Spontaneous} \\ \mathbb{1}_{Platform} \times \mathbb{1}_{Spontaneous} \end{pmatrix} \quad (2)$$

where $\mathbb{1}_X$ is a dummy variable indicating that X is realized. β_{plat} and β_{spon} respectively allow to test Hypothesis 1 and Hypothesis 2. Adding the interaction effect measured by $\beta_{plat \times spon}$ allows to test Hypothesis 3. To test hypothesis 4, we interact the *orga* vector with the respondents' gender.

Match is a vector containing proposed carpooler's gender and age in both driver and passenger alternatives. These carpooler characteristics are crossed with the respondents' individual characteristics. It allows to distinguish the carpooler's gender effect depending on the respondent's gender (i.e. four types of gender matching are possible: male/male, male/female, female/male, and female/female). These utility functions are discussed in more detail in the Appendices. Taking into account both respondent individual variables and the proposed carpooler's profile, the *Match* vector is the following:

$$\beta_{match_{ijk}} \times Match_{ijk} = (\beta_{Male_i}, \beta_{Male_i \times rel}, \beta_{Male_j}, \beta_{Male \times Male}, \beta_{AgeMatch}) \begin{pmatrix} \mathbb{1}_{Male_i} \\ \mathbb{1}_{Male_i} \times (1 - \mathbb{1}_{Platform}) \times (1 - \mathbb{1}_{Spontaneous}) \\ \mathbb{1}_{Male_j} \\ \mathbb{1}_{Male_i} \times \mathbb{1}_{Male_j} \\ AgeMatch \end{pmatrix} \quad (3)$$

$\beta_{Male_i \times rel}$ allows to test Hypothesis 5 (carpooling with a relative is appreciated more by women as by men). Hypothesis 6 (a carpooler of about the same age is more easily accepted) is tested in Model 6 through $\beta_{AgeMatch}$. The *AgeMatch* variable is coded "1" when the age difference between respondent and its potential carpooler is under or equal to 15 years and "0" if this

difference is over 15 years. β_{Male_j} allows to test Hypothesis 7.

4.2. Organization effects

Table 2.4 shows results of multinomial logit estimations of Equation (1) for the four modes (solo driver, carpooling driver, carpooling passenger, and public transport). We estimate five different specifications. The first specification in column (0) does not include organization effects. This model is the reference to compare other models with. In specification (1) we introduce a Platform dummy to estimate an average platform effect, and in Specification (2) a Spontaneous dummy to estimate a spontaneous effect. On top of that we include an interaction effect between these dummies in specification (3) to estimate average effect of the four organizations studied (planned with a relative, planned via a platform, spontaneous with a hitchhiker or spontaneous via a platform). Specification (3) corresponds to Equation (2). Organization effects are differentiated depending if the carpooling trip is made as a driver or as a passenger in specification (4). We also consider a differentiation by gender in specification (5). The reference mode is solo driver, so generally a negative (resp. positive) coefficient implies a negative (resp. positive) marginal effect of the variable on the probability of choosing carpool over solo.

The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) confirm that using interaction effects and differentiated organizations coefficients in specification (5) produces the best goodness of fit. We focus here on the organization effects and delegate the full table of results including alternative specific constants, time components differentiated by mode, time components diff. by stage of the trip and individual Characteristics to Appendix D.

Specification (1) allows to estimate an average platform effect for both drivers and

passengers. The estimated coefficient is positive (0.102), meaning that other things being equal, respondents are more willing to accept carpooling trips when the carpooler's is met via a platform. This result reflects a globally positive effect of the platform, without consideration of the mode (driver or passenger) or the way carpooling is organized (planned or spontaneous). Hypothesis 1 is then verified.

An average spontaneous effect is estimated in specification (2). We find a significantly negative value (-0.0089). This means respondents will tend to accept more carpooling alternatives if its organization is planned ahead, all other things being equal. This result confirms Hypothesis 2.

Specification (3) combines the two previous effects, adding an interaction variable. The key result is that the platform effect becomes negative. In this model, the platform coefficient estimate measures the difference between the planned situation with and without platform (i.e. with a relative). The negative estimate (-0.107) shows that individuals, when taking a planned carpool, prefer carpool with a relative rather than with someone met through a platform. The difference between hitchhiking and carpooling with a relative is also directly observable through the spontaneous estimate (-0.301), indicating a large preference for carpooling with a relative over hitchhiking. To measure the effect of the platform in the spontaneous carpooling, we consider both the platform and the interaction between spontaneous and platform coefficients. With a high positive value (0.414), the interaction coefficient overcomes the negative value found previously. It confirms platform has a positive impact concerning spontaneous carpooling. The difference between hitchhiking and spontaneous carpooling organized via a platform is the sum of the two previously cited coefficient ($0.414 - 0.107 = 0.307$), which remains strongly significant after a test at a 99.9% confidence level. This highly positive impact also reflects how hitchhiking is depreciated compared to other forms of organization.

In specification (4) we differentiate these effects for drivers and for passengers. Estimates are of the same sign as those found previously showing consistency through the models (except the platform coefficient which is not significant for passengers). The platform coefficient estimate is significantly higher for passengers than for drivers (t-ratio: 2.31, 95% confidence level). This result, combined to similar estimates for the interaction coefficients (0.0406 and 0.442), shows that platforms are more valuable to passengers than to drivers. The difference between the spontaneous effect for drivers and passengers is also significant, revealing an even higher depreciation for hitchhiking as passengers compared to drivers. Passengers are more sensitive to carpooling organization than drivers which confirms Hypothesis 3.

The last specification differentiates estimates between male and female respondents. The female respondent (i.e. the reference) estimates are consistent with results from specification (4). The results of interest are the “x Male” estimates, which are systematically of the opposite side of the female estimates (e. g. “platform” estimate for drivers is negative and “platform x male” estimate for drivers is positive). This means the organization effects are systematically lower for males (they even become insignificant for some estimates) than for females. This confirms Hypothesis 4 that females are more sensitive to the different forms of organization.

Table 2.4: Organization effects estimates

	(0) Base	(1) Platform	(2) Spontaneous	(3) Pltfm + Spont.	(4) Driver/pass	(5) dri/pass + gend
Organization effects						
Platform		0.102 ***		-0.107 **		
Spont			-0.089 **	-0.301 ***		
Spont x Ptfm				0.414 ***		
Driver-specific organization effects						
Platform x Driver					-0.171 ***	-0.271 ***
Spont x Driver					-0.208 ***	-0.593 ***
Spont x Ptfm x Driver					0.406 ***	0.658 ***
Platform x Driver x Male						0.181 *
Spont x Driver x Male						0.677 ***
Spont x Ptfm x Driver x Male						-0.443 ***
Passenger-specific organization effects						
Platform x Passenger					-0.005	0.070
Spont x Passenger					-0.397 ***	-0.607 ***
Spont x Ptfm x Passenger					0.442 ***	0.577 ***
Platform x Passenger x Male						-0.134
Spont x Passenger x Male						0.386 **
Spont x Ptfm x Passenger x Male						-0.265 .
Cost	-0.068 ***	-0.070 ***	-0.067 ***	-0.064 ***	-0.063 ***	-0.063 ***
Alternative-specific constants	Y	Y	Y	Y	Y	Y
Time components differentiated by mode	Y	Y	Y	Y	Y	Y
Time components diff. by stage of trip	Y	Y	Y	Y	Y	Y
Individual Characteristics	Y	Y	Y	Y	Y	Y
# individuals	3632	3632	3632	3632	3632	3632
# observations	21792	21792	21792	21792	21792	21792
# parameters	29	30	30	32	35	41
LL(final)	-26561.8	-26553.5	-26557.9	-26516.2	-26503.8	-26464.3
Adj.Rho-square (0)	0.1198	0.1200	0.1199	0.1212	0.1215	0.1226
AIC	53181.5	53166.9	53175.9	53096.3	53077.6	53010.6
BIC	53413.2	53406.6	53415.5	53352.0	53357.2	53338.1

Notes: The organization reference level is carpool without platform in Model (1) and planned ahead carpool in Model (2). P-values: 1 () 0.1 () 0.05 (*) 0.01 (**) 0.001 (***) 0. See Appendices A4 for more detailed results

4.3. Matching effects

We present in Table 2.5 results of four new specifications to study matching. We start from specification (4) in Table 2.4, and add new variables. Specification (6) includes male and male x relative dummies, differentiated according to the distinction between carpool driver and carpool passenger. In specification (7) we add the age match variable and in specification (8) the gender of the proposed carpooler. Specification (9) allows the latter to be differentiated by the gender of the respondent. It corresponds to the utility function described by Equations (1),

(2) and (3).

Again, AIC and BIC show the richest specification produces the best goodness of fit. We focus on the matching effects. Detailed results are available in Appendix A4.

Specification (6) shows a negative effect of the male x relative dummy for drivers (-0.390), indicating female respondent prefer carpooling with a relative when they are drivers. Surprisingly, the male x relative coefficient is not significant for the passenger mode. Hence, our Hypothesis 5 is only verified for drivers and not for passengers.

The age match coefficients in specification (7) are not statistically significant. Other variables remain consistent compared to previous model. The age match between respondent and the proposed carpooler does not affect the decision to choose carpooling modes. Hypothesis 6 is consequently rejected.

The proposed carpooler gender coefficients added in specification (8) are significantly negative in both driver and passenger modes. It indicates that carpooling modes are chosen less often when the proposed carpooler is a male, other things being equal. Individuals are on average more willing to carpool with a female, which verify Hypothesis 7.

Finally, specification (9) considers a gender match through the interaction between the respondent gender variable and the proposed carpooler's gender variable. This interaction is positive for both carpool driver and passenger modes (significant at a 10% threshold for passenger). The Carpooler Male coefficient measures the difference between the situation where a female is matched with a female (reference) versus the case where the female is matched with a male. These negative estimates indicate that females prefer carpooling with a female both in driver and passenger modes. Now to compare the male matched with a male

situation and the male matched with a female situation, we consider both the Carpooler Male variable, and its interaction with the Male variable. Estimates of this interaction are such that they compensate the Carpooler Male estimates in both driver and passenger modes. It indicates that males are not significantly impacted by the carpooler's gender. This result is then consistent with our supposition that females are more impacted by their carpooler's gender than males.

Table 2.5: Matching effects estimates

	(6) Relative matching	(7) Age matching	(8) Carpooler's gender	(9) Gender matching
Driver-specific organization effects				
Platform x Driver	-0.390 ***	-0.406 ***	-0.358 ***	-0.300 ***
Spont x Driver	-0.426 ***	-0.443 ***	-0.398 ***	-0.340 ***
Spont x Ptfm x Driver	0.625 ***	0.641 ***	0.592 ***	0.534 ***
Passenger-specific organization effects				
Platform x Passenger	-0.004	-0.010	-0.060	-0.094
Spont x Passenger	-0.400 ***	-0.383 ***	-0.320 ***	-0.286 **
Spont x Ptfm x Passenger	0.440 ***	0.427 ***	0.366 ***	0.331 **
Driver-specific matching effects				
Male	0.001	0.001	0.001	0.104 .
Male x Relative	-0.390 ***	-0.390 ***	-0.390 ***	-0.286 ***
Age Match		0.045	0.044	0.044
Carpooler Male			-0.102 **	-0.226 ***
Male x Carpooler Male				0.217 **
Passenger-specific matching effects				
Male	-0.408 ***	-0.407 ***	-0.408 ***	-0.477 ***
Male x Relative	0.003	0.002	0.004	0.070
Age Match		-0.037	-0.035	-0.033
Carpooler Male			-0.120 **	-0.195 **
Male x Carpooler Male				0.145 .
Cost	-0.064 ***	-0.064 ***	-0.063 ***	-0.063 ***
Alternative-specific constants	Y	Y	Y	Y
Time components differentiated by mode	Y	Y	Y	Y
Time components differentiated by stage of the trip	Y	Y	Y	Y
Individual Characteristics	Y	Y	Y	Y
# individuals	3632	3632	3632	3632
# observations	21792	21792	21792	21792
# parameters	37	39	41	43
LL(final)	-26516.2	-26487.0	-26479.7	-26473.8
Adj.Rho-square (0)	0.1220	0.1220	0.1221	0.1223
AIC	53050.2	53051.9	53041.9	53033.7
BIC	53345.8	53363.5	53368.6	53377.2

Notes: P-values: 1 () 0.1 () 0.05 (*) 0.01 (**) 0.001 (***) 0. See Appendices for more detailed results

4.4. Willingness to pay

In the frame of stated preferences study, it is usual to translate the varying utility impacts of varying situations into monetary equivalents. To do so, we here use the results from specifications (4) and (9) respectively to estimate average Willingness To Pay (WTP) for each organization (Table 2.6) and for each gender matching (Table 2.7)²².

Table 2.6 shows a clear rejection of hitchhiking, here considered as the baseline. As an example, a respondent is on average willing to pay 3.7 euros to be matched via platform in a real-time carpool rather than hitchhiking, other things being equal. This rejection is even stronger when the individuals are passengers, with a WTP higher than 6 euros to carpool with one of the three other carpooling organization option rather than hitchhiking.

Table 2.6: Organization willingness to pay

Mode	Alternative	WTP
Carpool Driver	With a relative/ a colleague	3.3€
	Planned ahead via platform	<i>0.6€</i>
	Real-time via platform	3.7€
	Hitchhiking	Reference
Carpool Passenger	With a relative/ a colleague	6.3€
	Planned ahead via platform	6.2€
	Real-time via platform	6.8€
	Hitchhiking	Reference

Notes: The WTP represents here the price that people would pay to avoid the reference situation i.e. hitchhiking. Values in italic are not significantly different from 0.

Table 2.7 presents the WTP of respondent for carpooler gender, differentiated according to the distinction between driver and passenger as well as the respondent's gender. The Male/Female WTP shows a gender divergence between the passengers and/or driver modes. The 1.7€ WTP in the driver mode indicates that males seem to prefer this mode compared to females. On the other hand, the -7.6€ WTP in the carpool passenger mode suggests that females are more willing to carpool as passenger than males.

²² The WTP is obtained by dividing the corresponding coefficient by the cost coefficient.

The key result here resides in comparing WTP depending on the carpooler's gender. For females, the comparison is easy as only the Female/Male WTP is enough to observe that females prefer being matched with another female. The -3.6€ WTP found in driver mode implies that females would be willing to pay 3.6 euros on average to avoid being matched with a male passenger. To observe the impact of carpooler's gender on males, the Male/Male WTP should be compared to the Male/Female WTP. In both driver and passenger modes, this difference has been tested and is not significantly different from 0. This result points out that, contrary to females, we do not find that carpooler's gender affects male choices.

Table 2.7: Matching willingness to pay

Mode	Respondent	Carpooler	WTP
	Driver	Passenger	
Carpool Driver	Male	Male	1.5€
		Female	1.7€
	Female	Male	-3.6€
		Female	Reference
	Passenger	Driver	
Carpool Passenger	Male	Male	-8.4€
		Female	-7.6€
	Female	Male	-3.1€
		Female	Reference

Notes: In this table WTP can be negative. In this case, it represents here the price that people would pay to access to the reference situation which here is Female/Female.

5. Welfare Analysis

5.1. Method

Short-distance (e.g. urban) trips are a perfect example of second-best equilibrium setting due to the existence of under-priced externalities caused by cars' traffic. Since numerical platforms impact individuals' utility and their likelihood to carpool, these may also affect social welfare by altering vehicles' occupancy rates and total flows. In order to put our results in this perspective, we now analyse the collective effects of the introduction of a new carpooling platform. This knowledge may offer relevant policy insights about the potential needs for

regulating this market.

In the followings, we take as a starting-point situation 1,000 individuals who have to make a 30-minutes trip by either public transport, solo-driving and hitchhiking (i.e. the reference carpool organization). The idea is to observe the impact of a new real-time platform on modal shares according to a wide range of prices set for using it, either as driver or passenger. Individual choices are based on specification (9) and prices range from 1€ received to 1€ paid per minute of in-vehicle travel. We allow both passengers and drivers to pay or to be paid (or to be subsidized) in order to carpool through the platform. Importantly, carpool waiting times are calculated according to the number of users (the more passengers, the less drivers wait, and *vice versa*) and in-vehicle travel times vary according to the number of cars on the road due to the existence of congestion²³. It is worth noting that modal shares are balanced in cases there are more carpool drivers than carpool passengers, the latter being the “scarce resource” and the upper bound to the former. New modal shares then modify traffic conditions and travel times which, in turn, lead to new utilities and market shares. This process stops when the loop converges.

