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Economic and non-economic incentives for modal shift toward sustainable mobility solutions

Fawaz Salihou

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Economic and non-economic incentives for modal shift toward sustainable mobility solutions

*Incitations économiques et non-économiques au report modal vers des
solutions de mobilité durable.*

Thèse de doctorat de l'université Paris-Saclay

École doctorale n°573 : interfaces : matériaux, systèmes, usages (INTERFACES)
Spécialité de doctorat : Ingénierie économique
Sciences de l'ingénierie et des systèmes, Référent : CentraleSupélec

Thèse préparée au LGI (Université Paris-Saclay, CentraleSupélec), et à l'institut
VEDECOM

sous la direction de **Pascal Da Costa**, Professeur,
le co-encadrement de **Julie Bulteau**, Maître de conférences,
le co-encadrement de **Rémy Le Boennec**, Chargé de recherche,
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Thèse soutenue à Paris-Saclay, le 28 mars 2023, par

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Titre : Incitations économiques et non-économiques au report modal vers des solutions de mobilité durables.

Mots clés : Incitations économiques ; Incitations non-économiques ; report modal ; externalités négatives

Résumé: Malgré ses avantages, le transport routier génère des externalités négatives telles que la pollution atmosphérique, la congestion, les accidents de la route et le bruit. Face à l'urgence climatique, ces externalités négatives doivent être réduites en favorisant le report modal de l'autosolisme vers des modes de transport plus durables tels que le covoiturage, les transports publics et les modes actifs. Cette thèse examine comment promouvoir le report modal vers des modes de transport plus durables pour les déplacements domicile-travail et l'éducation et est divisée en trois chapitres.

Le premier chapitre fait une revue la littérature sur les incitations vers le modal de l'autosolisme vers des solutions de mobilité durable. Il montre qu'il existe deux formes d'incitations (économiques et non économiques) qui, lorsqu'elles sont appliquées isolément, ne peuvent être efficaces que dans certains contextes et présentent des limites. Une combinaison d'incitations est nécessaire pour encourager le modal vers des solutions de mobilité plus durables.

Le deuxième chapitre analyse la combinaison d'incitations économiques, comprenant les subventions aux employeurs (Forfait Mobilité Durable=FMD) et d'incitations non économiques (nudges, la confiance aux autres pour covoiturer) pour encourager le covoiturage pour se rendre au travail ou à l'école en Île-de-France (région métropolitaine de Paris). Nous montrons que les nudges sont plus efficaces chez les individus plus jeunes et plus éduqués et encouragent ces utilisateurs de la mobilité à covoiturer davantage. L'application de nudges isolés semble être plus efficace pour encourager le covoiturage pour les déplacements domicile-travail que la combinaison de nudges avec des subventions employeurs pour la mobilité durable. Les hommes sont plus susceptibles de faire du covoiturage entre leur domicile et leur lieu de travail ou d'études avec un inconnu que les femmes.

Le chapitre 3 mesure l'intention de choisir des modes de transport plus durables plutôt que l'autosolisme, dans le contexte de moyennes et courtes distances pour les déplacements domicile-travail (ou études) en Île-de-France, sous l'effet d'incitations ou de combinaisons d'incitations. Globalement, les combinaisons d'incitations économiques et non économiques sont plus efficaces que les mêmes incitations appliquées isolément. (2) Cependant, il existe des situations de mobilité (distance) et des profils d'usagers de la mobilité pour lesquels des applications isolées d'incitations sont plus efficaces.

Title : Economic and non-economic incentives for modal shift toward sustainable mobility solutions

Keywords : Economic incentives; non-economic incentives; modal shift; negative externalities

Abstract: Despite its benefits, road transport generates negative externalities such as air pollution, congestion, road accidents, and noise. In the face of the climate emergency, these negative externalities must be reduced by promoting a modal shift from private cars to more sustainable modes of transport such as carpooling, public transport, and active modes. This thesis examines how to promote a modal shift to more sustainable modes of transportation for commuting and education and is divided into three chapters.

The first chapter reviews the literature on incentives for a modal shift from private cars to sustainable mobility solutions. It shows that there are two forms of incentives (economic and non-economic) that, when applied in isolation, can only be effective in certain contexts and have limitations. A combination of incentives is needed to encourage a modal shift to more sustainable mobility options.

The second chapter analyzes the combination of economic incentives, including employer subsidies (Forfait Mobilité Durable=FMD) and non-economic incentives (nudges, trusting others to carpool) to encourage carpooling to work or school in the Île-de-France (Paris metropolitan area). We show that nudges are most effective among younger and more educated individuals and encourage such mobility users to carpool more. Applying nudges in isolation appears to be more effective at encouraging carpooling for commuting than combining nudges with employer subsidies for sustainable mobility. Men are more likely to carpool from home to work or school with a stranger than women.

Chapter 3 measures the intention to choose more sustainable modes of transport over solo driving, in the context of medium and short distances for home-to-work (or study) trips in the Île-de-France region, under the impact of incentives or combinations of incentives. Overall, combinations of economic and non-economic incentives are more effective than the same incentives applied in isolation. (2) However, there are mobility situations (distance) and mobility user profiles for which isolated applications of incentives are more effective.

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Contents

General Introduction	9
1.Sustainable mobility.....	11
1.1 Externalities related to the road transport of people.....	15
1.2 Research questions and methodologies.....	22
1.3 Structure of the thesis and publications	25
References.....	29
CHAPTER 1 Incentives for modal shift towards sustainable mo-bility solutions: A review	35
1. Introduction	35
2. Literature review	36
3. Research methods	43
4. Comparison and discussion on incentives for modal shift towards sustainable mobility solutions	51
5. Conclusion.....	54
Appendix 1.....	57
References.....	72
CHAPTER 2 The impacts of combining incentives on carpooling for commuting in Paris Metropolitan area	79
1. Introduction.....	79
2. Literature review.....	81
3. Methodology and results	83
4. Results.....	91
5. Discussion.....	99
6. Conclusion.....	100
References.....	103
Chapter 3 Which combinations of incentives for transitioning towards sustainable mobility solutions for medium and short commuting trips in Ile de France?.....	107
1. Introduction.....	107
2. Literature review	109
3. Methodology	114
4. Results.....	119
5.Discussion.....	139
6.Conclusion.....	141
References.....	143

APPENDIXES.....154
Conclusion and Recommendations..... 161

List of Figures

Figure 1: The three dimensions of sustainability, with alternatives schematic representations	14
Figure 2: Sustainable transportation (by authors)	15
Figure 3: Taxes and emissions.....	19
Figure 4 : Subsidies and emissions	20
Figure 5: Emissions permit market (Source : Bonnieux & Desaignes, 1998)	21
Figure 6: Theory of planned behavior (Ajzen, 1991)	40
Figure 7: Relationship between persuasive technologies and transport mode choice (Source: prepared by the authors)	43
Figure 8 : Research methodology for the bibliometric analysis (Source: prepared by the authors).....	43
Figure 9: Annual number of articles considering the transportation of people, based on Scopus (Source: prepared by the authors).....	44
Figure 10: Distribution of published articles in the field of individual transportation, by subject area (Source: Scopus)	45
Figure 11: Method of journal selection.....	47
Figure 12: Methodology for the selection of articles (economic incentives	49
Figure 13: Methodology for the selection of articles (non-economic incentives)	51
Figure 14: The administrative organization of the Ile-de-France region.....	85
Figure 15: Nested structures	118
Figure 16: Impact of incentives in relation to respondents 'age for carpooling.....	128
Figure 17: Impact of incentives in relation to income per household for carpooling.....	128
Figure 18 : Impact of incentives in relation to level of education for carpooling.....	128
Figure 19: Impact of incentives in relation to people per household for	

carpooling.....	128
Figure 20 : impact of incentives in relation to respondents 'age for public transport.....	129
Figure 21: Impact of incentives in relation to income per household for public transport	129
Figure 22: impact of incentives in relation to level of education for public transport.....	130
Figure 23: impact of incentives in relation to people per household for public transport	130
Figure 24 : Impact of incentives in relation to place of residence for public transport.....	130
Figure 25: Impact of incentives in relation to respondents' age for carpooling.....	132
Figure 26: Impact of incentives in relation to income per household for carpooling.....	132
Figure 27: impact of incentives tin relation to level of education for carpooling.....	132
Figure 28: Impact of incentives in relation to people per household for carpooling.....	132
Figure 29: Impact of incentives in relation to place of residence for carpooling.....	132
Figure 30: Impact of incentives in relation to respondents 'age for public transport.....	133
Figure 31: Impact of incentives in relation to income per household for public transport	133
Figure 32: Impact of incentives in relation to level of education for public transport	
Figure 33: Impact of incentives in relation to people per household for public transport.....	134
Figure 34: Impact of incentive in relation to place of residence for public transport	

Figure 35: Impact of incentives in relation to respondents'age for cycling.....135

Figure 36: Impact of incentives in relation to level of education for cycling135

Figure 37: Impact of incentives in relation to people per house hold for cycling.....135

List of Tables

Table 1: Pollutants and their effects. (source: Santos et al., 2010)	16
Table 2: Structures of thesis.....	26
Table 3: List of academic articles on the impact of psychological factors on modal shift towards sustainable mobility solutions	41
Table 4 : List of the journals with the highest number of publications	46
Table 5: Economic incentives.	57
Table 6: Non-economic incentives.	66
Table 7: Descriptive data on the sample (N=1326)	87
Table 8: Scenario without incentives	90
Table 9: Scenario with nudge as a non-economic incentive	90
Table 10: Multinomial Logit Model (M1).....	93
Table 11: Binomial logit models (M2-M3-M4).....	97
Table 12: Specific attributes.....	115
Table 13: Nudge scenario for short distance commuting trips (7 km)	115
Table 14: Health impact scenario for short distance commuting trips (7 km).....	116
Table 15: Summary of profiles that are sensitive economic and non-economic incentives to use carpooling and public modes for medium-distance trips.....	138
Table 16 : Summary of profiles that are sensitive economic and non-economic incentives to use carpooling, public transport and electric bikes for short distance trips	138

GENERAL INTRODUCTION

Overview

Today, there is no doubt that climate change is real, with natural disasters occurring in many countries. Every day during the previous 50 years, a climatic or hydrologic calamity has been reported (WMO, 2021). Cities, especially urban areas, contribute significantly to climate change. They represent economic opportunities, accounting for 80% of global gross domestic product, on the one hand, but challenges in terms of global climate change response, as they are responsible for 70% to 76% of greenhouse gas (GHG) emissions due to final energy use worldwide (Green Climate Fund, 2019), on the other hand. The United Nations Framework Convention on Climate Change (UNFCCC) shows that cities could reduce GHG emissions in key sectors by 24% by 2030 and 47% by 2050 through concrete measures aimed at decarbonized and climate-resilient development at the local level (Erickson & Tempest, 2014). The mobility and urban transport sector are one of them, as it has negative impacts on the environment, such as greenhouse gas emissions and air pollutants, noise, land artificialization, with the effects of cutting off ecosystems linked to infrastructures, then affecting biodiversity, and besides leading to congestion and road insecurity (Ministry of Ecology and Sustainable Development, 2006). In this PhD thesis, I seek to understand how local authorities or governmental authorities could limit the environmental pressures of road transport. The methodology used in this thesis is the econometric evaluation of mobility and modal shift policies, through discrete choice experiments, applied to surveys of urban and peri-urban sites in France. This chapter presents the underlying ideas of my work by defining sustainable mobility in the first section of this chapter. In the second section, we show how to internalize the negative externalities of road transport. The chapter concludes by outlining the structure and main contributions of this thesis.