As compared to the situation where hitchhiking is the reference carpool organization, we compute the change in social welfare (ΔSW) for 10,201 combinations of prices²⁴ set to use the newly introduced real-time platform:

$$\Delta SW = \Delta Surplus + \Delta Profit + \alpha \Delta Public - \Delta X \quad (4)$$

The change in consumers’ surplus ($\Delta Surplus$) is calculated for each mode by multiplying the monetary equivalent of its utility by the flow of trips made with each mode. For the sake of simplicity, the cost of a driver-passenger pairing for the platform is supposed to be

²³ See details in Appendix.

²⁴ From -1 to 1 € per kilometer (from -30 to +30 € for the 30-km trip tested)

zero. Assuming that the company does not necessarily transfer the entire monetary flow, its profit ($\Delta Profit$) is found by multiplying the total volume of carpool users by the gap between what comes from passengers and what goes to drivers. Moreover, public subsidies may cover loss-making activities so that $\Delta Profit$ is bounded to zero. The public finance balance ($\Delta Public$) contrasts earnings linked to gasoline taxation and costs linked to pavement maintenance, net of potential subsidies and accounting for the marginal opportunity cost of public funds (α , here fixed at 1.2). As compared to previous components of ΔSW which are based on the number of travellers, $\Delta Public$ is based on the number of cars. In the same vein, the variation in external costs (ΔX) caused by cars' traffic (GHG, local pollutants, noise and accidents) is calculated on a per vehicle basis. Parameters' values are detailed in Appendix.

5.2. Carpool organization and welfare

Computing equation (4) for all the simulations, we can identify and discuss some illustrative configurations. It is important to notice that numbers in Table 2.8 correspond to the differences between the reference situation (i.e. where carpool is made by hitchhiking) and those under study. The column “Without monetary exchange” - for which carpool passengers (drivers) do not pay (receive) anything – thus shows there are 101 solo-drivers less than in the hitchhiking baseline case, which increases the cars' occupancy rate from 1.26 individuals per vehicle to 1.35. This column therefore indicates the “pure” welfare effect of the real-time platform, i.e. a corollary of the WTPs shown in Table 2.6. Since numerical platforms are likely to decrease the safety risks linked to sharing a vehicle with strangers, this situation results in higher carpooling shares and – with less cars on the road – to a worse situation in terms of public finance balance because gasoline taxation currently exceeds pavement damages. Logically, this situation also implies savings on external costs of cars' traffic. Adding the gains in consumers' surpluses, we get a higher social welfare (+9%).

Table 2.8: Simulation Results

	Hitchhik. (ref)	Real-time platform				
		Without monetary exchange	Profit max	Welfare max	Welfare max bis	BlaBlaCar
Price Driver (€/trip)	0	0	21.3€	6.3€	0	-2.1€
Price Pass. (€/trip)	0	0	16.5€	-4.5€	-7.8€	3€
#Dsolo	560	-101	+142	-111	-183	-55
#CpDriv	193	+55	-84	+16	+66	+30
#CpPass	193	+56	-72	+106	+134	+31
#PT	54	-10	+13	-11	-18	-6
Welfare	-28673	+2606	+1162	+3331	+3053	+2362
Platform Profit	0	0	+4321	0	0	+203
Pub. Fin. Balance (in which subv.)	1274	-78	+99	-196	-3260	-43
External costs	0	0	0	-35	-3063	0
External costs	1853	-113	+144	-235	-287	-63
Surplus	-28094	+2571	-3115	+3292	+6026	+2139
Solo Drivers	-11592	+2532	-3996	+3121	+4582	+1435
Carp. Drivers	-6219	-507	+590	-237	-115	+508
Carp. Pass.	-7184	-57	+1180	-7474	+467	-140
Pub. Transport	-3099	+602	-889	+699	+1091	+336
WT driver	5m40s	-25s	-20s	-2m30s	-2m10s	-15s
WT passenger	4m15s	-15s	+55s	+55s	+10s	-10s
Travel Time	40.6	-2.3	3.7	-4.4	-5.2	-1.4
#Cars	753	-46	+58	-95	-117	-25
Cars' occupancy rate	1.26	1.35	1.15	1.45	1.51	1.31

Notes: The Hitchhiking column indicates the welfare components results as the reference situation. Other columns present the differences compared to the reference situation. In these situations, positive (resp. negative) prices indicate how much drivers or passengers pay to (resp. receive from) the platform. There is no direct monetary exchange between drivers and passengers.

Surplus is calculated for each mode as the sum of the surplus of the mode users. As the individual surplus is negative, an increase in modal share leads to a negative delta for the mode surplus if its utility remains constant.

The platform profit increases when its users pay high prices and receive low earnings. However, excessive prices lead to potentially low carpool modal shares. Table 2.8 shows that the platform gets maximal profits when passengers pay 16.5€ for their trip. Interestingly, even drivers should pay the platform (21.3€) to host one individual in their vehicles. This counter-intuitive result comes from the fact that individuals prefer driving one car as compared to being driven, reason why the tipping point is associated with higher prices for drivers. Logically, this setting leads to very lower carpool shares and to a higher number of cars on roads as compared to the reference hitchhiking situation (the vehicles' occupancy rate decreases to 1.15). Despite

reduced consumers' surpluses and higher external costs of road traffic, the situation is profitable in terms of social welfare thanks to the increase in the private operator's profit as well as the improvement in the public finance balance (here magnified by the shadow price of public funds). It seems unrealistic, however, that such carpool organization could be accepted by users.

As shown in Table 2.8, the social welfare is maximized when passengers are encouraged to carpool through subsidies which would amount approximately to 4.5€ per trip. Conversely, drivers should still pay to receive passengers in their cars, around 6.3€ per trip. These findings mirror results found previously (Le Goff et al., 2022) stressing that passengers are – among potential drivers – the scarce resource for daily carpooling. In this setting, we see that modal shares of solo-driving substantially decreases (-20%) and, on the opposite, the vehicles' occupancy rate grows from 1.26 in the benchmark to 1.45, as carpool's market share. Even if the required subsidies are costly for public finance, the drop in external costs (by -13%) and the huge improvements in travellers' surpluses (by +12%) lead to a +11.5% increase in the social welfare.

The “Welfare Max Bis” column has been created to find a more “acceptable” situation for drivers. In fact, it seems very unlikely that people accept to share their car if they must pay for it. Hence, this situation describes the maximal welfare when the carpool drivers do not have to pay. Among the scenarios in Table 2.8, this situation allows the highest number of carpool passengers (+70%) and consequently the lowest number of cars on roads (-16%), which reduces the corresponding external costs. The social welfare is lower than in previous situation since the subsidy needed to attract as much passengers as possible must be very high (from 4.5 to 7.8 € per trip), which dramatically affects public expenses.

Finally, the “Blablacar” situation was created considering a passenger cost of 3€ per trip, partly reversed to the driver who earns 2.1€, which reflects what the private company could propose for a 30km trip. Therefore, this situation is a compromise between the profit maximization setting and relatively acceptable prices, for both drivers and passengers. As shown in Table 2.8, the social welfare is slightly lower in that case than in the situation without any monetary exchange. It is noticeable, however, that most of the welfare gains arisen from the platform effect are still mainly captured through consumers’ surplus and that public subsidies are not required in this setting.

5.3. Gender matching and welfare

Since the utility levels of carpooling differ by both respondents’ and carpoolers’ genders, we can also analyse what happens when we randomly match individuals and make vary the gender shares within the population. To simulate these matches, we again consider the introduction of a real-time carpool platform and we use utility functions implied by the specification 9 (see more details in the appendices).

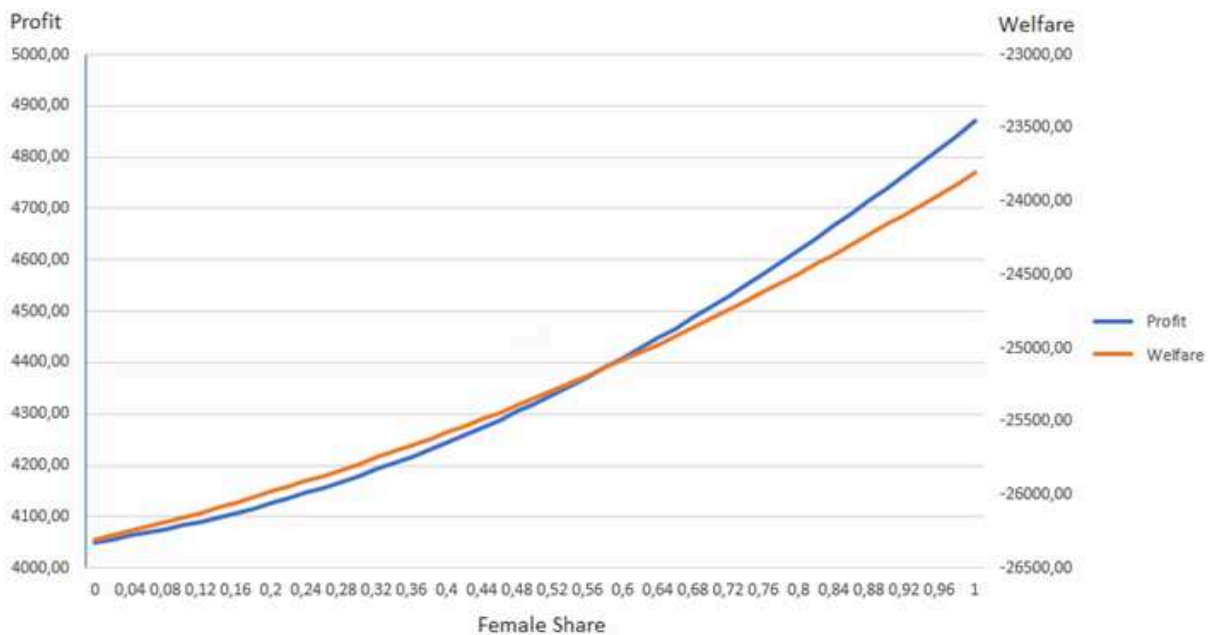


Figure 2.1 – Evolution of the maximal profit and social welfare depending on the female’s share within the population

We consider a random process in which individuals are matched proportionally to the shares of men and women in the population. Hence, social welfare and modal shares evolve differently according to the proportion of men and women in the population. These results are presented graphically below.

Figure 2.1 shows that the maximal social welfare reaches higher values when the female share is higher. Two results found in the previous section can explain this phenomenon. First, women prefer to carpool as passengers compared to men. Since the passenger mode is "limiting" because more people want to carpool as drivers, higher carpool modal shares are found when there is a higher proportion of women in the population, *ceteris paribus*. Second, women are preferred as carpoolers, both as drivers and as passengers. Therefore, carpooling is more often accepted if the probability to carpool with a woman is higher, *ceteris paribus*. For the same reasons, we can also notice that prices displayed in for drivers are lower and those for passengers are higher when the female share in the population is higher.

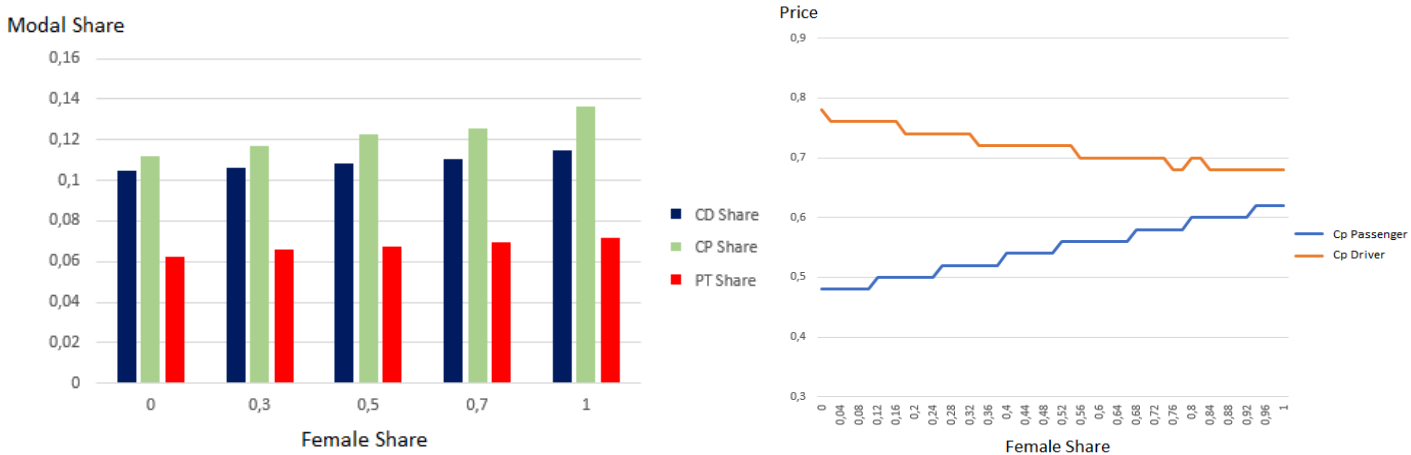


Figure 2.2. Modal shares and prices applied for profit maximized situations depending on female share



Figure 2.3. Modal shares and prices applied for welfare maximized situations depending on female share

If we compare profit maximization to welfare maximization situation, we can see higher prices when profit is maximized (Figure 2.2) than when welfare is maximized (Figure 2.3). This result is expected as the platform seeks to charge passengers as much as possible without decreasing their modal share too much (since passengers are the carpooling limiting resource). This implies lower carpool modal shares and a driver/passenger ratio close to 1.

In the welfare maximization scenario, we find more passengers in number and proportionally compared to drivers. This result is explained because one passenger more is one car less and therefore externalities less. Hence, the maximum welfare is obtained for situations which tends to increase the modal share of passengers.

6. Conclusion

This paper addresses the issue of individual preferences in the transport modal choice for daily trips, with a specific focus on carpooling. For this purpose, we conducted a stated choice survey on 3,632 inhabitants of the Lyon's region who responded to 6 choice tasks each for more than 20,000 choices observed. Their preferences are analyzed in terms of carpooling organization variables and socio-demographic differences – or similarities – between the respondent and his or her potential carpooler.

Our results indicate that carpooling platforms are valuable from the individuals' perspective. They seem efficient to build trust and willingness to carpool, with even stronger effects for passengers.

The analysis of what we call matching effects show a strong influence of the potential carpooler's gender, as the willingness to carpool is higher when it is a woman, both as a driver and as a passenger. On the opposite, there is no impact of the potential carpooler's age on the respondent choices. In addition, the effects of the carpooler's gender are different depending on the respondent's gender. Indeed, this impact is higher for female respondents than for male. This result suggests that carpooling could potentially be easier to implement in areas with a high female presence, such as hospitals in France²⁵.

Furthermore, the welfare analysis built thanks to these individual preferences underlines a potential lack of carpool passengers, with an optimal welfare reached in a situation where drivers pay and passengers are paid. This situation is in complete contradiction to what is currently done and seems unacceptable from the drivers' perspective.

²⁵ In 2018 in France, more than 3 out of 4 hospital civil servant are females according to the national institute of statistics : <https://www.insee.fr/fr/statistiques/6528822>

Finally, we know that this welfare analysis is incomplete since our estimates are based on a single transport supply situation for all individuals. To better understand the effects of a carpooling pricing policy, further research needs to apply it to concrete data, with transport supplies varying from one individual to another, depending on its departure and arrival locations.

Appendices

Appendix A. Planned and Real-time carpooling presentation screens

Planned carpooling presentation screen

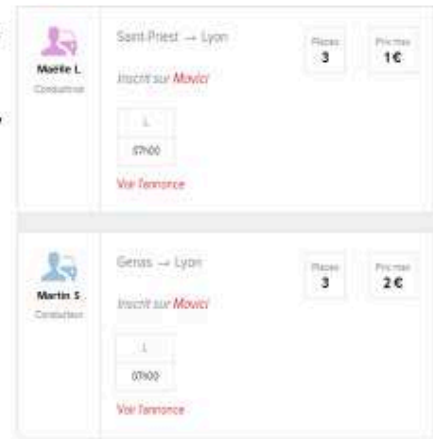
Carpooling is arranged before the trip begins with a set location and time for the passenger to pick up.

This may involve a time to get to the meeting point, a time to wait and a time to get to the final destination.

The trip is organized:

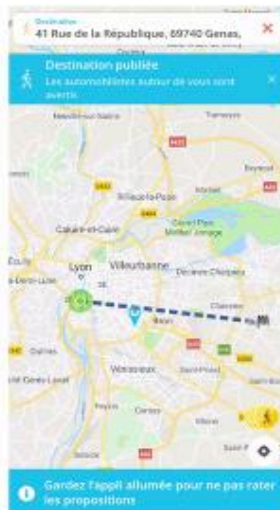
- Either via a platform (like BlaBlaCar) where members are listed
- Or informally with a relative/neighbor/colleague

Your return can be done by carpooling under the same conditions.



Example of a carpooling application

Spontaneous carpooling presentation screen



A real time application

In this survey, carpooling is organized spontaneously during the trip, and carpoolers may meet at a station or at the roadside.

This may involve a time to get to the meeting point, a time to wait and a time to get to the final destination.

The trip is organized:















- Either via a smartphone application in real time that links driver and passenger
- Or with a stranger in hitchhiking

Your return can be done by carpooling under the same conditions.



A carpooling station

Appendix B. Example of choice screen for a respondent with an 8:30 preferred arrival time

Mode	Driver Alone	Driver in a Carpool	Passenger in a Carpool	Public Transport
Trip Characteristics	Start : 7:20  Drive Alone: Between 30 and 40 min Arrival: Between 7:50 and 8:00	Start : 7:30 Join the station: no detour Wait:  5 min  Carpool : Between 25 and 40 min Join your destination:  5 min walk Arrival : Between 8:15 and 8:30	Start : 7:35 Join the station:  5 min walk Wait:  5 min  Carpool : Between 30 and 40 min Join your destination:  5 min walk Arrival : Between 8:20 and 8:30	Start : 7:30 Join the station:  10 min by car Wait:  5 min  Public Transport: Between 25 and 40 min Join your destination:  5 min walk Arrival : Between 8:15 and 8:30
Monetary aspects	You pay your usual transportation costs	You pay your usual transportation costs Carpooling makes you earn 1€	You save on your usual transportation costs Carpooling costs you 1€	You save on your usual transportation costs Public Transport costs you 0,80€
Carpooler's profile		Your passenger:  45 years old, Hitchhiker	Your driver:  25 years old, Referenced on the carpool platform	
Which mode do you choose ?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Appendix C. Utility functions details

For the solo driver (ds):

$$V_{D_{solo}} = ASC_{ds} + Cost + TT_{ds} + TV_{ds} + SchedEarly + SchedLate + Z_{ds}$$

Where ASC_{ds} is the constant specific to the solo driver mode, $Cost$ is the price, TT , TV are the on-board vehicle and variable time respectively. The subscript ds indicates that the coefficients associated with these variables are estimated specifically for this mode. $SchedEarly$ and $SchedLate$ are the variables indicating early and late scheduling. Finally, Z represents the socio-economic characteristics of the respondent (for the moment only gender has been tested in the models).

For the carpooling driver (*dcp*):

$$\begin{aligned}
 V_{Dcarpool} = & ASC_{dcp} + Cost + Gain + TT_{dcp} + TV_{dcp} + DT + WT_{dcp} + Spont_{dcp} + Platform_{dcp} \\
 & + Spont_{dcp} * Platform_{dcp} \\
 & + NotRelative(MM_{dcp} + MF_{dcp} + FM_{dcp} + FF_{dcp} + AgeMatch_{dcp} + (Platform_{dcp} * male)) \\
 & + Z_{dcp}
 \end{aligned}$$

Where *Gain* measures the difference between the sensitivity to money paid versus money received. *DT* and *WT* measure the sensitivities to detour time and wait time respectively. *Spont_{dcp}* measures the impact of spontaneous (vs. planned) carpooling organization. *Platform_{dcp}* measures the impact of the platform on the propensity to accept carpooling. We also consider the interaction between spontaneous and platform effects via the interaction *Spont_{dcp} * Platform_{dcp}*.

Finally, the influence of matching with the carpooler is treated. Gender interactions are modeled via the coefficients associated with *MM_{dcp}*, *MF_{dcp}*, *FM_{dcp}* et *FF_{dcp}* where the first letter symbolizes the gender of the respondent (M=Male, F=Female) and the second symbolizes the gender of the proposed carpooler. We also test if the age of the proposed carpooler has an impact via the age difference between this carpooler and the respondent via *AgeMatch*. Finally, we check if the impact of the platforms on the perception of the carpooler changes according to the gender of the respondent by using the interaction measured by *Spont_{dcp} * Platform*.

For these variables concerning the matching with the carpooler, we observe differences between the platform situations vs. the hitchhiking situation, taking care to exclude the situations where one is facing a relative via *NotRelative*.

For carpooling passenger (pcp):

$$\begin{aligned}
 V_{Pcarpool} = & ASC_{pcp} + Cost + TT_{pcp} + TV_{pcp} + AT_{pcp} + CorrespAcc_{pcp} \\
 & + ET + CorrespEgr + WT_{pcp} + Spont_{pcp} + Platform_{pcp} + Spont_{pcp} * Platform_{pcp} \\
 & + NotRelative(MM_{pcp} + MF_{pcp} + FM_{dcp} + FF_{pcp} + AgeMatch_{pcp} + (Platform_{pcp} * male)) \\
 & + Z_{pcp}
 \end{aligned}$$

Where *Corresp* are the variables indicating a change in transportation mode. This can be for access, where the passenger is likely to drive to the carpooling station with their own car, and then exit from the carpooling, where the individual is likely to take public transportation to finish their trip. *AT* and *ET* are the corresponding access and egress times in the modes mentioned above.

For public transports (pt):

$$V_{PubTransport} = ASC_{pt} + Cost + TT_{pt} + TV_{pt} + AT_{pt} + CorrespAcc_{pt} + WT_{pcp} + Z_{pt}$$

Where we find only previously used variables. There is no egress time (*ET*) since we assume that the public transports drop off near the individual's final destination and therefore does not imply a change of transport mode.

Table: Organization Effects

Model name	Model 0 Times only	Model 1 Platform Effects	Model 2 Spontaneous Effects	Model 3 Sport x Platform interaction	Model 4 Driver vs Passenger Effects	Model 5 Gender differentiated effects of platform
# individuals	3632	3632	3632	3632	3632	3632
# observations	21792	21792	21792	21792	21792	21792
# parameters	29	30	30	32	35	41
LL(final)	-26561.8	-26553.5	-26557.9	-26516.2	-26503.8	-26464.3
Adj. Rho-square (0)	0.1198	0.1200	0.1199	0.1212	0.1215	0.1226
AIC	53181.5	53166.9	53175.9	53096.3	53077.6	53010.6
BIC	53413.2	53406.6	53415.5	53352.0	53357.2	53338.1
Estimates						
ASC						
Carpooling Driver	1.589 ***	1.548 ***	1.589 ***	1.664 ***	1.663 ***	1.842 ***
Carpooling Passenger	1.487 ***	1.419 ***	1.487 ***	1.620 ***	1.583 ***	1.608 ***
Public Transport	0.746 ***	0.746 ***	0.746 ***	0.759 ***	0.753 ***	0.749 ***
Organization		0.102 ***			Driver Effects	Driver Effects
Platform					-0.171 ***	-0.271 ***
Sport					-0.208 ***	-0.593 ***
Sport x Pthm					0.406 ***	0.658 ***
Cost	-0.068 ***	-0.070 ***	-0.067 ***	-0.064 ***	-0.063 ***	-0.063 ***
Individual Characteristics						
Male						
Carpooling Driver	-0.099 **	-0.099 **	-0.100 **	-0.099 **	-0.099 **	-0.099 **
Carpooling Passenger	-0.410 ***	-0.411 ***	-0.411 ***	-0.409 ***	-0.413 ***	-0.413 ***
Public Transport	-0.195 ***	-0.195 ***	-0.195 ***	-0.195 ***	-0.196 ***	-0.196 ***
Age						
Carpooling Driver	-0.031 ***	-0.031 ***	-0.031 ***	-0.031 ***	-0.031 ***	-0.031 ***
Carpooling Passenger	-0.040 ***	-0.040 ***	-0.040 ***	-0.040 ***	-0.040 ***	-0.040 ***
Public Transport	-0.024 ***	-0.024 ***	-0.024 ***	-0.024 ***	-0.024 ***	-0.024 ***
Income						
Carpooling Driver	0.120 ***	0.121 ***	0.121 ***	0.121 ***	0.121 ***	0.121 ***
Carpooling Passenger	0.138 ***	0.139 ***	0.138 ***	0.139 ***	0.140 ***	0.140 ***
Public Transport	0.185 ***	0.185 ***	0.185 ***	0.185 ***	0.185 ***	0.185 ***
Time components differentiated by mode	Yes	Yes	Yes	Yes	Yes	Yes
Time components differentiated by stage of the trip	Yes	Yes	Yes	Yes	Yes	Yes
Organization x Male					Driver Effects	Driver Effects
Platform x Male					0.181 *	-0.134 *
Sport x Male					0.677 ***	0.386 **
Sport x Pthm x Male					-0.443 ***	-0.265 *

Notes: P-values: 1 () 0.1 () 0.05 (*) 0.01 (**) 0.001 (***) 0.

Table: Matching Effects

Model name	Base (Model 4 Table 1) Times only	Model 6 Relative Male	Model 7 Age Match	Model 8 Carpooler Male	Model 9 CpnlMale x Rspdt Male
# individuals	3632	3632	3632	3632	3632
# observations	21792	21792	21792	21792	21792
# parameters	35	37	39	41	43
LL (final)	-26516.2	-26516.2	-26487.0	-26479.7	-26473.8
Adj. Rho-square (0)	0.1215	0.1220	0.1220	0.1221	0.1223
AIC	53077.6	53050.2	53051.9	53041.9	53033.7
BIC	53357.2	53345.8	53363.5	53368.6	53377.2
Estimates					
ASC					
Carpooling Driver	1,663 ***	1,824 ***	1,822 ***	1,827 ***	1,829 ***
Carpooling Passenger	1,583 ***	1,580 ***	1,579 ***	1,595 ***	1,599 ***
Public Transport	0,753 ***	0,749 ***	0,748 ***	0,756 ***	0,756 ***
Organization	Driver	Driver	Driver	Driver	Driver
Platform	-0.171 ***	-0.390 ***	-0.406 ***	-0.358 ***	-0.300 ***
Spont	-0.208 ***	-0.426 ***	-0.443 ***	-0.398 ***	-0.340 ***
Spont x Prflm	0.406 ***	0.625 ***	0.641 ***	0.592 ***	0.534 ***
Cost	-0.063 ***	-0.064 ***	-0.064 ***	-0.063 ***	-0.063 ***
Matching	Driver	Driver	Driver	Driver	Driver
Respondent Male	-0.099 **	0.001	0.001	0.001	0.104 .
Male x Relative	NA	-0.390 ***	-0.390 ***	-0.390 ***	-0.286 ***
Carpooler Male	NA	NA	NA	-0.102 **	-0.226 ***
CPDMale x RspdtMale	NA	NA	NA	NA	0.217 **
Age Match	NA	NA	0.045	0.044	0.044
Individual Characteristics					
Male					
Public Transport	-0.196 ***	-0.194 ***	-0.194 ***	-0.194 ***	-0.194 ***
Age					
Carpooling Driver	-0.031 ***	-0.031 ***	-0.031 ***	-0.031 ***	-0.031 ***
Carpooling Passenger	-0.040 ***	-0.040 ***	-0.040 ***	-0.039 ***	-0.040 ***
Public Transport	-0.024 ***	-0.024 ***	-0.024 ***	-0.024 ***	-0.024 ***
Income					
Carpooling Driver	0.121 ***	0.122 ***	0.122 ***	0.122 ***	0.122 ***
Carpooling Passenger	0.140 ***	0.140 ***	0.140 ***	0.139 ***	0.139 ***
Public Transport	0.185 ***	0.185 ***	0.185 ***	0.185 ***	0.185 ***
Time components					
Time differentiated by mode	Yes	Yes	Yes	Yes	Yes
Time components differentiated by stage of the trip	Yes	Yes	Yes	Yes	Yes

Notes: P-values: 1 () 0.1 (.) 0.05 (*) 0.01 (**) 0.001 (***) 0.

Appendix E. Simulation details

1) Congestion

In order to model road congestion, we use is the following BPR function:

$$TT = T_0 * \left(1 + \gamma \left(\frac{\#cars}{K}\right)^\alpha\right)$$

Where TT is the total travel time, T_0 the initial travel time, in our case equal to 30 minutes.

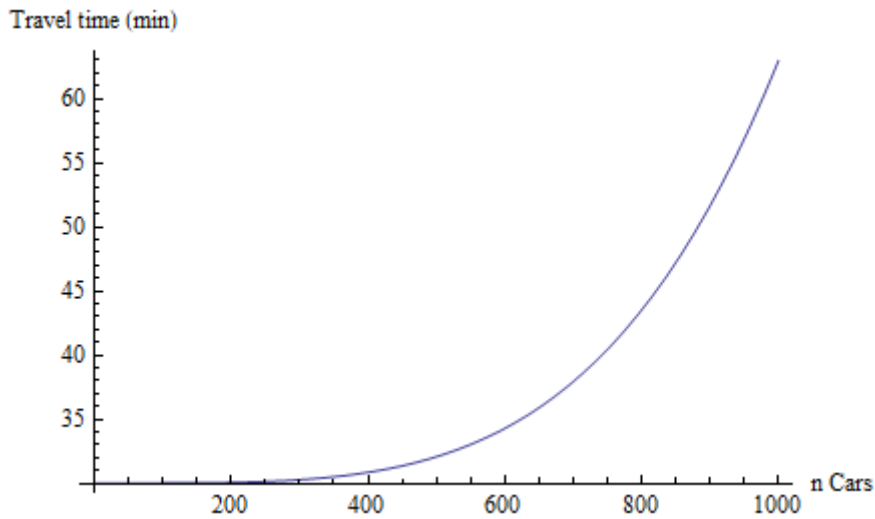
Following Leurent & Simonet (2001), the γ parameter is set to 0,45.

In this simulation, we want to test how 1,000 individuals who want to travel would react in a potentially congested situation. We need to fix a capacity parameter K for which the congestion is consistent. In an extreme case, if everyone uses his own car, the result obtained must be such that the travel time increases considerably. Let us consider the situation where these 1,000 people want to use a 2-lane road during a time interval of a quarter of an hour. If we consider that one lane can accommodate 1,600 people per hour, then the capacity of a two-lane road for a quarter hour is 800 people. We then fix K to 800 in this simulation.

The road use is then measured by the total number of cars, which depends on the mode choices individual have made. In this simulation, we consider every driver will take up space on the road and passengers will not. That is why the number of people who chooses public transportation or carpooling as passenger will not affect congestion. We have $\#cars$ equal to the number of people who chooses solo driver plus the number who chooses carpool driver.

Finally, α is set to 4 as recommended by Leurent & Simonet (2001) for a 2-lane axis.