1. SUSTAINABLE MOBILITY

The concept of sustainable mobility arose as a result of the introduction of the concept of sustainability in a variety of sectors, including transportation. The term "*sustainable development*" was first used in the report by the World Conservation Union (IUCN, 1980), and it was defined and popularized in the Brundtland Report (United Nations, 1987), which was initiated by the United Nations Commission on Environment and Development. This report specifies sustainable development as development that meets current needs without compromising future generations' ability to meet their own. Sustainability was conceptualized as a holistic approach based on three interdependent dimensions at the 1992 *Rio Earth Summit*: environment, economy, and society (Figure 1). The alternative schematic representations are well known, and it is clear that they reflect quite different approaches, particularly in the place that the

environment should occupy in relation to other spheres. In its most common form (Figure 1.a), achieving total sustainability requires striking a balance between the three dimensions. The environmental dimension refers to the preservation of finite natural resources. The social dimension is defined as the ability to meet all basic human needs while promoting social equity. In terms of the economic dimension, it enables us to reconcile the pursuit of growth objectives with economic efficiency.

Since 1992, the international summits organised by the UN have followed one another. The Earth Summit held in Johannesburg in 2002, resulted in the signing of a treaty on natural resource preservation and biodiversity conservation. The Kyoto Protocol, prior to the above, which entered into force in 2005, establishes concrete targets for achieving certain sustainable development principles, primarily the reduction of greenhouse gas emissions from developed countries (so-called Annex 1 countries). To summarize, sustainability is the preservation of natural resources. Stiglitz (1997) believes that natural environmental destruction is unavoidable (notably through the limitation of fossil resources leading to their disappearance), and that capital growth can compensate for this loss. Other authors, on the other hand, argue that capital should not be substituted for natural resources because they are critical to our survival (Pearce *et al.*,1989). Thus, Ayres *et al.* (1998) distinguish between two types of sustainability: weak and strong. Weak sustainability assumes that the next generation will inherit a stock of wealth that is equal to or greater than the stock inherited by the previous generation, including both human-made and natural assets. Strong sustainability assumes that the next generation will inherit an equal or greater stock of environmental assets than the previous generation. Faced with climate change, these various approaches agree on the fact that we must reduce our greenhouse gas emissions, only the speed of the reductions to be implemented differs (*cf.* the discussions and controversies around the Dice model¹ in particular, concerning the monetary value of damages, the value of the social discount rate, irreversibility effects and their thresholds, etc.).

These concepts and events have aided in integrating sustainability in various areas, including transportation. However, there is no international agreement on what constitutes sustainable mobility yet. In 1997, the Center for Sustainable Transportation in Toronto defined *sustainable transportation* as a system:

1. One that enables individuals and societies to meet essential access needs in ways that are safe and compatible with human and ecosystem health and intergenerational equity.
2. Is inexpensive, efficient, offers a variety of transportation options, and contributes to a thriving economy.

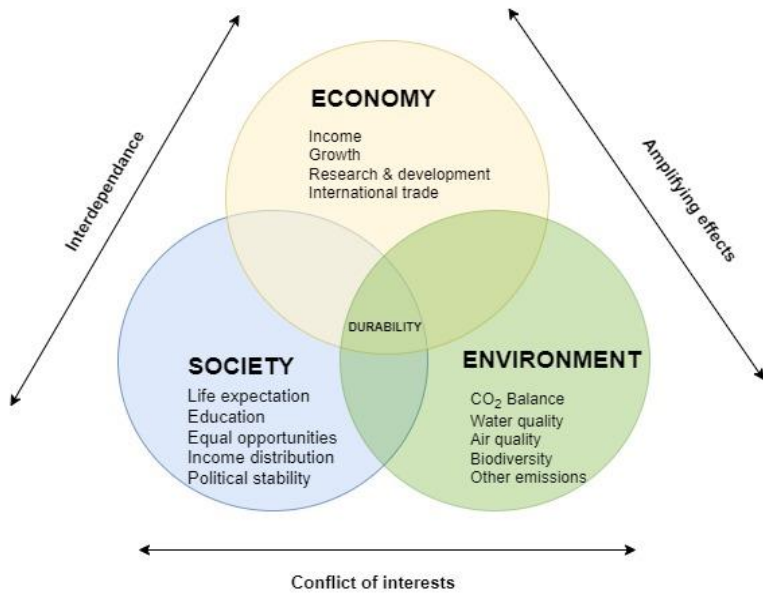
¹ Nordhouse (2008) developed the Dynamic Integrated Climate Change (DICE) model, which assumes that a single global producer must choose the levels of three concurrently determined variables: current consumption, investment, and greenhouse gas reduction.

3. Limits emissions and waste so they do not exceed the planet's ability to absorb them; Minimize consumption of nonrenewable resources; Limits consumption of renewable resources per sustainable development principles; And reuses and recycles its components while minimizing noise and land use.

According to the OECD (1998), environmentally sustainable transportation does not endanger public health or ecosystems. Furthermore, it seeks to meet accessibility needs by utilizing renewable resources in a manner that does not exceed their capacity to renew themselves, as well as utilizing non-renewable resources in a manner that does not exceed the capacity of alternative resources. *Sustainability* in transportation is defined by the International Association of Public Transportation (UITP) as “making decisions that consider their effects in terms of social justice, environmental protection, and economic sense” (UITP, 2007). Although the concepts of transportation and sustainable mobility are used for similar purposes, there is a minor distinction in their definitions.

Transportation refers to the transportation systems that allow people and/or goods to move, whereas mobility refers to what moves. In short, sustainable transportation refers to efforts directed toward infrastructure and vehicles, whereas sustainable mobility refers to efforts directed toward individual behaviors. According to Stephenson *et al.* (2018), sustainable transportation is any combination of government policies, infrastructure, technologies, and behaviors that reduce negative externalities (both environmental and social) while maintaining or improving economic outcomes (Figure 2). The paradigm of sustainable mobility presented by Bannister (2008) includes initiatives such as decreasing the need to travel, supporting modal transition, and shortening the length of trips.

(a)



(b)

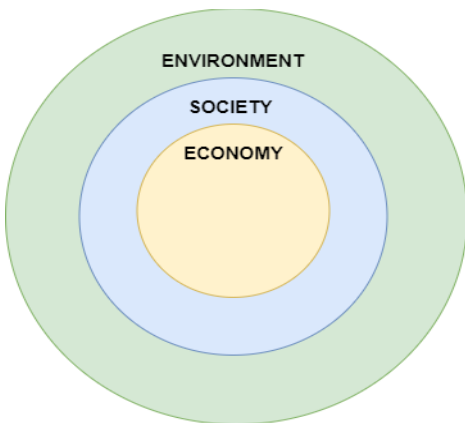


Figure 1: The three dimensions of sustainability, with alternatives schematic representations

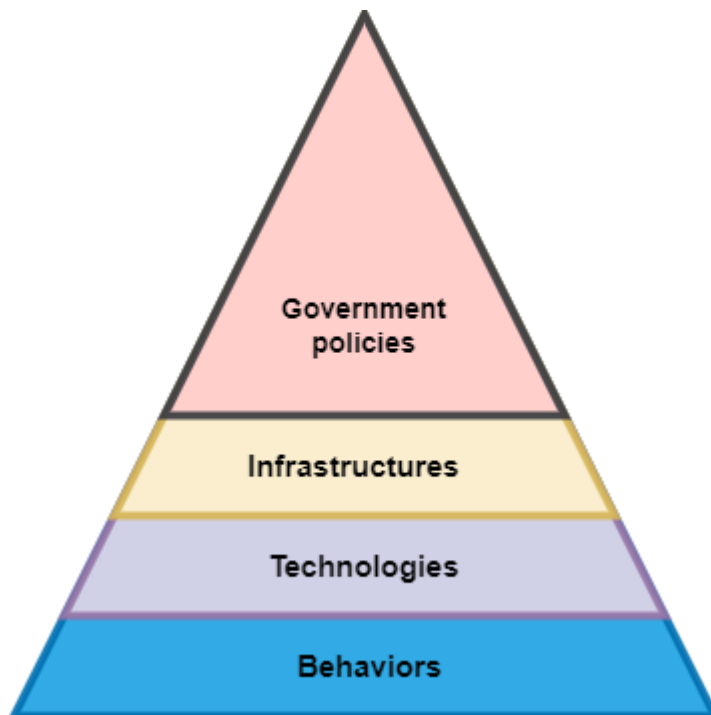


Figure 2: Sustainable transportation (by authors)

1.1 EXTERNALITIES RELATED TO THE ROAD TRANSPORT OF PEOPLE

1.1.1 Externalities

During the second part of the twentieth century, there was significant growth in passenger and cargo movement, primarily by road (MEDD, 2006). Between 2000 and 2019, land-based passenger transport grew by 16.6% and freight transportation by road, rail, inland waterways, and oil pipelines grew by 22% more than passenger transportation (EAA, 2022). In France, domestic passenger transport increases from 957.3 to 988.3 billion passengers between 2014 and 2019 (SDES, 2021). The increase of road transport is responsible for some negative externalities. *Externalities* are defined by economists as the result of one actor's production (or consuming) activity affecting the wellbeing (or profits) of another without either agent getting or paying compensation for that effect (Pigou, 1920). In this thesis, the focus is on the negative externalities related to passenger transport. These negative externalities are environmental damages, congestion, and road accidents.