Graphically, we get:



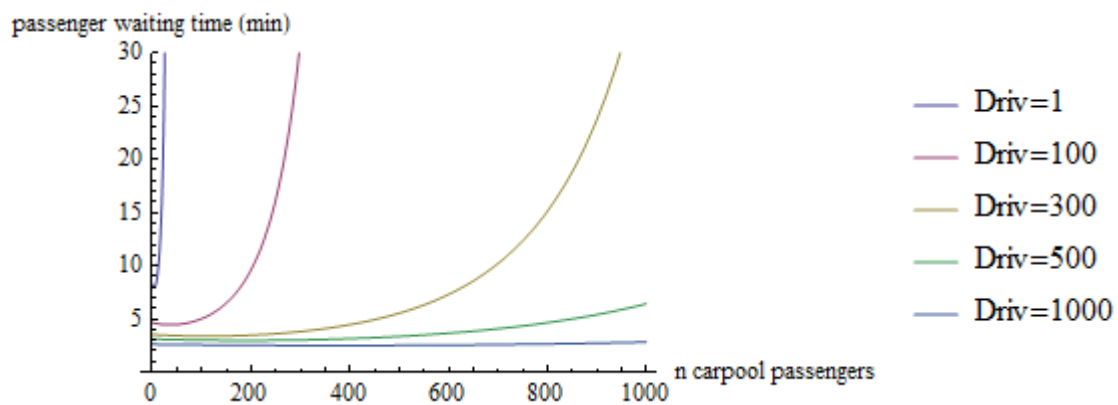
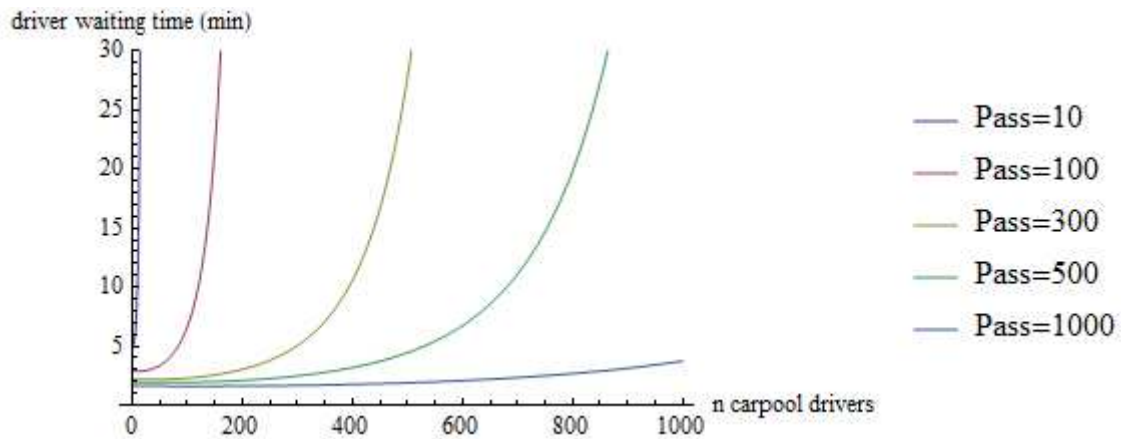
2) Waiting times

We want waiting times to be slightly different for passengers and drivers as a driver can allow several passengers while the reverse situation is impossible. Hence, drivers' waiting time should be such that the lack of passengers (more drivers than passengers) should increase more the waiting time compared to a situation where there are more passengers than drivers. We also want to add a component which takes into account the total number of carpoolers. The more the carpoolers, the fewer the waiting time. We hence model waiting times as:

$$WT_{cd} = \frac{\exp\left(\left(\frac{N_{driv}}{N_{pass}}\right)^2 - 1\right) * 25}{(N_{driv} + N_{pass})^{\frac{1}{4}}}$$

$$WT_{cp} = \frac{\exp\left(\left(\frac{N_{pass}}{2 * N_{driv}}\right)^2 - 1\right) * 40}{(N_{driv} + N_{pass})^{\frac{1}{4}}}$$

Graphically, these waiting time function give:



3) Public finance balance

Three factors here affect public finance. The first one is the money collected by fuel taxation. We consider the average fuel cost is around 0.09€ per vehicle-kilometer (Cordier, 2019). From this fuel cost, around 60% is taken by taxes (Source: Government <https://www.economie.gouv.fr/facileco/prix-lesence> Accessed Nov. 21).

The second one is the cost of road wear maintenance, approximated to 0.008€- per vehicle-kilometer by Bergerot et al. (2021).

Finally, public finance balance also takes into account a possible subsidy to the carpool platform. In this simulation, we consider that if the platform gives more than it receives, it must be subsidized by the amount of the deficit.

Considering a t 30 km trip (which is the average trip distance in the Lyon's area, see SYTRAL, 2016) and a shadow cost of public funds (SCPF) of 1.2, as recommended by Quinet (2014), we get:

$$Publifinance = SCPF * (\#Cars * distance * (0.6 * FuelCost - RoadWear) - Subsidy)$$

4) External costs

Finally, the external costs due to car traffic are estimated based on Bergerot et al. (2021), who propose an average cost of 0.082 € per vehicle-kilometer considering noise, air pollution and road insecurity. Hence:

$$Externalities = \#Cars * distance * 0.082$$

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CHAPTER III.

Social cost analysis of carpool incentives and spatial heterogeneities

1. Introduction

In contemporary society, the sustainability and efficiency of transportation systems have become critical concerns due to the predominance of individual vehicles' usage. Solo driving represents a substantial majority of car use for commuting trips nowadays. In France, the last national survey (SDES, 2021) shows that 88% of car trips shorter than 80 kilometers for professional purposes are made alone.

Promoting carpooling is often cited as a solution to reduce traffic nuisances in daily mobility, such as pollution or greenhouse gas emission (Shaheen et al. 2018). Particularly, it could mitigate congestion and parking problems considering space savings that could be achieved with a better allocation of travelers in the cars.

However, it is now well-known that promoting carpooling has some limitations, such as some undesirable rebounds effects (Coulombel et al., 2021). Indeed, it could lead to an undesired modal shift from public transportation, to higher trip distances or to an induced demand that could increase the number of car-kilometers and hence, increase car external costs.

The main objective of this paper is to evaluate how incentive policies to encourage carpooling or external shocks impact the collectivity. We will therefore test how consumer costs, external costs, public and private profits vary across several scenarios, such as time gain for carpoolers, raise of fuel prices or variations in prices paid or received by carpoolers. To measure differences between scenarios tested, we use a cost-benefit analysis method which have been widely used in transport economics literature, whether to estimate efficiency of

policy measures – e.g. Wang et al. (2015) for cordon toll and higher bus frequency in the case of Madrid – of an infrastructure – e.g. Sisiopiku et al. (2010) for HOV-lanes – or of a transportation mode – e.g. Litman, (2015) for public transport or Becker et al. (2020) for MaaS. In our case study, we estimate the total social cost of transport considering four main components: consumers' costs, external costs, public authorities costs, and private operator costs.

These components are determined through the transport supplies and flow obtained for 6,287 different origin-destination (O-D) in the eastern Lyon area, France. We then estimated modal shares thanks to a modal choice model calibrated on a stated preference survey realized in 2019 among 2,151 commuters of the Lyon area. Once modal shares obtained, for each scenario, we are able to infer for any O-D costs and/or revenues of the four components of social cost. This allows us to compare scenarios through the total social cost calculated across the whole considered zoning. Another result of interest of this study is to consider the impact of one measure on several O-Ds and analyze its spatial heterogeneity.

First results indicate consumer's cost constitutes the main component of the social cost. External costs seem to have a very low impact on the social cost in the simulations. Traffic reduction measures also appear to impact more public and private revenues than they reduce externalities, leading to higher total social costs. Moreover, results illustrate significant variations depending on the trips where the policies are applied.

Next section presents the study background. Section 3 presents the method while section 4 introduces the data used. Section 5 present the scenarios tested. Results are presented in section 6, discussed in section 7 with their limitations and section 8 concludes.

2. Background

2.1. Historical and local context

France is not exempt from the congestion problems common to all large cities in urbanized countries. As an example, Paris is one of the most congested cities in the world with 138 hours lost in congestion in 2022 according to INRIX (2022). Furthermore, car traffic also causes parking congestion. As pointed out by Héran & Ravallet (2008), a car requires an average of 40m² for parking. Carpool for commuting trips has the potential to reduce these problems by enabling better allocation of people in cars, which can also potentially reduce the number of cars – and hence space – needed.

Carpooling in France is now very popular, thanks to the success of the BlaBlaCar platform, which is widely used for long-distance travel. However, carpool for short distance trips is less popular for short-distance trips, which can be explained by several factors. Indeed, detours or waiting for a carpooler account for a much larger proportion of travel time for short trips. Furthermore, this effect is accentuated because individuals' time constraints are potentially stronger for short trips. The optimal spatial matching between carpool drivers and passengers can also be easily missed (Furuhata et al., 2013). Last but not least, public transport is much more competitive for short distances in France, which makes carpooling less attractive than for long distances.

In recent years, French public authorities have been trying to democratize the practice for commuting trips. For example, a law was passed in 2015 to enable companies to facilitate carpooling for their employees²⁶. This is coupled with a tax exemption for employees who

²⁶ https://www.legifrance.gouv.fr/jorf/article_jo/JORFARTI000031044948

organize carpooling to work²⁷. Locally, public authorities are also setting up reserved parking lots or matchmaking platforms, as well as partial or total reductions in motorway tolls for carpoolers. In the case of Lyon and a few other cities, a new infrastructure is being introduced in France. A High-Occupancy-Vehicle (HOV) lane has been implemented on the city's main north-south route in 2021. One of the three (or four) existing traffic lanes has therefore been reserved for carpool defined as vehicles with two or more occupants. While this system of reserved lanes is common in North America, the only reserved lanes in France prior to 2020 were bus lanes.

2.2. The Ecov supply (LANE)

Since the French are more accustomed to public transport than carpooling, a start-up named Ecov had the idea of creating a carpooling service similar to public transport. Carpooling lines are created, with predefined stops and station commodities where passengers can check in and wait for their carpooler as they would do with a high frequency public transportation.

One of these routes – called LANE – links Lyon, 1.4M inhabitants, to Bourgoin, a town of around 50,000 inhabitants, 50km away to the south-east. The two towns are directly linked by a highway, as shown on Figure 3.1.

With this service, passengers are guaranteed to find a driver within 20 minutes²⁸. Drivers are informed that a passenger is waiting by a traffic sign upstream of the stop. Each passenger transported earns them €2, whatever the traveled distance.

²⁷ <https://www.ecologie.gouv.fr/covoiturage-en-france-avantages-et-reglementation-en-vigueur>

²⁸ If the 20-minute delay is exceeded, the start-up will pay a taxi to get them to their destination.

The idea here is to analyze the impact of the introduction of the service and new incentives or price levels for carpooling, both on individuals and on the local community, by using the method presented in the next section.

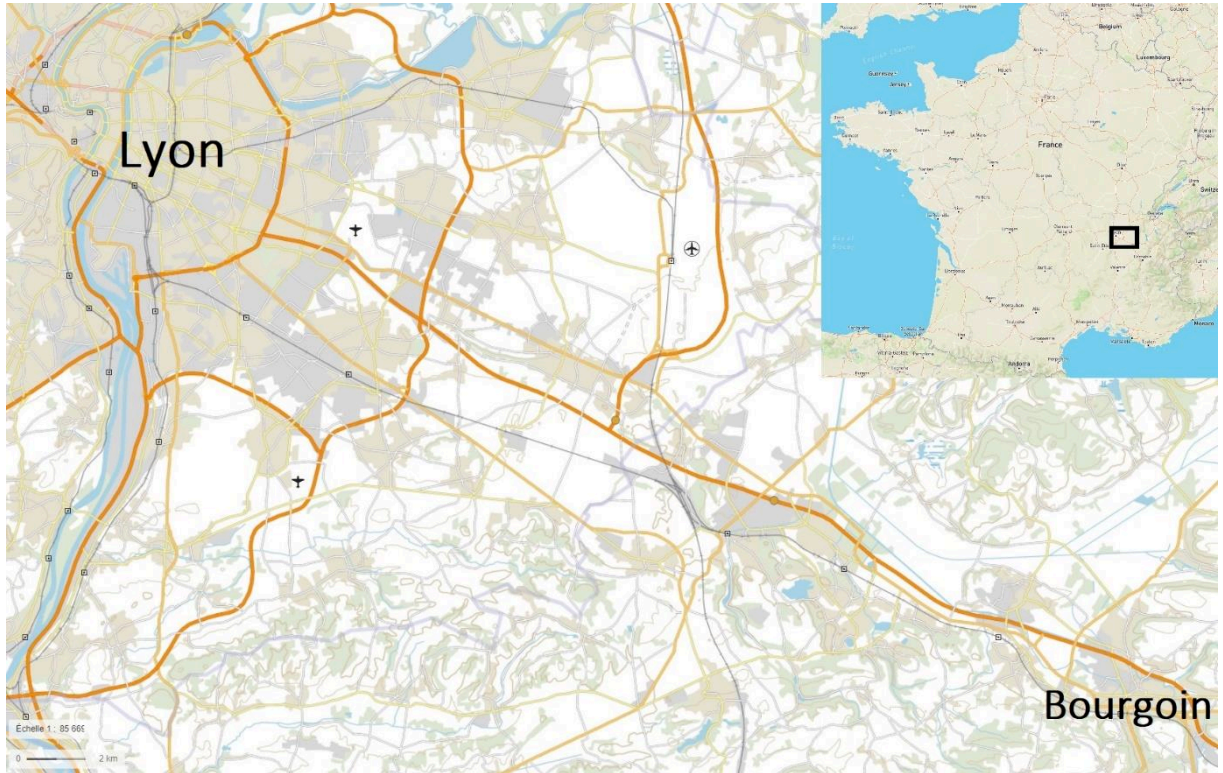


Figure 3.1 : The south-eastern Lyon region

3. Method

The objective in this paper is to estimate the total social cost of people's travel and its variations according to different policies. To obtain this total social cost, we first define its different components and detail the method used to sum them up for a considered zoning and scenario.

3.1. Social cost components

The total social cost is here made of four main aggregates: the trip generalized cost for consumers, the cost of the different externalities caused by the transportation modes, the public authorities' deficit and finally the deficit of the private companies. In most of the cases, public or private deficits are negative (i.e. their revenues are superior to their expenses) and the social cost is consequently reduced. This composition of the social cost is illustrated by the following equation:

$$\begin{aligned} \text{Social Cost} = \sum_k \sum_j & \text{Consumers' cost}_{kj} + \text{External costs}_{kj} + \text{Public Deficit}_{kj} \\ & + \text{Private Deficit}_{kj} \end{aligned} \quad (1)$$

Where k stands for the origin-destinations (O-D) and j for the transport mode. The social cost estimated for an area is hence the sum, for every mode and for every O-D in the area, of four components that are detailed in following subsections. To determine the social cost, we must first define the transport supplies. In this study, we will consider four modes: solo driver, carpool driver, carpool passenger and public transport. These supplies are defined for several origin-destinations (O-D) in the eastern Lyon area.

3.1.1. Consumers' cost

The cost of the trip for consumers includes two main categories. The first one is the monetary cost of the trip. This includes gasoline, possible toll pricing and fees or payment for the carpool.

The second part of the cost supported by consumer is the time spent. The detail of the consumer's cost in O-D k for mode j is provided by the following equation:

$$\text{Consumers' cost}_{kj} = \text{Time costs}_{kj} + \text{Toll}_{kj} + \text{Fuel}_{kj} + \text{CPprice}_{kj} + \text{Ticket}_{kj} \quad (2)$$

Where *Toll* and *Fuel* represents respectively the monetary prices paid for tolls and fuel for the

trip. *CPprice* represents the amount paid (or received if negative) to access or offer the carpool service. *Ticket* represents the price paid to access to the public transport.

Time costs are the costs associated to the different stages of the trip. They respectively stand for free flow travel time, congested travel time, waiting time, detour time, access time, egress time and connection time. According to Wardman et al. (2016) meta-analysis on the topic, the value of time (VoT) varies depending on the stage of the trip. As an example, they found waiting time is valued around twice higher than time spent in the vehicle. In this paper, we will follow the valuation of the different stages of the trip recommended by French public authorities for cost-benefit analysis (Quinet, 2014) for France.

The on-board values of time recommended vary depending on the distance travelled. Therefore, the value of time is adjusted according to the distance of the trip for each O-D pair in the database. The value of time for the carpool driver is considered identical to the one of the driver alone in its car. Therefore, the time spent alone on the trip (before the carpooler is picked up), during the detour and the time effectively carpooled (i.e. when both driver and passenger share the car) are grouped together and multiplied by the value of time on board. The value of the time on board for the carpool passenger will also be considered equal to the one of car drivers. This value is then multiplied only by the time effectively carpooled, i.e. without considering detour, waiting, access or egress times. When considering other stages of the trip, Quinet (2014) recommends formulas that directly depends on the on-board VoT for each mode. These formulas are detailed in the data section. Moreover, sensitivity tests building on VoTs potentially deduced from our own stated preference experiment will be presented in section 6.6.

Consumer's cost is hence calculated for each mode depending on its associated times and cost (e.g. *Ticket* is null for all alternatives except public transport). The sum of different time spent on the trip multiplied by their respective values allow us to estimate the time cost supported by a consumer, for each mode and every O-D pair.

3.1.2. External cost

The costs due to externalities in O-D k for mode j contain several elements presented in the equation 3 below.

$$Externalities_{kj} = Local\ Pollutants_{kj} + Noise_{kj} + Accidents_{kj} + Climate\ Change_{kj} \quad (3)$$

At first, we focus on the costs related to local pollution. The local pollutants (NOX, PM10, NH3, SO2) valuation is given in the handbook on the external costs of transport (European Commission, 2020) which gives values in €/kg.

We will therefore consider the quantity of these pollutant emitted according to the Computer Program to calculate Emissions from Road Transport (COPERT, see EMEP/EEA 2019) data. To apply these values to our data, we first need to know the vehicle speed since according to the COPERT calculations it is an input of the quantity of pollutants emitted.

The emissions of local pollutants can also vary depending on the vehicle fleet. To take this parameter into account, we use the values of the French vehicle fleet in 2020, excluding hybrid vehicles because they are not included in the EU Commission handbook values. We therefore use a car fleet differentiated by two euro-norms (euro-3 and euro-6) and by type of fuel used (gasoline, diesel and electric), leading to five categories.

Once speeds and vehicle fleet obtained, COPERT estimates the kilometric emissions (in g/vkm). These values are then multiplied by the number of vehicle-kilometers (i.e. distances

travelled as solo or carpool drivers) to obtain the quantity of pollutants emitted.

For the case of NO_x, the EU Commission handbook gives two different values depending on whether they are emitted in or outside the city. As a consequence, we need to know the distance driven on the different road categories. Since most of our trips in this case study connect urban centers, we assume that 75% of the non-highway distances are on "urban" roads and 25% on "non-urban" roads. For the valuation of NO_x, we consider distances travelled on highways, approximated on toll prices (see 4.3.2), are "non-urban" roads.

The sum of all these components gives the value of the local pollutant emissions for one vehicle, which must be multiplied by the flows, considering both solo drivers and carpool drivers, to obtain the total local emission cost.

The climate change cost is similarly obtained by calculating the total volume of CO₂ emitted thanks to COPERT. This value is then multiplied by the climate change avoidance cost defined by the European Commission (2020).

Finally, regarding noise and accidents, we will consider values found in the EU Commission handbook and in Bergerot et al. (2021) where values are given in vkm²⁹.

3.1.3. Public Deficit

Public authorities' budget in O-D k for mode j is affected in this study by the elements in the equation below, presented in a cost perspective as public expenses.

$$Public\ Deficit_{kj} = OCPF \times (Road\ Wear_{kj} + Ptfm\ Subv_{kj} - PT_{kj} - Fuel\ Tax_{kj} - Corp\ Tax_{kj}) \quad (4)$$

²⁹ When values in literature are given in passenger-kilometer (pkm) and not in vehicle-kilometer (vkm), we will assume a 1.2 car occupation rate, and apply this factor when necessary to do the conversion.

The opportunity cost of public funds, $OCPF$, expresses a loss in individuals' satisfaction due to the fact that taxes must be raised to fund public expenditures when money is invested by public authorities.

Public authorities are responsible for compensating wear and tear on public (non-tolled) roads, which we will consider to be the entire non-highway network in this study. Public finances are also assumed to have several sources of income through fuel taxes and corporate income taxes. Public transport finance, PT , is also here presented negatively – i.e. as an income – because only their revenues will vary across the scenarios tested. Indeed, we will consider the public transport supply will remain constant. Consequently, the public transport operating costs included in PT are considered invariant between scenarios and hence, only the differences in revenues from tickets will be observed. Finally, another potential expense is added to the public budget. In the scenarios developed in section 5, some provide subsidies to implement and operate a carpool platform. These subsidies are therefore included in the public authorities' budget.

3.1.4. *Private Deficit*

$$\begin{aligned} \text{Private Deficit}_{kj} & & (5) \\ &= \text{Highway Road Wear}_{kj} - \text{Highway Tolls}_{kj} - \text{Platform Profits}_{kj} \end{aligned}$$

Profit of the highway companies

In the same way as before, we calculate the deficit of private companies in O-D k for mode j . As we reason in terms of deficit, revenues are considered negatively and expenses positively. In our case, highways earnings come from tolls, and expenses from the road wear. We will consider here only the number of car-kilometers on the highway to make the road wear

calculation.

To calculate distances travelled on highways, we base ourselves on the toll prices. Thanks to the available highway tariff grids, we have at our disposal the prices paid and the freeway distance used for this price. These values allow us, after regression, to obtain an average price for each kilometer travelled on the highway. We then use the toll price paid by individuals for each O-D to approximate the distance driven on the highway.

Profit of the carpooling platform

For the profit of the carpooling platform, we consider only the prices paid and received by the carpoolers, multiplied by their respective flows. In the reference situation, drivers receive money for agreeing to let individuals ride at the carpooling stations located on their route and passengers pay exactly the same amount. The platform will therefore have no income in the reference situation. In this paper, in each scenario where the profit of the carpooling platform is negative, it is assumed that public authorities compensate this loss with subsidies. The carpooling platform's profit is therefore always positive or equal to zero in our results. Furthermore, it is considered that the transactions are carried out as soon as the carpooling is effective.

3.2. Empirical approach

In this paper, we will consider total social cost as the sum of social costs of each trip realized in the zoning studied for each scenario.

We first define transport supplies in terms of flows, distances, travel times and costs for every O-D in the zoning. They are then used as input to a modal choice model to estimate the flows for each mode. These modal shares will then allow us to obtain – given the transport

supplies and the values found in literature – the different components of the social cost that we just described. The details of models and values used for the calculations are provided in the following section.

The method used is summarized in Figure 3.2 below. Once transport supplies and level of demand are defined, they allow, with our modal choice model, to estimate modal shares and flows the four modes. These modal shares will then allow us to obtain – given the transport supplies and values in the literature – the different components of the social cost that we have just described.

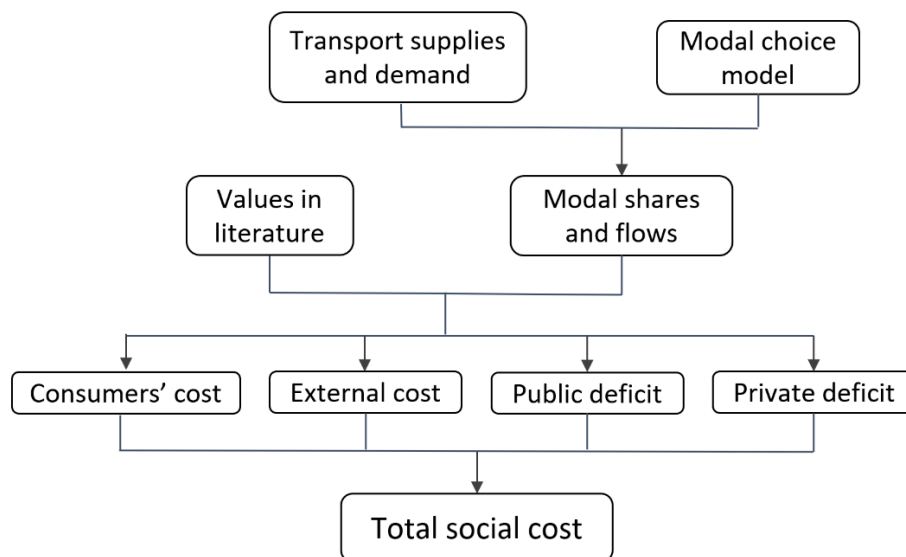


Figure 3.2 : Method summary to obtain total social cost

4. Data

4.1. Transport supplies

The transport supplies and flows on each O-D are based on the MOBPRO database, a national census that aim to survey the professional mobility over territories (INSEE, 2019). Only home-work trips originating in or going to the département of Rhône³⁰ were selected.

³⁰ Lyon's département

Some city territories are disaggregated according to a 1-km grid to gain precision. In cities divided in 1-km squares, the population distribution on the squares of trips origin is based on the population distribution and the distribution on the squares of trips destination is based on the job distribution. The zoning considered in this study is presented in Figure 3.3.

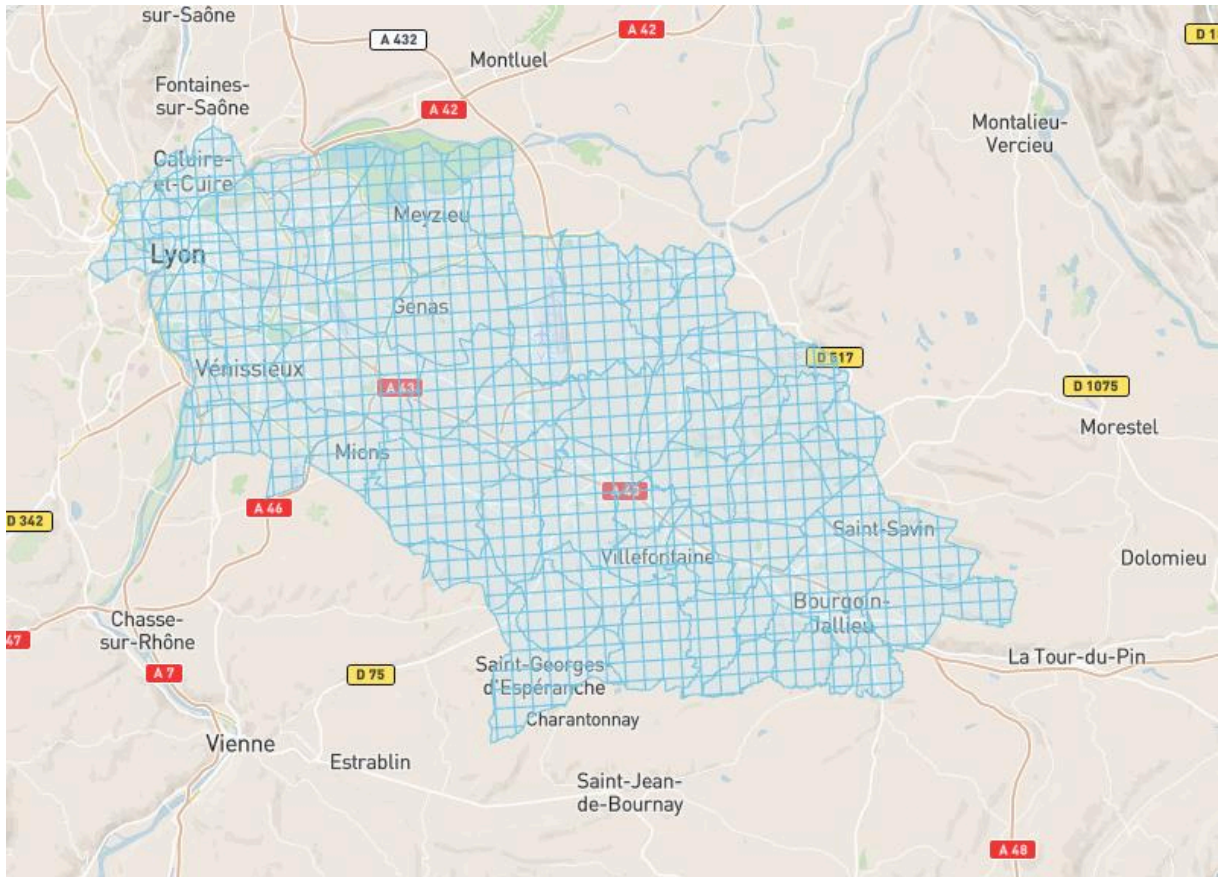


Figure 3.3 : Zoning considered in the survey

Distances are calculated following the car trip from origin to destination, considering the potential detour to a carpool station in the associated modes.

Toll costs, free flow and congested travel times are not directly available in open data or via open-source API calls. Therefore, we estimated the congested travel times and mapped the toll costs. An approximate of time lost in congestion was assigned on some sections of the road network to simulate a morning peak hour travel time. These time-lost approximates are derived from averages over Tuesdays in December 2021, excluding school vacations (Google

maps API). Waiting times are assumed depending on the mode:

- 5 minutes for public transports, assuming travelers arrange to arrive at the stop shortly before their bus or train
- 7 minutes for carpool passengers, as it is the current average waiting time during peak hours.

Fuel prices are calculated from the distance via an average ratio (MTE, 2019)³¹.

4.2. Modal choices

Once transport supplies are defined, we use a stated preference model calibrated through a survey conducted in 2019 on 2,515 commuters (see Le Goff et al., 2022 for more details) to estimate modal shares. Individuals are assumed to make their modal choice by choosing the alternative that provides them the highest utility. Each alternative therefore has its own utility, composed with a systematic and a random part like in the random utility model (Walker & Ben Akiva, 2002). The utility functions of the four modes are defined as follows:

$$U_{ik} = ASC_k + \beta_{tt_k} * TT_{ik} + \beta_{tv_k} * TV_{ik} + \beta_{at_k} * AT_{ik} + \beta_{wt_k} * WT_{ik} + \beta_{dt_k} * DT_{ik} + \beta_{cost} * Cost_{ik} + \beta_{connect_k} * Connection_{ik} \quad (6)$$

Where U_{ik} represents the deterministic part of the individual utility in O-D 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" travel time and the peak hour travel time. AT , WT and DT stand respectively for access, egress, waiting and detour times. $Cost$ represents the monetary cost (net

³¹ 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 of the 2015 and 2030 values. The value obtained is 0.0878 €/km.

of earnings for carpool drivers) of the alternative and *Connections* the number of connections in the trip.

Once the modal shares obtained, the flows for each mode can then be estimated for every O-D. Following the results from the modal choice model, the number of carpool drivers often exceed the number of carpool passengers due to individual preferences for the driver mode. The hypothesis we made is that the effective carpool driver share is limited by passengers and that the surplus of drivers (those who do not find a passenger) finish their trip as solo drivers. The *ASC* and β values are displayed in Table 3.1 below.

Table 3.1: Estimate values for the stated preferences model

Modes	Solo Driver	Carpool Driver	Carpool Passenger	Public Transport
ASC	0 (reference)	0.3575	-0.3488	0.1345
Hitchhike		-0.2441	-0.4299	
Times				
In-vehicle	-0.0349	-0.0457	-0.0411	-0.0322
Variability	-0.0140	-0.0267	-0.0330	-0.0336
Access			-0.0551	-0.0551
Wait			-0.0532	-0.0532
Detour		-0.0538		
Connect_acc			-0.0684	-0.0684
Connect_egr			-0.5364	
Platform effect		0.2441	0.4299	
Cost		-0.0895 (all modes)		

Notes: Hitchhike represents the difference in utility between a hitchhiking situation (i.e. no platform) and a situation with a carpooling platform. Time parameters are estimated as the disutility of one minute. The cost parameter is independent from mode.

We will consider the number of individuals and flows remain unchanged between the scenarios. These flows and the supplies from the four modes will allow the monetarization of the different components of the total social cost thanks to values found in the literature, as

presented in the following subsection.

4.3. Cost structures

4.3.1. Values of Time

We will now detail the values of time used to calculate the social cost. For cars and public transports, Quinet (2014) recommends values that vary depending on the distance as follows.