- **Environmental damage**

The environmental damage related to the road transport of people mainly considers greenhouse gas emissions, particulates matter, and noise. These externalities are the ones that have been best monetized and quantified (Santos *et al.*, 2010). The World Health Organization has shown that road transport noise affects the health of almost one-third of the population in Europe (WHO, 2007). The consequences of noise are

hearing and sleep disorders in the short term. In the long term, noise leads to cardiovascular diseases, hormonal stress, immune system deficiencies, and reduced performance at work or school (WHO, 2007). In France, the social cost of noise related to road transport represents 54.8% of the total social cost of noise per year (ADEME, 2021). Most energy consumed by road transport comes from fossil fuels (Santos *et al.*, 2010). Several air pollutants from the combustion of these fossil fuels have various environmental and health effects. Air pollution causes between 28,000 and 36,000 premature deaths in the United Kingdom each year (Sustrans, 2020). Table 1 lists these different pollutants and their effects.

Table 1: *Pollutants and their effects. (source : Santos et al., 2010)*

Pollutants	Environmental and health effects	Authors
<i>Nitrogen oxides (NO_x)</i>	The human respiratory system can be harmed by nitrogen dioxide. It helps to generate ozone, a highly hazardous secondary pollutant in the lower atmosphere. In urban locations, high ozone levels increase the likelihood of respiratory ailments and eye, nose, and throat irritations.	UK DfT (2007 a, p. 51) ; Santos <i>et al.</i> , (2010)
<i>Hydrocarbon (HC)</i>	Hydrocarbons (HC) cause eye and throat irritation and coughing. Hydrocarbons are also destructive to crops and trees.	Banister (1998); Santos <i>et al.</i> , (2010)
<i>Carbon monoxide (CO)</i>	Sulfur dioxide has a negative impact on the respiratory tract, especially in people who already have asthma or chronic lung illness. It is also to blame for acid rain.	Banister (1998); UK DfT (2007 a, p. 51), Santos <i>et al.</i> ,(2010)
<i>Particulate matter (PM)</i>	PM10 and PM2.5 are the two main types of particles. They are linked to various negative health consequences, including chronic cardiovascular disease,	Bell <i>et al.</i> , (2004)

	decreased lung function, and early death.	
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- **Congestion**

Traffic congestion is an important urban transportation problem that can stifle economic growth (Douglas, 1993). Traffic congestion can be defined in terms of demand, delay, and cost (Nguyen-Phuoc *et al.*, 2020). Congestion is a condition that occurs when the number of cars attempting to use a road at any given time exceeds the capacity of the roads to carry the load at generally acceptable levels of service (Rothenberg, 1985). Congestion means that there are more people attempting to use a specific transportation facility at a given time than the facility can handle with acceptable levels of delay or discomfort (Meyer, 1997). Finally, in terms of cost, traffic congestion indicates the additional costs incurred due to the interference of road users (Litman, 2022). Congestion causes slower speeds, longer travel times, and higher per-kilometer expenditures. It also imposes external costs on all other users (Santos *et al.*, 2010). The entire cost of traffic congestion would exceed 350 billion euros between 2013 and 2030 in France, according to an INRIX analysis. The annual bill for France will be 22 billion in 2030, a 31% increase over the current scenario.

- **Road accidents**

Road accidents represent an externality of road transport that generates other negative externalities. Newbery (1990) points out that these negative externalities occur when additional vehicles on the road increase the probability that other road users will be involved in an accident. He shows that there is compensatory behavior on the part of drivers to slow down their driving speed, and cyclists and pedestrians to be more careful. This compensatory behavior is due to increased congestion and is costly (Parry *et al.*, 2007). External costs of accidents may include property damage, legal and court costs, police and fire department costs, medical costs, lost earnings, and transportation costs, and the pain, grief, and suffering imposed on the victims, and their friends and families (Maibach *et al.*, 2008). According to the French Observatoire National Interministériel de la Sécurité Routière (ONISR), 2944 individuals were killed in road accidents in 2021 in France, a 16% rise from 2020. Motorist road deaths are reduced in 2021, with 1,414 fatalities (208 fewer fatalities or -13% fewer than in 2019 and 171 more fatalities or +14% fewer than in 2020). According to Statistica (2022), the cost of road accidents in France, in 2018, represents 44.1 billion euros; Material accidents represent 10.7 billion euros, and bodily injury accidents 33.4 billion euros.

1.1.2 Internalization of negative externalities

When there are negative externalities, the market cannot, automatically or by itself, reach the social optimal equilibrium (Pigou, 1920). To internalize these externalities, according to the academic field of public economics, several initiatives by public authorities are required. To be more precise, following the principles of environmental

economics, the methods of internalizing environmental externalities can be divided into two categories: Control-and-command policies, and incentive policies (Santos *et al.*, 2010).

A command-and-control policy is a method of achieving the lowest possible level of pollution. The regulator can set a maximum level of activity that causes it or limit the behavior of agents. A violation may be accompanied by a penalty. A control and command policy in transportation may be a standard that sets the emission threshold. The European Union's Euro emissions norm's, implemented in 1988, are one example. According to Button (1990), these measures produce predictable results and are simple to execute, but they are rigid and do not provide incentives beyond the statutory requirement. Another example of a command-and-control policy is the European commission's "Green Deal," which brings together standards to achieve climate targets by 2050. The green deal was presented by the European Commission in December 2019 and approved in December 2020. In terms of reducing CO₂ emissions in the context of mobility, the European Commission proposes reducing emissions from cars by 55%, emissions from light commercial vehicles by 50% by 2030 and zero emissions from new cars by 2035. Based on these targets, several standards have also been proposed. This is the case with the Euro 7 standard, which guarantees the marketing of low-emission vehicles only. Low Emission Zones are another norm that reduces CO₂ emissions (LEZ). This standard, which has already been applied in various French cities (Toulouse Metropole, Greater Paris Metropole, Aix-Marseille-Provence Metropole, Grenoble), intends to enhance air quality. It restricts the movements of certain vehicles. Diesel vehicles will be prohibited from the Greater Paris LEZ in 2024. Only vehicles fulfilling Euro 5 and 6 criteria (with Crit'Air 1, 2, or green badges) will be permitted to drive in the LOZs beginning in January 2025. The ban on driving in the EPZ affects heavy cargo and light commercial vehicles in Grenoble and Lyon.

Incentive policies include economic incentives that can directly alter the private utility or private benefit of a given behavioral response of targeted agents, Santos *et al.* (2010). A price is therefore set for a good or activity. Incentive policies can be in the form of a Pigouvian tax, subsidy or tradable emission permit that can lower the externality level. Pigou (1920) initiates this environmental tax, a taxation system that internalizes the negative externalities of environmental pollution. This taxation system is based on the "polluter pays" principle, decreed by the OECD in 1972. Noted τ , this tax is a fixed amount that equals the marginal social damage Dm of environmental pollution, if the emission volume is optimal. It is considered that the firm will continue to pollute as long as its marginal cost of emissions (τ) is lower than the marginal cost of depollution (Cm_j). Since the firm's objective is to maximize its profit, the quantity of pollutant discharge will be the same as that reached at the optimum ($Q_j=Q_j^*$) (Figure 3).

As an example of tools such as the tax on transportation, we have the gasoline tax. Specifically called "Taxe Intérieure de consommation sur les Produits Energétiques" (TICPE) in France, it is the leading domestic consumption tax collected. It concerns not

only energy products of petroleum origin but also energy products. The legal framework of this tax was defined at the European level by the directive 2003/93/CE of the council of October 27, 2003, and (EU) 2020/262 of December 19, 2019, covering all energy products as well as electricity (Ministry of the Energy Transition, 2023). Another tool implemented in the road transport context to internalize externalities is the congestion charge, more specifically "urban tolls". The congestion charge requires motorists to pay a tax to access or drive in some urban regions, mainly in city centers (ADEME, 2016). There are three types of tolls: financing, decongestion, and environmental tolls. The objective of financing tolls is to provide economic means to the infrastructure operator so that it can cover the investments made and possibly develop the road network. This is the case with the Oslo toll, which varies from €3.50 to €10.80 per trip. Congestion charging and environmental charging differ in the objective behind the toll. However, they are both based on the same objective of directing motorists towards cleaner modes of transport by changing the price signal of their journey. Congestion charging allows road users to pay for the time they waste on other users. This is the case with the London toll, which costs €17 per trip. The environmental toll allows users to pay for the environmental nuisance they cause to the area inhabitants who live and work there. The Milan toll is a perfect example. Its tariff per passage is 5 €.