Table 3.2 : Values of time in €₂₀₁₆/h depending on the trip distance

distance	d ≤ 20 km	20 km < d ≤ 80 km	80 km < d ≤ 400 km	d > 400km
Mode				
Private car	8.4	$6.5 + 0.096 * d$	$13.6 + 0.006 * d$	16.2
Public Transports	8.4	$4.9 + 0.177 * d$	$20.5 - 0.02 * d$	12.7

*Notes: As an example, the value of time considered for a 50-km trip made in private car will be $6.5 + 0.096 * 50 = 11.3 \text{€}/\text{h}$.*

For variability, Quinet proposes considering the gap between the median travel time and the 9th decile and multiplying this gap by 2.5 for constrained trips. This requires knowledge of the distribution of travel times. Here, we only have the "empty" travel time and a peak hour travel time. For the valuation of this travel time variability, we will consider that they are uniformly distributed between the empty travel time and the travel time in peak hour. We will therefore take 40% of the difference between these two times (9th decile - median = 40% for a uniform function) and multiply it by 2.5, since we are dealing with daily trips, mainly to work, that we will therefore consider constrained. This means that this variability can be considered as the difference between the travel time in peak hours and the empty travel time ($40\% * 2.5 = 1$). This time is then multiplied by the value of time of the associated trip.

For the connections, Quinet recommends using twice the value of the travel time. It will be considered that each of the connections of a trip by passenger carpooling or by public

transport will last 5 minutes.

In terms of waiting, access and egress times, Quinet (2014) considers that they should be valued the same way as connection times, i.e. twice the value of the time of the associated mode. Detour time is not mentioned in the report and will be valued the same as the value of in-vehicle travel time.

4.3.2. Externalities

To calculate costs due to local pollutants, we need to know the vehicle fleet. In this survey we will consider that vehicle fleet is split into five main categories: petrol eu3 which represent 2% of the fleet, petrol eu6 (21%), diesel eu3 (6%), diesel eu6 (70%) and finally electric vehicles that represent 1% of the total fleet.

The type of road also must be calculated to estimate the local pollutant cost. Depending on where they are emitted, NOx have a different valuation. For instance, we estimate the distance covered on highways. Thanks to the toll grid of the highway company, we estimate by regression that the average toll is 0.11€ for each kilometer driven on the freeway. Giving this number and the level of toll in the transport supply, we can approximate the distance on highways (i.e. 9.1km driven per € paid on average).

Values for local pollutants are given in the table 14 of the EU Commission handbook in €/kg. The values for pollutants considered in this study are considered in Table 3.3 below.

Table 3.3: cost of local pollutant and CO2 in France in €₂₀₁₆/kg

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

Noise and accidents are valued both thanks to Bergerot et al. (2021). The value for highways is 0.006€/vkm on highways and 0.034€/vkm in urban roads. Accidents are valued on average on all roads at 0.031€/vkm.

Finally, we also want to consider the climate change cost due to CO2 emissions. Considering the table 24 of the EU commission handbook, we obtain a cost of 100€/tCO2 equivalent as specified in Table 3.3.

4.3.3. *Public and private deficits*

The main expense for public finances and the highway company in this survey will be the cost of road wear. This cost is valued at 0.008€₂₀₁₅/vkm by Bergerot et al. (2021).

Public finances also benefit from revenues, like fuel taxes, approximated to 60% of the fuel cost, which is defined in the transport supply. The corporate income tax also has to be considered. Its value will be assumed at a 25% rate on private profit benefits.

Moreover, we assume a 0.8€ average revenue per public transport user as this represents the average cost per travel for a subscriber in Lyon.³²

The operation of the carpool platform has a cost that will be approximated at 200.000€ per year. As we reason in terms of average cost per trip, we consider the total number of trips to approximate this fixed cost per trip made in the zoning. In 2019, there were approximately 80.000 cars per day on the Lyon-Bourgoin main axis³³. Assuming there are potentially several individuals in these vehicles and adding people using public transports, we can reasonably estimate there are 100.000 trips a day on the O-D corresponding to the axis. Considering only

³² Considering the €64 subscription fee for working people, halved by the employer, and 40 monthly trips.

³³ According to government data, map of road traffic in Lyon's region - 2019: <https://www.rhone.gouv.fr/contenu/telechargement/50676/279489/file/Carte%202019%20des%20trafics%20routiers%20dans%20le%20Rh%C3%B4ne.pdf>

work-related journeys, we retain only 42% of traffic according to national data (SDES, 2021). It represents 42.000 trips a day or 9.2 million trips a year in our case. Considering these values, the average operating cost of the platform per trip is around 0.022€.

We do not analyze public transport costs or private fixed costs in this study. This topic is deemed to be outside this study's scope since the transport supply will remain the same across the scenarios tested and hence evolutions will be null.

Furthermore, all expenses and revenues for public finances will be multiplied by 1.2 considering the opportunity cost of public funds, as recommended by Quinet (2014).

4.4. Model calibration and data filtering

To calibrate the modal split model, we used data from MOBPRO (INSEE, 2019). We compared modal shares observed between private cars and public transport for some O-D in the database to those given by our stated preferences model. The latter globally underestimated public transport modal shares. This led us to test by regression if the values of the different components of the trip were correctly estimated by our model. The result of this regression showed a higher impact of number of transfers on public transport modal share than our model suggested. Furthermore, public transport time variability was certainly overestimated for trips to the city center. Indeed, this time variability was calibrated on route modes whereas most of these trips were done by train. Hence, we raised the impact of a transfer on our utilities, lowered the travel time variability for trips to city center and adjusted the public transport constant to obtain modal shares very close those observed in the MOBPRO census.

The initial database contained slightly less than 300,000 different origin-destinations (O-Ds). We first removed the O-Ds 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 O-Ds

conserving for 98% of the total flows in the database. In a second data filtering, we decided to remove any O-D in which the carpool supplies could not be estimated. Thus, we can apply our model, calibrated to estimated modal choice in presence of carpool alternatives, on the remaining O-Ds. The final database we use contains 6,287 O-Ds.

4.5. Descriptive statistics

Descriptive statistics of the transport supplies for an average O-D are presented in Table 3.4 below. These descriptive statistics underline how heterogeneous the public transport supply is across the O-Ds in our data, with important standard deviations. This heterogeneity across O-Ds is also analyzed and illustrated through three selected O-Ds in the next section (see Table 3.11).

Table 3.4: 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.

5. Scenarios

The idea of building scenarios is to compare results after a supply change to results from the initial point. In our case, we create a LANE situation (i.e. with the implementation of a new carpool platform) which is then affected by time or monetary changes. The supply changes applied in each scenario are detailed in the next subsections.

5.1. Baseline situation and LANE supply

The baseline situation that will be considered in this study will consider both transport supplies and model calibrations described above. It is supposed carpooling trips are done in real-time, without monetary exchange and without a platform to connect carpoolers, i.e., hitchhiking. Meeting points for hitchhikers will be considered at the exact same place as carpooling stations in other scenarios. This baseline situation will be used to compare the potential gain from the implementation of the LANE service in from the social cost perspective.

In the LANE scenario, a carpooling platform is created, thus improving the carpooling offer perceived by users that are no longer obliged to hitchhike (see “platform effect” estimate in Table 3.1), without changing travel times. However, from a monetary point of view, the offer is changed since passengers pay their driver 2€ for their journey. This LANE situation will then serve as a reference that the following scenarios will modify.

5.2. Time-savings incentive scenarios

First, we describe scenarios that affect travel times:

-The "HOV" scenario simulates the implementation of an HOV-lane. It affects the travel times and the travel time variability of the three car modes. It is considered here that the HOV-lane is implemented on every highway section of the trip. It creates a time gain for carpoolers (equivalent to a speed-gain of around 10km/h) and a time loss for solo drivers (equivalent to a speed-loss of around 5km/h)³⁴. Their respective travel time variabilities are also reduced – for carpoolers – or raised – for solo drivers – by the same

³⁴ The time gain is proportional to distance covered on highways. The difference between travel times (and variability) for carpoolers and solo driver is estimated to 15 seconds per kilometer. These 15 seconds are split such as solo driver spend more time on road than in the reference situation for 30% of that amount, and carpoolers spend less time on road than in the reference situation for 70% of that amount (i.e. solo drivers lose $0.3 \cdot 15\text{s/km}$ on highways and carpoolers gain $0.7 \cdot 15\text{s/km}$ on highways).

amount.

-The "Easier access to stations" scenario will simulate the presence of nearby carpooling stations for each O-D in the database. The time spent by carpoolers to access the station is reduced for both drivers and passengers. For drivers, detour time is bounded to 2 minutes. For passengers, access time is bounded to 5 minutes, by walk. In this scenario, the demand for each carpool station is assumed to remain constant, without any increase in carpoolers' waiting times.

5.3. Monetary variations scenarios

We also simulate several scenarios that affect the monetary components of the trips:

-The "Fuel Price +" scenario simulates an increase in fuel prices from €1.7/L to €2.5/L.

It will be assumed here that public transport prices are not affected by this fuel price increase. It is therefore an indirect incentive to become a passenger in a carpool or in public transports.

-For the "Free of charge passengers" scenario, everything is in the title. Carpool drivers still earn 2€ when they carry a passenger, in every O-D. For passengers, the ride becomes free. Drivers payment would be made by the carpooling platform. Since it would not have any source of income in this scenario, public authorities would subsidize to compensate for the platform loss. The carpool platform profit in this scenario is hence equal to 0.

-In the "Private LANE" scenario, the carpooling drivers still earn 2€ as in the previous scenarios. This time, passengers pay 2.5€ for their trip. Therefore, the carpooling platform can this time pay the driver without being subsidized. It even makes profit for each carpooling trip realized.

6. Results

In this section, we compare the total social cost of the baseline and the LANE situation, and then compare the reference situation (i.e. LANE), with scenarios described previously. Consequently, we can evaluate the impact of each scenario on the social cost and its components, considering the number of travelers in the zoning remains unchanged. Results at the individual level, and hence average social cost, are presented in the following tables.

6.1. LANE service

Table 3.5 : LANE service

	Baseline (Hitchhiking)	LANE (reference)
Average social cost (in €/trip)	14.92	14.85
Consumer's cost	16.84	16.75
External costs	1.64	1.69
Public deficit	-2.22	-2.22
Private deficit	-1.33	-1.37
Modal Shares		
Solo Driver	61.4% (40.5%)	62.3% (33.8%)
Carpool Driver	9.3% (30.2%)	10.0% (38.5%)
Carpool Passenger	9.3%	10.0%
Public Transport	19.9%	17.7%
CO2 abatement cost (in €/t)	855	(ref)
Nb of car.km per capita	25.4	26.1
Occupation rate	1.13	1.14

Notes: 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 LANE scenario is $33.8\%+(38.5\%-10.0\%) = 62.3\%$.

The social costs and its components are displayed in €/trip.

CO2 abatement cost is the monetary value that should be given to a ton of CO2 to obtain the same total social cost in the given scenario and the reference situation, ceteris paribus.

Table 3.5 displays the main components of social cost and their variations between the baseline and the LANE situation. These first results indicate that the social cost is mainly driven by the level of the consumers' costs. Indeed, its absolute value is way larger than the other

components of the social cost. A detail of each social cost component is provided in Table 3.8 to Table 3.10 to understand better the displayed results. Another important result to underline 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 carpool passengers limits the number of carpool drivers. In the LANE case, the model predicts a carpool driver modal share of 38.5% which is limited by the lower carpool passenger's share of 10%. The 28.5% of carpool drivers "in excess" is then assumed to make their trip as solo drivers. We consider that the surplus of carpool drivers becomes solo drivers, who consequently become the predominant transport mode, used by over 60% of individuals.

When we compare the two situations, the LANE service improves the utilities of carpoolers by proposing a carpooling offer preferred to hitchhiking proposed in our baseline situation. This improvement in the carpooling offer has a positive impact on consumer costs. However, this is not the case for externalities. Indeed, the improvement in this offer creates a modal shift from public transport to the car. This creates a higher number of car-kilometers and therefore higher externalities. On the other hand, this higher number of vehicles has a positive effect on freeway revenues, as well as on fuel tax revenues. However, the introduction of the LANE service is subsidized by the public authorities. These positive and negative effects of LANE on public finances appear to offset each other between the two situations.

6.2. Time saving incentives

Table 3.6 below shows how the LANE (reference) scenario is affected by the time-related changes described in the previous section.

Table 3.6: Time saving incentives

	LANE (ref)	HOV	Closer Stations
Average social cost (in €/trip)	14.85	15.00	14.70
Consumer's cost	16.75	16.83	16.57
External costs	1.69	1.65	1.66
Public deficit	-2.22	-2.15	-2.18
Private deficit	-1.37	-1.33	-1.34
Modal Shares			
Solo Driver	62.3% (33.8%)	57.7% (28.6%)	59.7% (33.2%)
Carpool Driv.	10.0% (38.5%)	12.8% (41.9%)	11.4% (37.9%)
Carpool Pass.	10.0%	12.8%	11.4%
Public Transport	17.7%	16.7%	17.5%
CO2 abatement cost (in €/t)	/	2739	-2191
Nb of car.km	26.1	25.5	25.7
Occupation rate	1.14	1.18	1.16

Notes: 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.

The social costs and its components are displayed in €/trip. Toll and fuel costs are expressed in average cost for drivers.

CO2 abatement cost is the monetary value that should be given to a ton of CO2 to obtain the same total social cost in the given scenario and the reference situation.

In our "HOV" scenario, the time saved by carpoolers and lost by solo drivers respectively result in an increase and a decrease of their associated modal shares as expected. This results in a reduced number of car-kilometer – 0.6 per trip made – which leads to reduce externalities. In the same time, it produces a lower private profit, which is here entirely carried by highways' profit. 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 public finances balance. Unexpectedly, the consumers' costs seem barely affected by the changes of the HOV scenario. This result is due to the opposite effect that positively affect carpoolers and negatively solo drivers. Furthermore, even though the time loss by solo drivers is smaller than the time gain by carpoolers, the global effect on consumers is negative. The explanation comes from the solo driver modal share which is way higher than the

carpoolers' one. The detailed consumers' cost table give more details to explain this phenomenon (see Table 3.8). The total social cost of this measure is slightly superior to the one of the LANE scenario. This increase is also mainly due to the reduction of both private companies and public authorities' revenue. 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 values. This is 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 total social. Costs of externalities are also detailed in Table 3.9.

The second scenario simulates the presence of a station easily accessible for every O-D. As the modal shares indicate, the gain in utility is substantially higher for carpool passengers than for drivers.³⁵ The carpool passenger modal share increases less than in the HOV scenario. Thus, externalities are less reduced and public and private profits are also slightly lower. From this perspective, this scenario with closer carpool stations is kind of an intermediate between the reference situation and the "HOV" scenario. The incentive to induce more carpooling seems lower than the HOV-lane situation. However, in this scenario, the utility of consumers is only positively affected, in contrast to the "HOV" which degrades the utility of solo drivers. Consequently, consumers' costs are reduced, which makes the total social cost lower. As both externalities and total social cost are reduced, the abatement cost of CO2 becomes negative, indicating the low-CO2-emission scenario is more economically efficient. Nonetheless, this result does not necessarily imply that this scenario is the best of the three presented. Indeed, it assumes that waiting times would not be increased. This hypothesis would only be possible if

³⁵ In the equivalent scenario without a gain in detour time for carpool drivers, their associated modal share is 30.5%, 0.1 percentage point lower. This indicates detour times were already small and hence the gain for carpool drivers is minor.

the carpooling market share were to increase significantly compared to its current state. Furthermore, the costs of creating and maintaining carpool stations are not included. This scenario therefore favors carpooling offers – and reduce carpoolers' costs – compared to a situation where the number of carpoolers remains unchanged.

6.3. Monetary incentives

Erreur ! Source du renvoi introuvable. below indicates the results obtained from the simulations of our monetary variations scenarios. These results confirm first observations made in the previous Table 3.6. The link between the carpool shares, number of car-kilometer, externalities and private profits is still observable. However, as these scenarios may directly affect public finances, it is not obvious that a higher number of car-kilometer implies reduced public expenses through higher revenues from fuel taxes, but this link should be kept in mind.

The first scenario assumes an increase in fuel prices. This increase induces higher modal shares for passenger modes than in the LANE situation. There is no surprise in the increase in consumers' cost since this scenario only raises drivers' cost. It should be noted that this scenario leads to the largest decrease in car-kilometers and externalities from all scenarios tested. As a consequence, 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-km.

Table 3.7: Monetary incentives

	LANE (ref)	Fuel Price +	FOC Passengers	Private LANE
Average social cost	14.85	15.32	15.03	14.80
Consumer's cost	16.75	17.90	16.60	16.77
Externalities	1.69	1.63	1.65	1.69
Public deficit	-2.22	-2.90	-1.89	-2.26
Private deficit	-1.37	-1.32	-1.34	-1.39
Modal Shares				
Solo Driver	62.3% (33.8%)	59.1% (32.8%)	59.2% (33.2%)	63.1% (34.0%)
Carpool Driv.	10.0% (38.5%)	11.0% (37.3%)	11.7% (37.7%)	9.6% (38.7%)
Carpool Pass.	10.0%	11.0%	11.7%	9.6%
Public Transport	17.7%	18.9%	17.4%	17.7%
CO2 abatement cost	/	4019	2480	1991
Nb of car.km	26.1	25.3	25.6	26.2
Occupation rate	1.14	1.16	1.16	1.13

Notes: 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.

The social costs and its components are displayed in €/trip. Toll and fuel costs are expressed in average cost for drivers.

CO2 abatement cost is the monetary value that should be given to a ton of CO2 to obtain the same total social cost in the given scenario and the reference situation.

The second scenario presented assumes that the carpooling platform still pays 2€ to the carpooling drivers, but passengers are free of charge. As a consequence, the carpooling platform is subsidized by public authorities to be able to pay this amount, in addition of the operational costs of 200k€. This is similar to an incentive distributed to carpool passengers. This results in a lower consumer's cost, but higher public expenses. As the passengers' modal share is limiting the total carpool share, this incentive results in a lower number of car-kilometers and a higher occupation rate than the LANE scenario. Externalities and private profits are hence slightly reduced. Nonetheless, the increase in public expenses outweigh the gain from the reduce in consumers' cost which lead to a higher total social cost than in the LANE scenario.

In the last scenario, the drivers' gain remains the same but the passengers pay a price slightly higher than this gain. The platform can therefore directly pay the amount due to the drivers without requiring a subsidy and even make a small profit. This profit can therefore finance the introduction of the LANE service, which does not need any subsidy. Thus, public expenses are lower than in the reference situation. The increase in the cost of carpooling for passengers directly induces an increase in consumers costs, but also a decrease in its modal share and an increase in car-kilometers, again increasing public and private revenues and externalities. The total social cost is here lower than in the previous situation. This scenario shows that it seems more desirable – from the total social cost perspective – to have a private carpooling platform. And this is despite a lower carpooling market share and thus a higher number of car-kilometers than in the latter two situations. This counter-intuitive result shows that promoting carpooling and reducing the number of vehicles on the road does not reduce - with the values used - the total social cost.

In these scenarios, CO₂ abatement costs are very high, underlining the difficulty to make these scenarios economically efficient and with low emissions objectives, as discussed in section 6.6.

6.4. Total social cost component details

Next tables detail the four main components of the social cost. Table 3.8 displays details of the consumer's costs, mainly through time components.

We can observe that the "HOV" scenario offers a reduced cost for carpoolers but an increased cost for solo drivers. Two main reasons explain why the overall consumers cost is slightly higher in HOV scenario. First, the cost of the mode with the highest modal share, solo driver, is increased. Second, the HOV-lane is an incentive to switch to carpool, which is a more

costly mode than solo driver, despite the time gain for travelers. Furthermore, this very low modal share of carpool passengers implies the same modal share for carpool drivers, despite a very attractive time cost. In the scenario with closer stations, the entire gain for consumers is based on the gain granted to carpool passengers. Other phenomena can be observed on the costs related to travel time. The "Fuel Price +" scenario increases the time costs of passenger modes. This is explained because carpool modes, despite being more time consuming, are more attractive after an increase in fuel costs. The opposite effect is also found when we observe the evolution of the cost of individuals choosing public transport in the "HOV" and "closer stations" scenarios. Indeed, since the carpooling modes have better supplies than in the reference situation, users can more easily find an alternative to public transport and thus, use this mode only when its cost is low. Finally, the "Private LANE" scenario appears to be similar in every aspect to the reference situation. Here, the difference between the consumer costs is explained because the passengers have to pay for their carpooling trip. This payment is not fully given to the driver, which should worsen the consumer cost. However, this payment is also the reason why the modal share of the carpooling passenger decreases in this scenario. This decrease in the carpool passenger modal share leads to a modal shift towards the least expensive mode for consumers: solo driver. This shift explains a lower average consumer's cost in the " Private LANE" scenario.

Table 3.8: Consumer's cost detailed

	LANE (ref)	HOV	Closer Stations	Fuel Price +	Private LANE
Consumer's cost	14.82	14.97	14.67	15.29	14.79
Time components					
Solo Driver	9.43	10.00	9.42	9.42	9.42
Carpool Driver	6.35	4.94	6.33	6.34	6.35
Carpool Pass.	24.09	22.69	22.05	24.14	24.58
Public Transport	20.87	20.80	20.84	20.94	20.87
Toll cost	2.71	2.71	2.71	2.71	2.71
Fuel cost	3.09	3.09	3.08	4.54	3.09

Notes: Consumer's cost is the average individual cost. Time, toll and fuel costs are expressed in average cost for the mode user, e.g. a solo driver has on average 9.43€, 2.71€ and 3.09€ costs due respectively to time spent during its trip, tolls and fuel in the reference situation.

The analysis of Table 3.9 below is very straightforward as all externalities are linearly dependent from the number of car-kilometers. External costs are mainly driven by accidents, which represent around half of the total. Valuation for CO2 emitted and noise each account for around 20% of the externalities' costs. Finally, the valuation of local pollutants only represents 10% of the total external costs.

Table 3.9: Externalities cost detailed

	LANE	HOV	Fuel Price +
Total Externalities	1.69	1.65	1.63
Local pollutants	0.18	0.17	0.17
Noise	0.33	0.32	0.32
Accidents	0.81	0.79	0.78
Climate change	0.37	0.37	0.36

Notes: This table presents average values at the individual level, in € per trip.

Table 3.10: Public expenses and private profit detailed

	LANE	HOV	Fuel Price	FOC Passengers	Private LANE
Public Deficit	-2.22	-2.15	-2.90	-1.89	-2.26
Road Wear	0.08	0.08	0.08	0.08	0.08
Fuel Tax	-1.61	-1.57	-2.29	-1.58	-1.62
Corporate Tax	-0.55	-0.53	-0.53	-0.53	-0.56
PT revenues	-0.17	-0.16	-0.18	-0.17	-0.17
Ptfm Subsidy	0.03	0.03	0.03	0.31	0.00
Private Deficit	-1.37	-1.33	-1.32	-1.34	-1.39
Platform	0.00	0.00	0.00	0.00	0.02
Highway	-1.37	-1.33	-1.32	-1.34	-1.37

Notes: This table presents average values at the individual leve. Results for public finances are here presented as expenses, so the public revenues are displayed as negative values and expenses as positive values.

Table 3.10 displays details of public and private expenses and revenues. Fuel tax and highway profits are directly correlated with the number of car-kilometer. This higher profit also benefits to public finances through corporate tax. This table also illustrate how fuel prices raise impacts fuel tax and how impactful the platform subsidy is on public finances in the “Free of charge passengers” scenario. The “Private LANE” scenario reveals that public finances benefits both from the withdrawal of the subsidy and from higher taxes because private profits are higher in this scenario. Furthermore, as the number of car-kilometer is also higher, public finances also benefits from more fuel taxes.

6.5. Spatial heterogeneity

First, we will focus on the spatial diversity of our data. Indeed, all O-Ds can be affected differently by the measures we simulated. Table 3.11 and Figure 3.4 below present three O-Ds with very different characteristics that illustrate this phenomenon. The first O-D selected (O-D#1) connects the center of Bourgoin to the center of Lyon. The public transport supply is excellent and its market share is therefore important. The O-D#2 connects a village in the North

of Bourgoin to Lyon. In this O-D, access to public transports 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 O-D#3, which connects Bourgoin to the southeastern suburbs of Lyon, has a public transportation offer 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 O-D like this one.

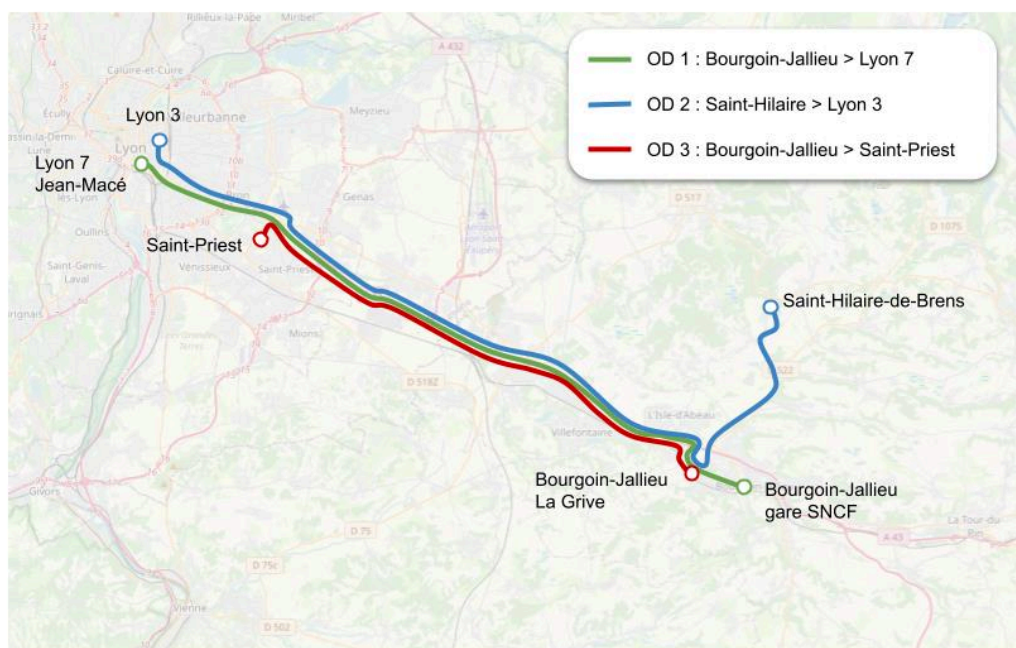


Figure 3.4 : The three O-Ds selected

Table 3.11: descriptive statistics of the 3 selected O-Ds

	O-D#1	O-D#2	O-D#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

Notes: Values are weighted by flows and rounded.

Table 3.12: HOV and FP+ scenarios applied to the three selected O-Ds

	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's 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						
Solo Driver	-1.1 p.p.	-4.9 p.p.	-8.9 p.p.	-1.0 p.p.	-1.1 p.p.	-0.9 p.p.
Carpool Driver	+1.7 p.p.	+3.1 p.p.	+4.1 p.p.	-0.9 p.p.	-1.2 p.p.	-1.0 p.p.
Carpool Passenger	+1.1 p.p.	+2.1 p.p.	+4.9 p.p.	+0.0 p.p.	+1.5 p.p.	+1.8 p.p.
Public Transport	-1.7 p.p.	-0.3 p.p.	-0.1 p.p.	+1.9 p.p.	+0.8 p.p.	+0.1 p.p.

Notes: Social cost values in this table display the differences at the individual level between the scenario and the reference situation. E. g. the HOV-lane scenario increases the average social cost for an average individual in O-D#1 by €0.05.

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

Table 3.12 displays results of the HOV-lane and the fuel price increase scenarios for the three chosen O-Ds. It shows a lot of heterogeneity in the simulations' impact. The HOV-lane scenario is a clear gain from the total social cost perspective in O-D#3. As the trip is almost entirely done on highways, time savings make carpooling alternatives very attractive. It provides gains from both externalities and consumers costs perspective that outweigh the lower revenues for public authorities and private companies. This HOV-lane scenario is inefficient for both O-D#1 and 2 for different reasons. In O-D#2, the HOV-lane degrades the solo driver supply which represents a large majority of the modal share on this O-D. The incentive towards carpool does not compensate for this loss. It allows for externalities reduction but the loss for public authorities and private companies due to the decrease in car-kilometer outweighs it. In the O-D#1, the HOV-lane encourage people to switch to carpool whereas they are mostly using public transport. This measure results in a loss even from the externalities' perspective,

considering the public transport 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 O-Ds are impacted in different ways. O-D#1 is barely affected as the majority of the demand use public transport and we assume public authorities do not raise the ticket price. O-D#2 is the most impacted O-D as a large majority of the population use their car and the carpool alternatives are not attractive. This is the contrary in O-D#3 in which the carpool alternative offers an alternative to solo driving, so the increase in car cost can be mitigated.

6.6. Sensibility tests

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

6.6.1. Reassessing externalities and public action

As mentioned previously, social costs obtained by our simulations will be different if one uses other values for our parameters. The first example of this case is when we consider a different value for CO₂ emissions, as presented in Table 3.13. The "CO₂+" scenario gives the valuation of externalities if one considers the high valuation of CO₂ proposed by the EU commission (2020) for the long-term projects. This value is five time superior to the value for current projects (€498/tCO₂ vs €100/tCO₂ currently). Even considering this value, the total value of externalities would be slightly less than doubled. This valuation would still consider the HOV-lane scenario as less desirable, from the total social cost perspective, than the reference situation, *ceteris paribus*. In order to make the total social cost of the HOV-lane scenario smaller than in the reference situation, the ton of CO₂ emitted should be valued at around €2,739 (cf. CO₂ abatement cost in Table 3.6) if one wants to obtain a smaller social cost

than the reference (LANE) scenario. This valuation of CO2 would be more than an order of magnitude larger than the current one. Therefore, considering the low weight of externalities in the social costs, it seems unlikely that scenarios requiring some effort to reduce externalities would be interesting from a cost benefit analysis perspective.

Table 3.13: CO2 valuation sensibility test

	CO2 current value (100€/t)		CO2+ (498€/t)	
	LANE	HOV	LANE	HOV
Average social cost	14.85	15.00	16.32	16.45
Consumer's cost	16.75	16.83	16.75	16.83
Externalities	1.69	1.65	3.16	3.10
Of which CO2	0.37	0.37	1.85	1.82
Public deficit	-2.22	-2.15	-2.22	-2.15
Private deficit	-1.37	-1.33	-1.37	-1.33

Notes: This table presents average values at the individual level, in € per trip.

Another important value that could make scenarios ranking different is the OCPF (see 3.1.3). The OCPF affects both revenues and expenses of public authorities. It is valued in this paper at 1.2. As an example, if one wants to compare the “HOV” scenario to “FOC Passengers” (see Table 3.6 & Table 3.7), the total social cost is slightly higher for the second (+0.03 in “FOC passengers”). This result would be different if one does not consider the OCPF (or OCPF=1, see Table 3.14). In this case, this reduces the absolute value of public deficit, dividing it by 1.2. This would result in a -1.79 value for “HOV” scenario and a -1.58 value for “FOC Passengers”. These new values would result in a social cost of 15.36 for “HOV” and 15.33 for “FOC Passengers”. Without considering the OCPF, the “HOV” scenario would have a higher social cost than the “FOC Passengers” one.

Table 3.14: OCPF sensibility test

	OCPF = 1.2		OCPF = 1	
	HOV	FOC Passengers	HOV	FOC Passengers
Average social cost	15.00	15.03	15.36	15.33
Consumer's cost	16.83	16.60	16.83	16.60
Externalities	1.65	1.65	1.65	1.65
Public deficit	-2.15	-1.89	-1.79	-1.58
Private deficit	-1.33	-1.34	-1.33	-1.34

Notes: This table presents average values at the individual level, in € per trip.

6.6.2. Reassessing values of time (VoTs)

Another way to value differently the scenarios is to consider different VoTs than those described in the data section. Table 3.15 below displays results equivalent to Table 3.8 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 3.15: Consumers costs considering our VoTs

	Reference	HOV	Closer Stations	Fuel Price +	Private LANE
Consumer's cost	26.33	26.22	26.30	27.82	26.32
Time components					
Solo Driver	15.42	16.40	15.41	15.41	15.42
Carpool Driver	17.61	14.16	17.53	17.58	17.61
Carpool Pass.	35.17	31.62	33.63	35.22	35.66
Public Transport	41.33	41.08	41.27	41.66	41.35
Toll cost	2.71	2.71	2.71	2.71	2.71
Fuel cost	3.09	3.09	3.08	4.54	3.09

Notes: Consumer's cost is the average individual cost. Time, toll and fuel costs are expressed in average cost for the mode user, e.g. a solo driver has on average 15.42€, 2.71€ and 3.09€ costs due respectively to time spent during its trip, tolls and fuel in the reference situation.