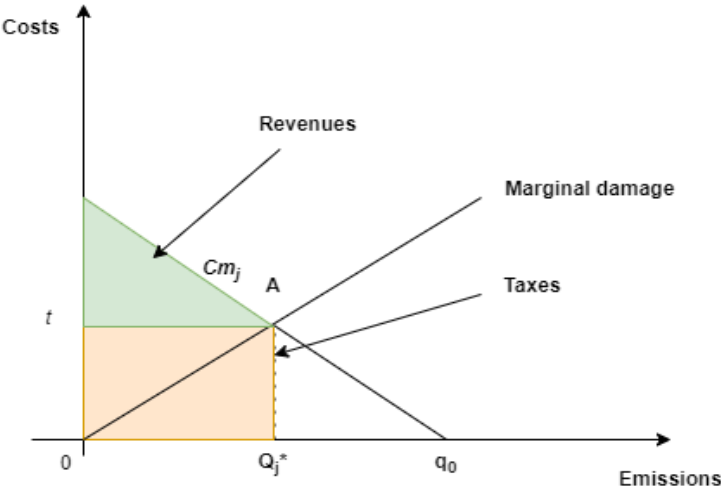


Figure 3: Taxes and emissions

The act of paying for something, or the fear of losing something, generates a sort of coercion that drives people to modify their behavior. This is also true for wages and subsidies. Subsidies are incentives that encourage economic agents to reduce their activity levels by compensating them for their losses (Santos *et al.*, 2010). The polluting agent receives a subsidy proportional S to the reduction in emissions. He will continue

to pollute during his cleanup efforts (Cm_j). When the polluting agent emits the quantity Q_j^* such that $Cm_j = S$ the maximum profit is realized (Figure 4):

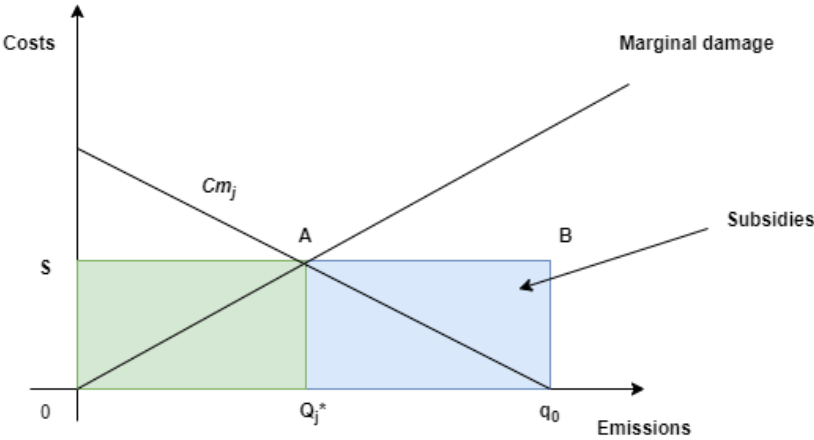


Figure 4 : Subsidies and emissions

User demand can be influenced by quantity as well as price. The system of tradable emission permits is a quantity-based incentive policy. The economic theory of permit markets has its origins in the work of Coase (1960) on external costs, then Dales (1968) on the regulation of water uses, and finally Montgomery (1972) on the formalization of permit markets. In this permit market, agents hold permits (quotas) for using natural resources (pollutant emission permits) that are authorized among themselves during a given period. Allowance players between buyers and sellers take place either on marketplaces, directly or via an intermediary, or over the counter. Public authorities set the overall pollution cap and handle the allocation of permits that can be distributed in various ways (auction, free of charge, etc.). The confrontation between supply and demand determines the price of permits. Figure 5 shows a market for tradable emission permits whose equilibrium is at point E. The total number of permits issued is equal to Q^* and their price is p_q^* . The marginal private benefits of pollution are represented by $Q(t) = B_m$. The damage D_m represents the aggregated supply of permits. The global pollution will be limited to Q^* when the market sets the price which is equal to the level of the marginal costs of damage. Each company will behave as if it were confronted with a tax and will therefore commit to depollution efforts consistent with its technology.

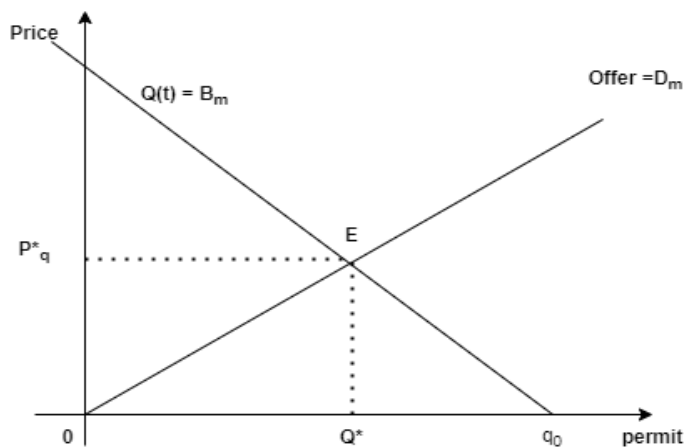


Figure 5: Emissions permit market (Source : Bonnieux & Desaiques, 1998)

Aiming to achieve climate neutrality by 2050, the European Union established the carbon market, also known as Emissions Trading Schemes (ETS), in 2005, to measure, control, and reduce emissions from its industry and electricity producers. The EU ETS was made permanent in the March 2009 energy-climate package adopted at the end of 2008 under the French Presidency. The principle is that EU member states impose a cap on emissions from companies in various sectors. The ETS system started in 2005 and has 4 phases:

- 1st phase of three years (2005-2007)
- 2nd phase of five years (2008-2012)
- 3rd phase of eight years (2013-2020)
- 4th phase of ten years (2021-2030).

Note the ETS was introduced in the air transport sector in the second phase in 2012 (Ministère de la transition énergétique, 2021). Since the price of permits is decided by the confrontation of supply and demand, it rises when there is a high demand for permits. On the European market, the average price of a one-tonne CO₂ allowance has climbed from 37.45 euros in 2021 to roughly 80 euros in 2022. (Oliver, 2022).

Like the instruments used in environmental economics to reduce the negative externalities of road transport, social psychology and behavioral economics also offer tools that can be effective. In social psychology, Ajzen & Fishbein's theory of reasoned behavior (1970), theory of planned behavior (1991), and theory of interpersonal behavior (Triandis, 1977, 1982) show how certain psychological factors influence an individual's behavior or choice. A study conducted by Baca-Motes *et al.* (2012) with hotel guests showed that commitment could lead individuals to publicly and freely express their intention to adopt a specific behavior. The experiment was to have guests sign a form at the front desk upon arrival, stating that they are committed to the environmental protection approach initiated by the hotel. If they accept, they receive a badge symbolizing their commitment. The experiment results showed that 40% of the hotel's towels were reused.

In the context of behavioral economics, a nudge is an effective example of a tool that can be used to encourage sustainable behavior without being coercive. Richard Thaler popularized the concept of nudge based on the work of Daniel Kahneman (Nobel Prize in Economics 2002), who questions human decision-making rationality. He proposes a paternalism that "does not prevent anything or limit people's options," but that can influence. This work earned him the Nobel Prize in Economics in 2017.

Nudge approaches are now numerous and employed in a variety of contexts. It has been used to promote food waste recycling in Sweden (Linder *et al.*, 2018), increase vegetable consumption in Denmark (Friies *et al.*, 2018) and in other countries in Europe, and even in increasing sustainable transportation (Hilton *et al.*, 2014). Singapore's MRT system employs a traffic light system to indicate the level of traffic on the platforms, assisting passengers in making the best decision. Green indicated that they could board the next train. Orange signified waiting for two trains, while red suggested a considerable delay and considering alternative modes of transportation (Ee, 2014). The French transport operator Kéolis has tested nudges in school buses in Isère and Auvergne-Rhone-Alpes to encourage seat belts. The nudge is a foam sheath that covers the seatbelt and makes sitting on the seat particularly uncomfortable without the seatbelt fastened. Applying this nudge had positive and lasting effects on young people, multiplying the use of the seat belt by 2.4 (Bressoux *et al.*, 2018). Nudging will be used to encourage travelers exiting the metro to take the stairs instead of the elevators with simple colored footprints on the ground. This is an initiative of the city of Paris for the next Olympic Games that will be held in Paris in 2024 (Horizons Public, 2018). To encourage users to make a physical effort in Sweden, the website Rolighetsteorin.se in collaboration with the car manufacturer Volkswagen, have transformed the steps of a subway staircase into a giant piano. A pedestrian who uses it can hear piano notes. This nudge has increased the use of the stairs by 66%.

Another form of non-economic incentive used in transport is persuasive technology. Persuasive technologies (Fogg 2002) refer to the application of psychological principles of persuasion (such as credibility, trust, and reciprocity) to interactive media, with the goal of changing user attitudes and behaviors. Reitberger *et al.* (2007) designed a mobile application called "perCues" that aimed to persuade people to use public transportation instead of their cars to reduce emissions. The application contained bus schedules and information on the state of pollution. Another example is Froehlich *et al.* (2009), who developed an application, "UbiGreen" that encourages the use of environmentally friendly transportation such as carpooling, public transport, or walking by providing visual feedback when users reduce their driving.

1.2 RESEARCH QUESTIONS AND METHODOLOGIES

Research question of the thesis

This thesis assembles three research articles in various levels of publication. Through these articles, we wish to answer the following issue: How can we promote a modal shift from solo driving to more sustainable mobility solutions? Generally speaking, modal shift is the change of transport mode. According to Eng-Larsson and Kohn (2012), "*modal shift, is the shift from an all-road to an intermodal road-rail transport solution*". The objective of this thesis is to provide the public decision-maker with fine elements for understanding modal choices in various incentive contexts, and also contributing to the reduction of negative externalities associated with road transportation.

Methodologies, chapter by chapter

To analyse the impact of incentives on sustainable transport mode choice, this dissertation uses several methods. We promptly present the methodology used in each chapter: the first chapter uses bibliometric analysis for review; the second and third chapters use econometrics to conduct case studies on mobility data.

Chapter 1 therefore reviews the literature on incentives for a modal shift from solo driving to more sustainable mobility solutions. A bibliometric analysis compares economic and non-economic incentives in terms of their effectiveness on modal shifts. By economic incentives, we refer to fuel tax, carbon tax, road charges, congestion charges, tradable emission permits, subsidies, etc. which have been outlined in the previous section. By non-economic incentives, we refer to psychological factors, nudges, etc. other than price or monetary signals, which are generally more common or older in the literature. A bibliometric approach uses mathematical and statistical methods to analyze articles quantitatively. It is used to assess the evolution and trend of a field (Ying *et al.*, 2021). Bibliometric analysis has recently gained immense popularity in business research (Donthu *et al.*, 2020). It is generally manifested through two categories: (1) Performance analysis and (2) Scientific mapping (Donthu *et al.*, 2021). For the authors, performance analysis considers the contributions of research components, while science mapping focuses on the relationships between research constituents. In Chapter 1, performance analysis is considered in the context of transportation incentives. Next, a comparative study is made between a selection of articles in the case of economic incentives and the case of non-economic incentives following well-defined criteria. Fifteen papers are selected for each type of incentive (economic and non-economic).