Our values of time are overall higher and this affect even more carpooling trips as our carpool values are higher than solo driver 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's cost than the reference situation, whereas it was the opposite with values from the literature used previously. As our values give a smaller valuation of connection and access to a carpool station, the gain for carpool passenger is also lowered in the « closer stations » scenario. This reduced gain is illustrated by the carpool passenger cost, that is now only €1.54 lower compared to the reference situation (€2.04 with values from literature, see Table 3.8).

To summarize, we find with values from the literature that the total social cost is mainly driven by consumers' costs. The values given to externalities seems too low to have an impact on the total social cost and outweigh the public and private revenues from traffic. Private LANE scenario is one of the scenarios with the lowest total social cost, even though it is the scenario with the lowest car occupation rate and the highest number of car-kilometer. However, these results can vary depending on assumptions made. This concerns values used for the OCPF, or those 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 total 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.

7. Limitations

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 O-D, 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 any hypothesis, these can be criticized and changed, which would of course affect values found in the results.

The main limitation of this paper comes from the use of a logit model without nested structure or other forms taking into account individual heterogeneity for the individuals' modal choice. 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 rather be put in perspective with each other than considered for the exact values found for each scenario.

8. Conclusion

This paper presents an analysis of social cost changes simulating in several scenarios. The implementation of carpooling incentives or external shocks affecting the demand have been tested. The social costs are composed of four main components: consumer's cost, externalities, public authorities' deficit and private profits.

The results show that consumer's cost constitutes the majority of the total social cost with values commonly used. Values given to externalities seems too low to have an impact on the total 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, they also have an interest in keeping a high number of cars on the road to benefit from more revenues from taxes.

Consequently, the private platform scenario is one of the best scenarios tested – from the total social cost perspective – whereas it is the one with the lowest car occupation rate and the highest number of car-kilometer. This result underlines the difficulty to make low-emission scenarios economically efficient considering the current values of externalities.

Moreover, our results show a substantial spatial heterogeneity of policy impacts. As an example, incentive measures towards carpooling alternatives should not be implemented where public transport supply is already a good alternative to car. On the other hand, deploying a carpooling alternative when public transport alternative does not exist is an excellent measure to mitigate consumer's cost when a negative exogeneous shock happens, such as a fuel price increase.

This study tends to show promoting 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 to provide 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.

Appendix

Table: Total social cost composition detail (in €/capita)

Scenario		Baseline	LANE	HOV	FP+	Priv LANE
Modal Shares						
		41%	34%	29%	33%	34%
	DS	(62%)	(63%)	(58%)	(59%)	(63%)
		30%	39%	42%	37%	39%
	DCP	(9%)	(10%)	(13%)	(11%)	(10%)
	PCP	9%	10%	13%	11%	10%
	PT	20%	18%	17%	19%	18%
Total social cost		14,92	14,85	15,00	15,32	14,81
Consumer's cost						
	TOTAL	16,84	16,75	16,83	17,90	16,77
Per mode	Solo Driv	9,29	9,44	9,08	9,78	9,55
	Cp Driv	1,32	1,22	1,37	1,50	1,17
	Cp Pass	2,06	2,41	2,89	2,66	2,36
	Pub T	4,18	3,69	3,48	3,96	3,70
At individual level						
Solo	Total	15,19	15,23	15,80	16,67	15,23
Driv	Travel Time	4,65	4,66	4,96	4,65	4,66
	TT Variability	4,72	4,74	5,05	4,73	4,74
	Cost	5,82	5,83	5,79	7,28	5,83
Cp						
Driv	Total	14,13	12,16	10,74	13,58	12,15
	Travel Time	3,44	3,45	2,72	3,45	3,45
	TT Variability	4,66	4,68	3,95	4,69	4,68
	Detour Time	0,25	0,25	0,27	0,22	0,25

	Cost	5,77	3,78	3,80	5,22	3,78
<hr/>						
Cp						
Pass	Total	22,05	24,09	22,69	24,14	24,58
	Travel Time	3,44	3,45	2,72	3,45	3,45
	TT Variability	4,66	4,68	3,95	4,69	4,68
	Wait Time	1,75	1,76	1,76	1,76	1,76
	Access Time	1,90	1,90	1,92	1,91	1,90
	Egress Time	6,78	6,79	6,81	6,80	6,78
	Connections	2,91	2,92	2,93	2,93	2,92
	Cost	0,60	2,60	2,61	2,60	3,10
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Pub T	Total	20,96	20,87	20,80	20,94	20,87
	Travel Time	6,90	6,84	6,80	6,89	6,84
	TT Variability	1,96	1,93	1,91	1,94	1,93
	Wait Time	1,41	1,41	1,41	1,41	1,41
	Access Time	4,73	4,75	4,74	4,75	4,75
	Egress Time	3,73	3,75	3,75	3,75	3,75
	Connections	1,43	1,40	1,38	1,42	1,40
	Cost	0,80	0,80	0,80	0,80	0,80
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Externalities						
	TOTAL	1,64	1,69	1,65	1,63	1,69
	Local pollutants	0,17	0,18	0,17	0,17	0,18
	Noise	0,32	0,33	0,32	0,32	0,33
	Accidents	0,79	0,81	0,79	0,78	0,81
	Climate change	0,36	0,37	0,37	0,36	0,37
	CO2 (g)	3607	3708	3651	3589	3726
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Public Deficit						
	Total	-2,22	-2,22	-2,15	-2,90	-2,25

Fuel Taxes	-1,57	-1,61	-1,57	-2,29	-1,62
Corporate Taxes	-0,53	-0,55	-0,53	-0,53	-0,56
Road wear	0,08	0,08	0,08	0,08	0,08
Income Pub Trprt	-0,19	-0,17	-0,16	-0,18	-0,17
Ptfm Subsidy	0,00	0,03	0,03	0,03	0,02
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Private deficit					
Total	-1,33	-1,37	-1,33	-1,32	-1,41
Highway profit	-1,33	-1,37	-1,33	-1,32	-1,37
Platform profit	0,00	0,00	0,00	0,00	-0,04
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Number of Veh.km	25,41	26,13	25,52	25,28	26,25
Occupancy rate	1,13	1,14	1,18	1,16	1,13

Notes: Modal shares between parenthesis are effective modal shares considering carpool drivers who cannot find a carpool passenger become solo drivers. 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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CONCLUSION

Main results

This manuscript deals with carpooling for daily trips, addressing mainly the issues of individuals' preferences toward carpooling and its potential benefits for the community. Our results are mainly based on a stated preference survey designed to address the first research objective, which was, as a reminder: "*understanding individual choice mechanisms towards carpooling for daily trips*".

Given the results presented in Chapter I, it seems that solo driving commuters are difficult to convince to switch to carpool – with VoTs in carpooling around 50% higher than solo driver VoT. This is especially the case for the passenger mode even though the VoT is not higher than the one of carpool drivers. Indeed, the alternative specific constant of this mode is always estimated lower³⁶ than driver modes, suggesting the preference for the latter is not based on time characteristics. One of the most frequently cited objectives for introducing carpooling incentives is to reduce the number of vehicles on the road, particularly at peak hours, in order to reduce the nuisances caused by congestion and environmental pollutions. However, this reduction in traffic is only possible if current drivers become future passengers. The traffic reduction hoped for by incentive measures therefore does not seem to be a guaranteed outcome.

Furthermore, the heterogeneity of the respondents shows that a typology of drivers can be drawn up, in which we could only hope to find carpool passengers for one group out of four in the population, representing around one third of the population surveyed. An additional issue comes from the fact that these individuals would also be willing to leave their cars and take

³⁶ Or not significantly different for some models

public transport. Local authorities will therefore need to ensure that passenger carpooling and public transport do not compete too much, to avoid the implementation of ineffective public policies.

Chapter II of this manuscript also analyzes individual preferences, focusing more on the organizational factors of carpooling. It shows that carpooling platforms play a positive role on individuals' propensity to carpool. The results even go beyond our hypotheses, since we find small or even non-significant differences between carpooling with someone met on a platform, and carpooling with a close friend or colleague. Moreover, carpooling platforms seem to be more efficient for passengers than for drivers, with a willingness to pay (WTP) around 4€ for drivers and 7€ for passengers to meet their carpooler via a carpool platform rather than hitchhiking. They could therefore play a key role in overcoming the barriers specific to passenger carpooling. Despite being an almost non-existent form of carpooling at the time of the survey, the real-time carpooling platform also obtained good results, suggesting that this type of platform has the potential to reassure individuals at least as much as the "planned" platforms to which they are yet more accustomed. Regarding the effects of carpooler profiles, it seems that women are more sensitive than men to the gender of their carpooler – with a WTP around €3.5 to have a female carpooler rather than a male, whereas male respondents also prefer female carpoolers, but this effect is measured only at €0.5 on average. Women are also more likely than men to accept to carpool as passengers.

In addition, a better understanding of these individual preferences enabled us to calculate costs and benefits more accurately, in order to measure social welfare framework. This brings us to the second research objective of this manuscript: « *assessing the impact of carpooling incentive policies or exogeneous economic shocks for the community* ».

To follow up on the latest results quoted in Chapter II on gender differences, it seems that carpooling programs could be more effective when implemented in a predominantly female environment, such as hospital sites in the French case. Chapter II also discusses the contradiction between what seems necessary from a social welfare point of view – i.e. paying passengers rather than drivers – and what is currently practiced in carpooling platforms nowadays. Furthermore, it seems difficultly acceptable from drivers' perspective to pay to a carpooler in their car.

The results from a social welfare perspective are discussed in greater detail in Chapter III. The results are quite surprising, since they seem to indicate that the most acceptable situations are those with the fewest carpoolers. Indeed, the costs to society of having one car on the road are outweighed by the benefits obtained by private companies and public authorities. Moreover, the results show highly differentiated potential impacts of policies on a spatial scale, with very different results from the same policy on different routes. Carpooling incentive policies may even have adverse effects on some routes, increasing the number of cars on the road, which contradicts the stated objectives of carpooling public policies. On the other hand, encouraging carpooling can be highly beneficial in the case of an exogenous shock such as an increase in oil prices, mitigating its negative impacts. Carpooling therefore has the potential to be a resilience measure to maintain a high level of transport service at lower cost. Overall, it is not clear-cut whether carpooling for daily trips should be encouraged or not. An analysis must therefore be carried out before any policy is put in place, to ensure that it is adapted to its local context.

Limitations

The limitations of the results presented in this thesis are mainly due to the nature of the methodologies employed. Thus, our results on individual preferences are based on the results

of our stated preference survey, assuming that respondents would have made the same choices in the survey as in a real situation. This is called “hypothetical bias”, which commonly lead to overestimated WTPs or VoTs.

Moreover, the analysis of these choices was mainly made through logit models. These models themselves suffer from limitations when it comes to their predictive capacity, especially when they do not take individual heterogeneity into account as in the “Red Bus/Blue Bus Paradox”³⁷. The logistics function also becomes highly inelastic when the alternatives have very different utility levels. This effect can also lead to a demand still existing at overestimated price levels, such as the profit-maximizing scenario in Chapter II.

Furthermore, our welfare analysis in Chapter II is based on a hypothetical reference situation in which we defined transport supplies, which ignores potential spatial heterogeneities leading potentially to other optimal price levels. Our scenarios are then applied on this situation and does not consider induced demand – which could affect congestion and/or carpoolers’ waiting times. In the Chapter III, we use a social cost approach on realistic transport supplies over the eastern Lyon area, allowing this time for spatial heterogeneities in our simulations. However, we did not consider congestion in this chapter. Indeed, individual modal choices in an area can theoretically affect supplies in other areas of the zoning. Hence, transport supply and demand levels at each point in the zoning are indirectly connected and can also have an impact on induced demand that is not consider in Chapter III either.

We could also mention the lack of external validity of these results as a limitation. First, our stated choice experiment presents limited information on the carpoolers. Contrary to what

³⁷ For a development of this paradox, see McFadden, D., Tye, W. B., & Train, K. (1977). *An application of diagnostic tests for the independence from irrelevant alternatives property of the multinomial logit model*

they face in real carpooling platforms, respondents had no information about their carpooler's peer rating or comments, which limits the analysis of perceived risk. Second, we also lack of information on carpooling operating costs for platforms, or implementation and monitoring costs of carpool facilities such as an HOV-lane for public authorities. Hence, this may have led us to underestimate – or even not consider – these costs in our social cost analysis.

Furthermore, our sample is not perfectly representative of the population of the Lyon region, nor of France population. However, both the literature and the results of this thesis show that analysis can vary by country, region and even on a smaller spatial scale. This latter limitation is more a result of this thesis work, which shows that a case study findings cannot be directly converted into applications in every context.

Future Research and Perspectives

As I conclude this thesis manuscript, some lacks mentioned in limitations above could be enhanced. We could, for example, propose a traffic model that considers both congestion and spatial disparities to estimate the real potential (or lack of it) of carpooling to reduce congestion at peak hours, also considering the potential induced demand from outside the zoning under study. Such a model could also account for the ability of carpooling to offer an alternative transport supply with wider time windows than public transport timetables.

We could also address the question of optimal allocation of individuals in carpooling. In response to the results of Chapter II, we might ask: is it better for the community if women carpool only with other women? Splitting up the population this way could lead to higher waiting times and potential "perfect match" misses from a spatial and temporal point of view.

More detailed results could be provided on the monetary valuation of elements that have

been mentioned in the literature as having an impact on the choice of carpooler: rating system/identity check/comments/photos, etc. Another SP survey would therefore be needed to estimate a monetary valuation of each determinant presented on carpooling platforms previously mentioned.

Finally, I am also wondering how these results can be compared to other shared vehicles and generalized in the future. Especially in a context where the transport sector is set to potentially significantly change for daily commuting, with the European Union banning the sale of combustion-powered vehicles by 2035, and potentially fewer vehicles on the road and more shared trips. It could therefore be interesting to assess whether the values we obtain here for carpooling are comparable for other shared vehicles, such as on-demand services or shared autonomous vehicles.

Abstract

This thesis focuses on the determinants of behaviors leading to the practice of carpooling in daily mobility, as well as the issues associated with this practice at the collective scale. This study is mainly based on the results of a stated preference survey built up at the beginning of the thesis in order to better understand individuals' transport mode choices. The thesis is structured in three chapters. The first chapter deals with individual preferences for carpooling in daily mobility, with a particular focus on solo-driving commuters. The second chapter looks specifically at the role played by different ways of organizing carpooling, such as the presence of a carpooling platform, or the profile of the potential carpooler. This chapter also proposes a preliminary analysis of these effects and of carpooling incentives at community level. The third chapter assesses the impact of exogenous economic shocks or incentives on daily carpooling, through an analysis of the social cost of the trips. The results in Chapter I show that time seems to be valued higher in carpooling than in solo driving, and that individuals are more likely to carpool as drivers than as passengers. This indicates that the number of drivers is unlikely to fall, refuting the hypothesis that more carpooling would automatically lead to lower road traffic and emissions. The findings of Chapter II suggest that carpooling platforms appear to be effective in reducing the perceived risk of carpooling, even more for passengers than for drivers. Women are also more sensitive to their potential carpooler's gender, with a preference for carpooling in the company of another woman (excluding relatives). The ideal situation from the community's point of view would be for passengers to be paid and drivers to pay to carpool, which goes against what seems acceptable at the individual level for drivers. Chapter III is based on transport supply data from the eastern part of Lyon (France). It shows that the costs of trips carried at the individual level are much higher than those of private companies, public authorities and traffic externalities. In addition, the exogenous shocks and incentives tested had highly differentiated impacts at the spatial level, with cases where carpooling incentives could lead to negative environmental outcomes. This suggests that the local context and potential spatial inequalities should be carefully considered before implementing a daily carpooling policy.

Keywords: Daily carpooling, individual preferences, mode choice, cost-benefit analysis, public policies