Chapter 2 is a case study that seeks to measure the intentions to change one's behavior by adopting driver or passenger carpooling over solo driving. A mobility survey was conducted with 1502 respondent's representative of the Île-de-France region, including 509 people who drive alone. We are interested in the home-work journey. The effects of the nudge and carpooling with a stranger as non-economic incentives are analyzed, as well as the effects of the combination of the employer subsidy as an

economic incentive and the nudge as a non-economic incentive on carpooling intentions. Since we are in the case of transport choice analysis, discrete choice modeling is the best option to estimate the choice of the respondents. Discrete choice modeling was initiated and presented in the works of McFadden (1984), Maddala (1983), and Ben-Akiva *et al.* (1985) The econometric modeling of transport choices is carried out in two stages in this chapter.

At first, a multinomial choice estimation is performed where the respondent chooses between solo driving, driver carpooling, and passenger carpooling in a scenario without incentives. Second, a binary choice estimation is performed on respondents who travel only by solo driving and who have chosen to carpool to evaluate the change in behavior in scenarios where different incentives are applied. In these econometric models, the estimates are expressed in terms of the probability of choice or the odds ratio.

Chapter 3 measures the intention to switch modes of transport from the private car to other more sustainable modes of transport in the context of medium-distance and short-distance commuting trips. The probability of switching from a private car to carpooling and public transport is analyzed in the case of medium distances. In the case of short distances, we analyze the probability of choosing the same modes of transport as those for short distances, plus electric bicycles, over self-driving cars. The impacts of incentives are investigated for both medium and short-distance travels. The medium-distance trip is 20 kilometers, whereas the short-distance trip is less than 7 kilometers. New incentives and incentive combinations are also tried, and nested logit models are used to evaluate the effect of incentives on mode choice. In the medium-distance scenario, we first examine (1) the impact of an employer subsidy as an economic incentive, (2) the impact of a nudge as a non-economic incentive, and (3) the impact of combining the €250 carbon tax per ton as an economic incentive and a nudge as a non-economic incentive. In the short-distance scenario, we examine the impact of the same incentives as in the medium-distance case, except that we also consider social norms and health impacts as non-economic incentives in transportation mode choice. A nested logit model divides the possible choices into sub-groups, allowing the variance to fluctuate between the sub-groups while maintaining the IIA hypothesis within the groups — (Greene, 2011). The driver and passenger carpooling are bundled together in the case of a chapter.

a- Research question and main findings, chapter by chapter

The first chapter examines which types of incentives can induce a modal shift to active transport, public transport, and shared mobility and to what extent. What is the most effective incentive type. How can the effectiveness of these measures be maximized to induce modal shifts? In this first chapter, we show that a modal shift to other sustainable transport modes can be encouraged through economic (Parumog & Acharya, 2007; Storchmann, 2001; Bulteau, 2012) and non-economic (Schneider *et al.*, 2018) incentives. However, the independent application of each type of incentive in

isolation has strong limitations. Indeed, a combination of economic and non-economic incentives proves needed to encourage the modal shift to more sustainable modes, as confirmed by the work of Hilton *et al.* (2014).

Chapters 2 and 3 are empirical applications to validate our findings in Chapter 1. Chapter 2 examines whether a combination of specific economic and non-economic incentives would be more effective than the same incentives used separately. We measure the intention to change travel behavior and to carpool to work. The results show that, in carpooling, the economic incentive is more effective than the combination of economic and non-economic incentives among young adults. Men are more likely to carpool from home to work or school with a stranger than women.

Chapter 3 answers two research questions: i) Which combinations of incentives are effective for a modal shift for short and medium distances ? ii) For which sustainable transport modes are the combinations effective ? We show that an economic push incentive and a non-economic incentive are effective for carpooling among the most educated and for the choice of public transport among young adults for medium trips. For short trips, non-economic incentives are more effective in encouraging carpooling and cycling among young adults and those with higher levels of education. Non-economic incentives are most effective for carpooling and cycling among young adults and those with higher levels of education. In contrast, for public transport, a combination of both incentives is needed among young adults and those with higher levels of education.

1.3 **STRUCTURE OF THE THESIS AND PUBLICATIONS**

This fourth section presents the structure of the thesis and the contributions, chapter by chapter (this thesis consists of three chapters). The contributions are presented in the table 2 below:

Table 2: Structures of thesis

Chapter titles	Methodology adopted	Main contributions	Main findings
Chapter 1: Incentives for modal shift towards sustainable mobility solutions: A review	Bibliometric analysis and comparative study (Gandia et al, 2018)	Comparative study of economic and non-economic incentives for modal shift towards sustainable mobility solutions.	<ul style="list-style-type: none"> - The independent application of economic and non-economic incentives has revealed effectiveness but also limitations. - Economic and non-economic incentives need to be combined in order to prompt agents to adopt sustainable transport modes. - There are very few studies that analyze the combination of economic and non-economic incentives for modal shift towards sustainable mobility solutions.
Chapter 2: The impacts of combining incentives on carpooling for commuting in Paris Metropolitan area	<ul style="list-style-type: none"> - Multinomial Logit Model (Ben Akiva & Lerman, 1985) - Binomial Logit Model (Greene, 2011 ; 	Data from a questionnaire on 1,502 respondents in the Ile-de-France region to separately test (1) the effect of non-economic incentives, such as nudge and carpooling with a stranger, on intention to carpool to work as either driver or passenger, and (2) the effect of the combination of nudge and a economic incentive that is the employer subsidies	<ul style="list-style-type: none"> - Nudges are more effective among younger and more educated people as a way to encourage them to carpool more. - Men are more likely to carpool from home to work or school with a stranger than women. - Applying nudges in isolation appears to be more effective at encouraging carpooling for commuting than combining nudges with employer subsidies for sustainable mobility.

	Bressoux, 2010)		
Chapter 3: Which incentives for transitioning towards sustainable mobility solutions for medium and short distance transport in Ile-de- France?	-Nested logit Model (Greene, 2011)	Impact of various incentives and incentive combinations on mode choice in both short- and medium-distance instances. We first analyze (1) the effect of an employer subsidy as an economic incentive, (2) the effect of a nudge as a non-economic incentive, and (3) the effect of combining the carbon tax as an economic incentive and a nudge as a non-economic incentive. In the short-distance case, we look at the same incentives as in the long-distance case, but we additionally, consider societal norms and health impacts as non-economic incentives in transportation mode choice.	<ul style="list-style-type: none"> - the combination of the 250 Euro carbon tax and nudge is very effective in encouraging the modal shift to carpooling and public transport among young adults, low-income households, and people with a high level of education for medium-distances. - For short distances, nudge is effective for the choice of carpooling and electric bicycles among young adults and for the choice of public transport among people with a high level of education.

Finally, I present my main publications:

Articles submitted

Chapter 1: Salihou F., Le Boennec R., Bulteau J., Da Costa P. (accepted for publication) : Economic and non-economic incentives for modal shift to sustainable mobility solutions: a review, *Revue Economique Industrielle*, numero 178.

Chapter 2: Salihou F., Bulteau J., Le Boennec R., Berrada J. Da Costa P., (submitted) The impacts of combining incentives on carpooling for commuting in Paris Metropolitan area, *Travel Behavior and Society*.

Main conferences and invited seminars.

Chapter 1: Salihou F., Le Boennec R., Bulteau J., Da Costa P. (accepted for publication) : Economic and non-economic incentives for modal shift to sustainable mobility solutions: a review.

- 3èmes Rencontres Francophones Transport Mobilité (RFTM), 2021, Marne-la-Vallée, France, (online)
- International Association for Energy Economics (IAEE), 2021, (online)
- Journée doctorale, poster, 2021, online.

Chapter 2: Salihou F., Bulteau J., Le Boennec R., Berrada J. Da Costa P., (submitted) The impacts of combining incentives on carpooling for commuting in Paris Metropolitan area

- 4èmes Rencontres Francophones Transport Mobilité (RFTM), 2022, Esch-sur-Alzette (Luxembourg)
- International Transportation Economics Association (ITEA), 2022, Toulouse, France
- 3rd Momentum International Congress, Energy at the crossroads, 2023, ENS Paris-Saclay, France.

Chapter 3: Salihou F., Bulteau J., Le Boennec R., Berrada J. Da Costa P., Which combinations of incentives for transitioning towards sustainable mobility solutions for medium and short commuting trips in Ile-de-France?

- International Conference on Mobility Challenges, 2022, Paris-Saclay, France.

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CHAPTER 1

Incentives for modal shift towards sustainable mobility solutions: A review.

Abstract: Despite its advantages, road transport generates negative externalities. To reduce them, the use of single-occupant vehicles (SOVs) must be limited to promote other transport modes (active modes, public transport and shared mobility). This paper aims to examine the economic and non-economic incentives (as persuasive technologies and psychological factors) for a modal shift to sustainable mobility solutions. The independent application of these two types of measures has revealed effectiveness but also limitations. Economic incentives pose a problem of social acceptability for economic agents and limit the freedom to drive. The boomerang effect and inefficiency in specific cultural and economic contexts are the main limitations of non-economic incentives. To maximize effectiveness in terms of modal shift towards sustainable mobility solutions, economic and non-economic incentives need to be combined.

Keywords: Economic incentives; Non-economic incentives; Persuasive technologies; Psychological factors; Externalities; Modal shift; Transport mode; single-occupancy vehicle; Sustainable mobility; Review

1. INTRODUCTION

Decades of urban expansion, economic development and demographic explosion have driven strong growth in travel demand (Diao, 2019). In France, domestic passenger transport reached 941 billion passenger-kilometers in 2017 against to 886 billion in 2012 (+6.2%), and the modal share of individual transport is 80.5% against 19.5% for public transport (Commissariat général au développement durable, 2019). However, increased car use generates negative externalities such as air pollution, road congestion, road accidents, and noise. The share of road transport in France's final-energy consumption was 94.7% in 2017. Road transport accounts for 95% of total CO₂ emissions, and road accident mortality increased by 0.5% in 2016. Reducing these externalities is a major challenge that could positively impact both the environment and social welfare. The use of sustainable transport modes would reduce these externalities. Sustainable transportation generally refers to all combinations of

government policies, infrastructure, technologies, and behaviors that reduce negative externalities (environmental and social) while maintaining or improving economic outcomes (Stephenson *et al.*, 2018). Bannister's (2008) sustainable mobility paradigm presents actions such as reducing the need to travel, encouraging modal shift, reducing the trip length, and encouraging greater efficiency in the transportation system. All of these actions involve various policy measures. The modal shift involves measures that can reduce car use by promoting other transport modes that are sustainable.

Various types of measures can be designed and implemented by employers (Root, 2001), economic operators and local authorities (Aguilera-Garcia *et al.*, 2021) to reduce the negative externalities associated with road transport and encourage modal shift. Economists advocate economic measures, such as road pricing (Arnott *et al.* 1985, 1990, 1993; Le Boennec, 2014; Bulteau, 2016), whereas scholars in other disciplines favor other types of measures, such as psychological factors and persuasive technologies (Steg, 2003; Cialdini, 2003; Donald *et al.* 2014, Bucher *et al.* 2019). Legal aspects will not be considered in the scope of this article.

Here we have assumed that sustainable mobility is described by the modes of transport used as an alternative to single-occupancy vehicles (SOVs) to reduce the negative externalities associated with road transport. These include public transport, shared mobility (carpooling and car-sharing), and active modes (walking, cycling, scooters, etc.).

This review aims to answer the following questions: what types of incentives can induce modal shift towards active modes, public transport and shared mobility, and to what extent? What is the most efficient incentive method—economic or non-economic? How can the effectiveness of these measures be optimized in terms of prompting modal shift? We answer these questions by combining bibliographic analysis with bibliometric analysis. To the best of our knowledge, this is the first review to analyze both economic and non-economic incentives for modal shift.

The article is structured as follows. Section 2 presents a review of selected types of economic and non-economic incentives for a modal shift towards sustainable mobility solutions. Section 3 presents the methodology. Section 4 compares the different forms of incentives in terms of effectiveness and discusses the results. Finally, Section 5 ends with conclusions.

2. LITERATURE REVIEW

The presence of externalities related to road transport is characterized by the gap between social and private costs (Bontems & Rotillon, 2003). Policymakers then need to close this gap by internalizing the externalities, which will positively impact both the environment and social welfare. The previous literature has shown that the application of specific economic measures can play this role by helping to change the costs of the behaviors that cause externalities. These include price regulations (taxes and subsidies)

and quantity regulations (tradable emission permits, allowances, etc.).

2.1. Economic incentives

2.2.1. Price regulations

Taxes. External costs represent additional costs imposed by drivers on other users and the rest of society when they decide to make more trips. These costs are not taken into account by drivers. (Nash & Matthews, 2005). To this end, economists propose to internalize the negative externalities of car travel by increasing the cost of driving. Road pricing can be used to encourage a modal shift from SOVs to other transport modes (Menon *et al.* 1993). The most common pricing measure is the fuel tax. Parumog & Acharya (2007) studied the characteristics of road-transport taxes and charges in East Asia and found a negative relationship between retail gasoline-price tax and congestion. Storchmann's (2001) study in Germany shows that fuel tax increases have three effects. First, the distance travelled by cars for leisure and vacations decreases. Second, the increase in tax revenue due to the time needed to adapt to the new conditions generates a positive tax effect in the short term. Finally, the modal shift from SOVs to public transport occurs only during peak hours. Ang & Marchal (2013) show that fuel tax can be useful for a modal shift if the authorities jointly invest in public transport and other alternative modes.

Other research proposes congestion charging as an economic instrument to reduce externalities such as congestion and pollution (Le Boennec, 2014; Bulteau, 2016; Wu *et al.* 2017). The most widely used instrument is the urban toll, which consists of charging motorists if they want to travel in urban or demarcated areas. Prud'homme & Bocarejo (2005) show that the introduction of the London toll increased the modal share of public transport from 50% to 60%. The ADEME report (2014) on air quality assessment shows that the introduction of Milan's green toll has increased the number of passengers on public transport by +3%, the commercial speed of buses by +8.1%, and the supply of public transport by an additional 1,300 daily trips.² In 2008, the average number of SOVs per day decreased by 21%, and there was a positive impact on the environment. However, there was a rebound effect in the following two years, as congestion in Milan increased due to the composition of vehicles crossing the toll plaza, where a massive influx of clean cars resulted in a 4% increase in SOVs in 2009 and 5% more in 2010 (Danielis *et al.* 2011).

Parking policies are another widely used strategy applied in economics to urban contexts. There is ample literature on the influence of parking policies on transport mode choices and the revenue they can generate for local authorities. Dell'Olio *et al.* (2014) proposed mobility policies as part of a package to promote the use of more sustainable transport modes at the University of Cantabria, on the Llamas campus, in

² ADEME is the French agency of ecological transition.

Spain. They showed that university parking pricing can reduce car use and generate revenue that can be reallocated to the deployment and use of more sustainable transport modes, such as shared-bicycle systems and buses. Hammadou & Papaix (2015) showed that the application of a tax covering 50% of the price of a parking space reduces SOV use by 0.7% and increases public transport use by 4.5%.

Subsidies and aids. Individual behaviors can be changed through price increases (taxes) or price decreases (subsidies) (ADEME, 2016). Common types of subsidies used in the field of transportation include kilometer allowances, public transport subsidies, and bonus-malus-type subsidies. The Cerema report (2016) presents an evaluation of the bicycle-mileage allowance in the French public-administration service showing that the implementation of this policy has resulted in a roughly 25% increase in bicycle use for commuting.³ More than 60% of the initially non-cycling beneficiaries previously used private cars. Hilton *et al.* (2014) analyzed the effects of a bonus-malus system and injunctive norms on transport for students in the city of Toulouse (France) who have to travel either by train or by plane. Intention to choose train rather than plane increased by applying a bonus-malus tax.

2.1.2. Quantity-based regulations

Quantity instruments do not directly affect prices, and only consider the availability of the goods. Several studies propose solutions that will make it possible to reduce SOV use. Tradable emission permits or transferable allowances are the most intensively discussed quantity regulation instruments in research. Walton (1997) asserted that applying the concept of tradable emission permits in road traffic in the United Kingdom could reduce the number of cars on the road, increase public transport, and reduce pollution. The author proposed that car license tax discs (acquired through payment of vehicle excise duty) should be limited and auctioned. The total number of licenses in circulation should be continuously reduced, and the funds from these auctions should ultimately be reinvested in public transport. Bulteau (2012) studied the possibility of implementing a system of tradable emission permits for motorists and showed that the increase in price of motorists' tradable emission permits impacts the transport modes chosen. The increase in the price of tradable emission permits (due to the decrease in the allocated quantities of permits) increases the direct costs of the car ownership, resulting in a reduction in car use in favor of an increase in the use of public transport, and a decrease in CO₂ emissions.

The limits of economic incentives. The economic instruments described above contribute to a modal shift in favor of alternative transport modes to SOVs and provide an incentive to reduce negative externalities. They also generate income that finances local authority budgets. However, these economic measures are not readily accepted

³ Cerema is the French center for studies and expertise on risks, the environment, mobility and planning.

by the public (Jones, 1991, 2003; Schade and Schlag, 2003). The implementation of these policies on a large scale is not easily feasible (Schuitema *et al.*, 2009). The attitude towards economic incentives is represented by either acceptability or acceptance (Bamberg and Rölle, 2003; Eriksson *et al.*, 2006, 2008; Gärling *et al.*, 2008; Jakobsson *et al.*, 2000; Schade and Schlag, 2000). Acceptability describes the tendency to estimate an economic incentive in transport with some degree of favor or disfavor before application. Acceptance describes the tendency to value an economic incentive in transport with some degree of favor or disfavor after application (Schuitema *et al.*, 2009). The attitude towards the effectiveness of economic incentives differs between local government authorities and the public. Studying the British transport policy context, Xenias and Whitmarsh (2013) show that authorities or mobility experts prefer technical-economic measures. According to Garling & Schuitema (2007), such measures would be acceptable if they did not limit driving freedom by making car use less attractive. For users, behavior change, and improved public transport are the best options. Nevertheless, both groups (mobility experts and users) agree on reducing transport demand through qualitative measures (Xenias and Whitmarsh, 2013). The work of Eriksson *et al.* (2008) is consistent with this. The authors analyze Swedish motorists and test the effectiveness of two forms of measures, push and pull measures. Steg and Vlek (1997) define push measures as measures that aim to discourage car use, while pull measures aim to improve people's travel possibilities by providing better alternatives. Thus, pull measures are seen as effective, fair, and acceptable, which is not the case for push measures. Schade & Schlag (2003) showed that social norms, personal expectations of outcomes, and perceived effectiveness are positively related to the acceptability of economic measures. Increased awareness of the positive consequences of reducing SOV use would be essential to improve social acceptability (Steg, 2003). Another limitation Oum (1989) pointed out is the time it takes for economic instruments to bring effects, which may be uncertain. According to Coulombel *et al.* (2019), behavioral change (leading to a modal shift) can lead to rebound effects that mitigate environmental benefits. Finally, Bulteau *et al.* (2021) showed that the limits reached by a financial incentive can be exceeded when a psychological incentive is added (to encourage carpooling for commuting in the Paris region).

2.2. Non-economic incentives

The reduction of negative externalities related to road transport and the modal shift towards sustainable mobility solutions can also be achieved through non-economic incentives. Here we limit the analysis of these measures to psychological factors (Ajzen, 1991; Matthies *et al.* 2002; Cialdini, 2003) and persuasive technologies (Bothos *et al.* 2014; Anagnostopoulou *et al.* 2018).

Psychological factors. Social psychology plays a vital role in shaping specific transport issues (Schneider *et al.* 2018). Along with sociodemographic and structural factors, it can explain users' mode choices. Psychological factors can be used to nudge more

regular use of sustainable mobility solutions. There are three models widely used in the field of transportation to explain individual mode choices, decisions and behaviors. The first model is the theory of reasoned action (Ajzen & Fishbein, 1970), which aims to explain the relationship between beliefs, norms, attitudes, intentions, and behaviors. The second model—complementary to the first (Ajzen, 1991)—is the theory of planned behavior, which integrates the fact that individuals do not intend certain behaviors and adds perception of control over behavior to the starting model. Finally, the third model, Triandis’ theory of interpersonal behavior (Triandis, 1977, 1982; Landis *et al.* 1978), is very close to the first two models but adds habits and contextual factors.

In the theory of planned behavior, intention precedes the decision to adopt the behavior. The intention is the result of three conceptual determinants: attitude, subjective norm, and perceived behavioral control (Figure 6). Attitude represents the extent to which the individual has a positive or negative judgment of his or her actions, and an assessment of his or her failure or success (Ajzen, 1991). Subjective norms are individual perceptions shaped by social pressures (from family, friends, relatives) and the ability to conform to others’ opinions (Ham *et al.*, 2015). Perceived behavioral control is the perceived degree of simplicity or difficulty concerning the feasibility of the behavior. Habits are automated, objective-oriented acts that are mentally represented (Aarts & Dijksterhuis, 2000).

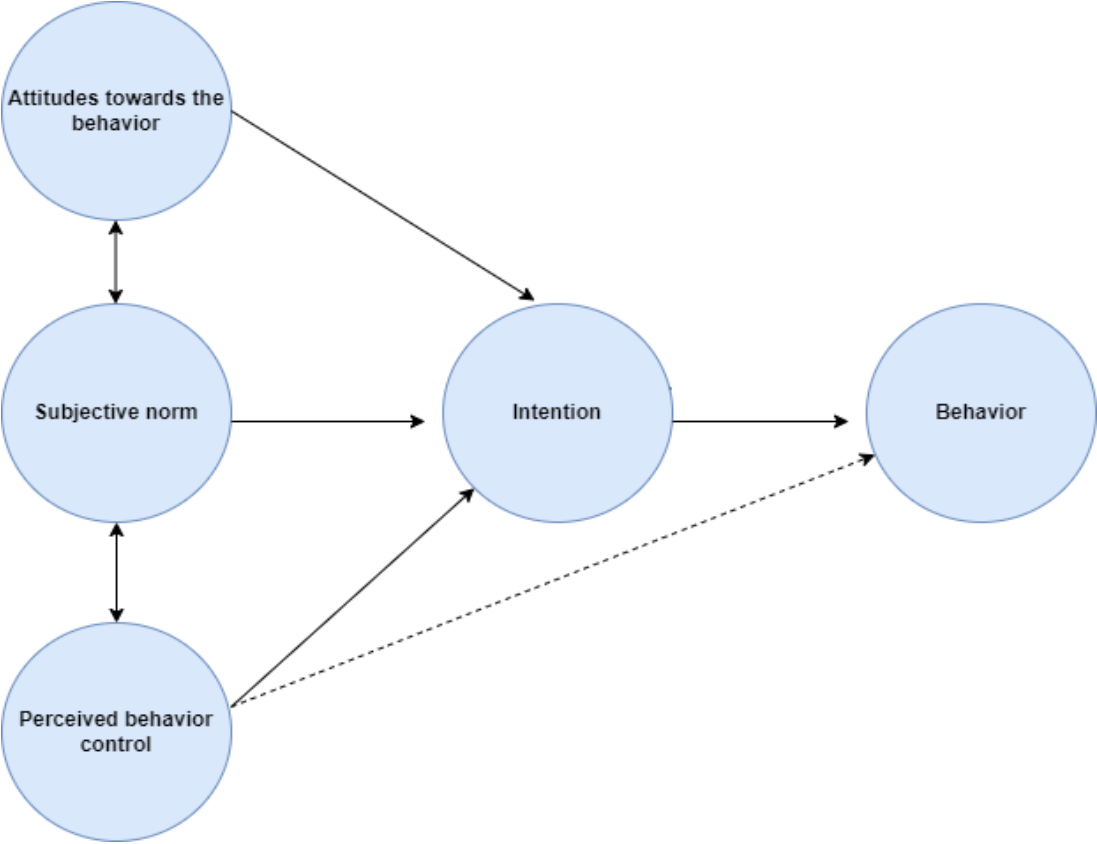


Figure 6: Theory of planned behavior (Ajzen, 1991)

Several studies have shown that mode choices are explained by these factors: attitudes, subjective norms, perceived behavioral control, and habits (Table 3). Regarding the relationship between mode choice and psychological factors, Matthies *et al.* (2002) found that women’s preferences for public transport and reduced car use may be influenced *much more by environmental concerns than by mode choice habits, which is not the case for men. However, the gender difference in transport mode choice cannot be attributed to environmental concerns and mode choice habits, and may revolve around other factors, such as stereotypes (Flade & Limburg, 1997). The orientation towards choosing to drive a car is already stronger among boys aged 10 to 16 than among girls. This implies that as adults, boys are already ‘car-driven’. Bouscasse et al. (2018) reached the same conclusions regarding the effect of environmental concerns on car-use patterns. People who are highly sensitive to environmental concerns perceive public transport as more pleasant and comfortable than people with no little environmental sensitivity. Thus, environmental concerns significantly influence mode choice habits, and perceptions and feelings around public transport partially mitigate this effect.*

Perceived behaviors and subjective norms can be used to influence mode choice habits and encourage use of public transport. Donald *et al.* (2014) reached this conclusion by testing an extended model of planned-behavior theory in mode choice. They also identified the factors influencing the choice to drive or use public transport to commute to work and found that perceived behavioral control is a better predictor of intentions to use public transport rather than private cars. They thus suggest that promotional campaigns in favor of adopting public transport will be effective if they target factors such as habits and intentions.

Injunctive and descriptive norms may also be useful to encourage sustainable mobility. Cialdini (2003) showed, through experiments, the difference between these two norms and their role in environmental protection. Injunctive norms are based on what individuals approve or disapprove of, while descriptive norms are based on what people do (Cialdini *et al.*, 1990). Cialdini showed that the involvement of injunctive standards in a message is more effective when it concerns environmentally harmful behavior, while descriptive standards are more effective when a message concerns environment-protective behavior. For example, a campaign containing an injunctive standard that formally prohibits waste discharge into a natural park in order to preserve it would be more effective than a campaign that describes the actions that some people take for the same purpose. However, aligning the two types of norms jointly in messages can encourage mobility users to adopt pro-environmental behaviors.

Table 3: List of academic articles on the impact of psychological factors on modal shift towards sustainable mobility solutions

Psychological factors	Description	References
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Attitude	Environmental concerns	Matthies et al. (2002), Walton et al. (2004), De Groot & Steg (2007), Bouscasse et al. (2018)
	Stereotypes	Flade & Limbourg (1997)
	Personal standards	Bamberg et al. (2007), Doran & Larsen (2016)
	Personal beliefs	Steg (2003)
	Emotional and symbolic motive	Bouscasse et al. (2018)
	Perception of quality	Fujii & Van (2009)
Subjective norms	Social pressures	Xin et al. (2019)
	Descriptive norms	Cialdini et al. (1990), Cialdini (2003), Donald et al. (2014), Hilton et al. (2014), Kormos et al. (2015).
	Injunctive norms	Cialdini et al. (1990), Cialdini (2003)
Perceived behavioral control	Culpableness involved in using a transport mode	Donald et al. (2014), Xin et al. (2019)
Habits	Frequency of using a transport mode	Bouscasse et al. (2018), Xin et al. (2019),

Source : prepared by the authors

Persuasive technologies. De Kort *et al.* (2007) defined persuasive technologies as a general class of technologies designed to change users' attitudes or behaviors through persuasion and social influence, and not through coercion.

There is a relationship between persuasive technologies and psychological factors, to the extent that persuasive technologies can manipulate psychological factors to encourage sustainable mobility solutions (Figure 7). Bothos *et al.* (2014) illustrated this relationship by analyzing how persuasion strategies in a smartphone application can provide travelers with itinerary-planning solutions that consider environmental impact. They found that technologies can encourage pro-environmental behavior by promoting the use of other modes of transport. However, this result cannot be confirmed in a context of a narrow set of alternatives. Anagnostopoulou *et al.* (2018) confirmed these results by analyzing all existing approaches, systems, and prototypes in terms of persuasive technologies. Their survey found that in 65% of studies, persuasive technologies were effective and encouraged a shift to sustainable transport modes. Nevertheless, all these studies shared the same main limitation, i.e. technology application lasted only one or two months, leaving no way to measure the long-term

effectiveness of persuasive technologies.

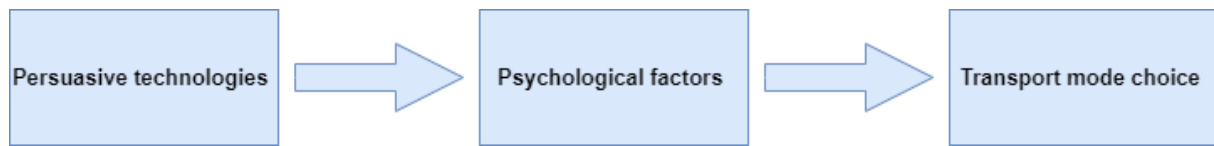


Figure 7: Relationship between persuasive technologies and transport mode choice (Source: prepared by the authors)

The limits of non-economic incentives. Like economic incentives, non-economic incentives have limits in terms of effectiveness. Baldwin (2014) analyzed the role of nudges in the overall state-control system and concluded that the effectiveness of norms at individual level may be limited if the cultural context, economic environment, and corporate policies encourage undesirable behavior. Moreover, responses to social pressures vary according to social context. Social norms may be negatively associated with behavioral intent (Perkins *et al.*, 2005) as a boomerang effect. Gardner & Abraham (2010) showed that drivers who expect others to drive less increase their driving time, as they anticipate a reduction in congestion-related problems. For these reasons, injunctive standards must be combined with descriptive standards.

3. Research methods

This section is devoted to a bibliometric analysis. This analysis aims to produce a sample of articles for comparative study between economic and non-economic incentives in terms of modal shift towards sustainable mobility solutions. The methodology used for the bibliometric analysis requires two main steps: first, a descriptive analysis of the transport literature, and second, selecting articles for the comparative study (Figure 8).

Step 1: Descriptive analysis

Figure 8: Research methodology for the bibliometric analysis (Source: prepared by the

authors)

3.1. Descriptive analysis

- **Number of articles per year**

The bibliometric analysis is done by inserting 'transport' as a keyword in the Scopus database, and then searching the title of the article, the abstract, and its keywords. Then, a filter by field of activity is applied. The period considered is from 2000 to 2020, following the Kyoto protocol signed in 1997. The objective of this international agreement is to reduce greenhouse-gas emissions in the countries concerned. To focus on the transportation of people, we limited the analysis to research fields such as social sciences, economics, econometrics and finance, psychology, energy, and environmental sciences. This gave a total of 183,841 publications. The most significant year for publications was 2020, with 18,056 publications. Publication numbers tended to grow over the period, signaling the growing attraction of the topic (Figure 9).

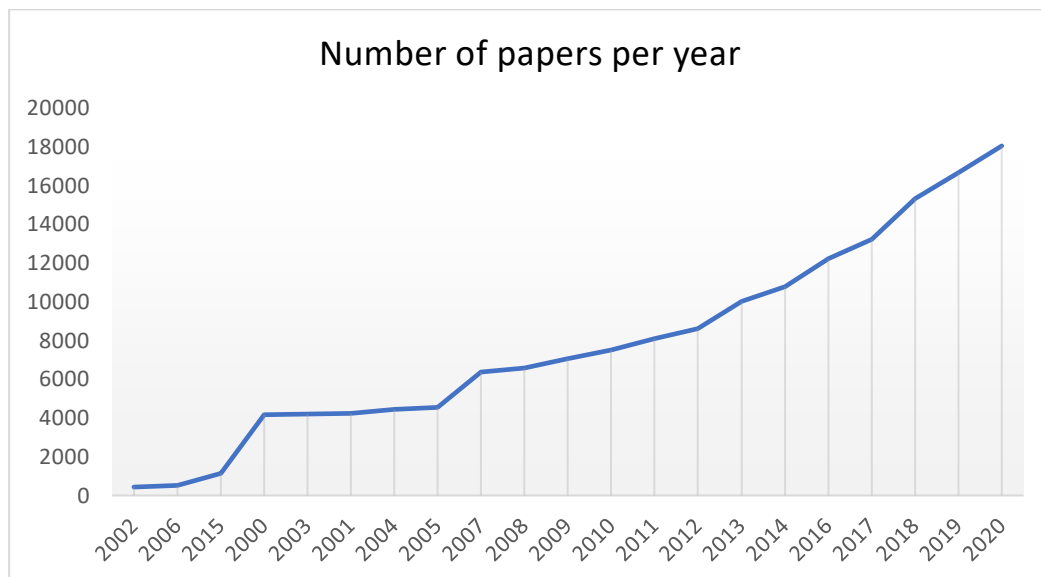


Figure 9: Annual number of articles considering the transportation of people, based on Scopus (Source: prepared by the authors).

- **Distribution of published articles by subject area**

Figure 10 presents the distribution of published articles by subject area. The highest share of publications was in the environmental sciences field (53% of the total), followed by energy (22%), social sciences (21%), economics, econometrics and finance (3%), and psychology (1%). This reflects a multidisciplinary approach to the development of knowledge in the field of transportation of people.

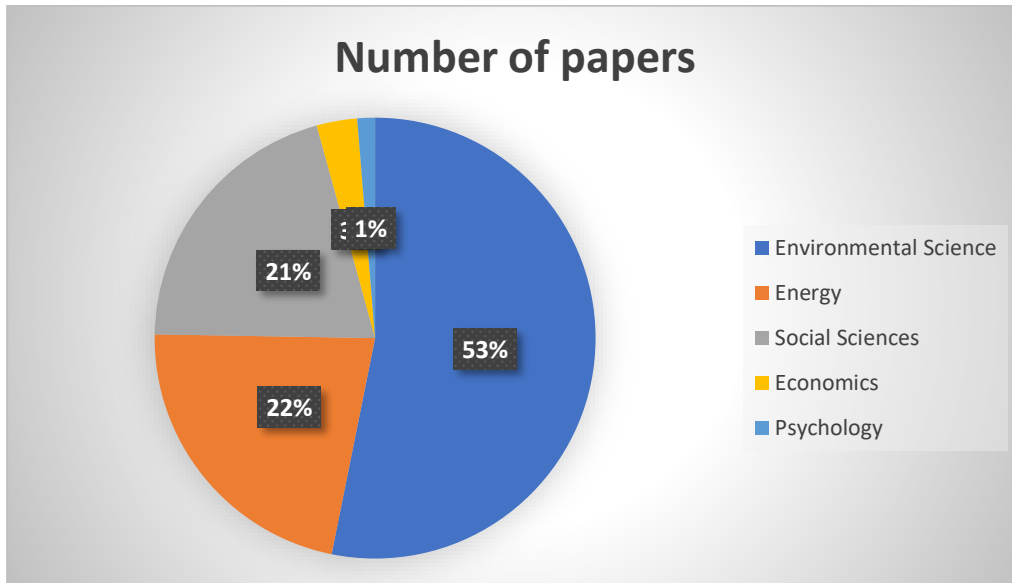


Figure 10: Distribution of published articles in the field of individual transportation, by subject area (Source: Scopus)

- **Most published sources**

Table 4 shows the 28 journals in economics, social sciences, and psychology ranked in descending order by AJG rank (Academic Journal Guides) and SJR score (SCImago Journal Rank). After applying the search field selection filter in Scopus, we selected the journals with the highest number of publications. The journals under consideration deal with the transportation of goods and people. Academic journals in the field of economics and social sciences are ranked according to the AJG 2018 and the SCImago Journal and Country Rank, while journals in the field of psychology are ranked according to the SCImago Journal and Country Rank. The AJG is a guide that classifies academic journals in the field of business and management according to issue and quality. Quality of the journal ranges from 1 (lowest) to 4 (highest). The SCImago Journal & Country Rank is a publicly accessible platform of academic journals and indicators from developed countries, based on information from the Scopus database. Quality of the journal is measured by the (SJR) indicator of prestige, impact, or influence of the journal.

There are more publications in the social sciences than in other fields. The top five journals are Transportation Research Part A Policy and Practice (1546), Journal of Transport Geography (1350), Transport Policy (1258), Transportation Research Part D Transport and Environment (1074), and Transportation Research Part B Methodological (730).

Table 4: List of the journals with the highest number of publications

Journals	Research area in Scopus	AJG 2018' rank	SJR	Number of papers
Transportation Research Part B Methodological	Social sciences	4	2.921	730
Journal of Urban Economics	Economics	3	2.724	57
International Journal of Production Economics	Economics	3	2.475	70
Urban Studies	Social sciences	3	2.115	233
Transportation Research Part A Policy And Practice	Social sciences	3	2.036	1,546
Energy Economics	Economics	3	2.003	87
Ecological Economics	Economics	3	1.767	101
Regional Science And Urban Economics	Economics	3	1.570	98
Accident Analysis And Prevention	Social sciences	3	1.481	344
Transportation Research Part D: Transport and Environment	Social sciences	3	1.448	1,074
Transport Reviews	Social sciences	2	2.138	410
Transportation	Social sciences	2	1.852	530
Journal of Transport Geography	Social sciences	2	1.668	1,350
Transport Policy	Social sciences	2	1.520	1,258
Marine Policy	Social sciences	2	1.242	52
Journal of Transport Economics and Policy	Economics	2	0.674	186
Applied Economics	Economics	2	0.499	66
Journal Of Air Transport Management	Social sciences	1	1.090	311
Research in Transportation Economics	Economics	1	0.983	458
Actual Problems of Economics	Economics	1	0.124	71
Journal Of Environmental Psychology	Psychology	-	1.961	16
Social Indicators Research	Psychology	-	1.685	28
Decision Support Systems	Psychology	-	1.536	15
Technological Forecasting And Social Change	Psychology	-	1.422	109
Travel Behaviour And Society	Social sciences	-	1.280	97
Human Factors	Psychology	-	1.094	17
Transportation Research Part F Traffic Psychology And Behaviour	Psychology	-	0.993	194
Social Inclusion	Psychology	-	0.276	17
Total		-		9,525

Selection of articles for the comparative study

Articles on economic (Figure 12) and non-economic incentives (Figure 13) were selected for the comparative study in four steps.

- **Step 1: Search all articles in Scopus**

We inserted the keyword 'transport' in the Scopus search field. As we previously mentioned, we limited the search to 2000 to 2020 for the time interval and to document-type articles (article, review, book, or book chapter etc.). The result was 939,640 publications.

- **Step 2: Select areas of research**

A selection was made by research area. The research areas were selected independently, and the analysis continued for each area. For economic incentives, we limited the search to social sciences (N=41,183) and economics, finance, and econometrics (N=5,952). For non-economic incentives, we selected the social sciences and psychology (N=2,688). N is number of publications.

- **Step 3: Selection of journals**

To select academic journals, we first inserted the keywords related to the different forms of incentive (economic and non-economic). The keywords for economic incentives were 'tax', 'modal shift', 'parking', and 'subsidies'. For non-economic incentives, we chose the theory of planned behavior and persuasive technology. Journals were then selected by applying a filter on name of the source and considering the score or rank of the journal. Using the AJG scheme, we considered journals with a rank of 3 or 4 and an SJR score greater than or close to 1 (economic incentives) (Figure 11). For non-economic incentives, only SJR score was considered (SJR greater than or close to 1).

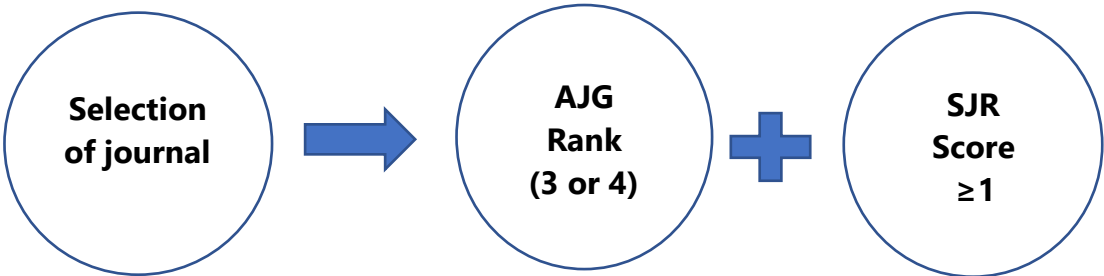


Figure 11: Method of journal selection

The selected social science journals are *Transportation Research Part A*, *Transportation*

Research Part B, Transportation Research Part D, Accident Analysis and prevention, and Urban Studies. The selected economics journals are *Regional Science and Urban Economics, Energy Economics, Ecological Economics, International Journal of Production, and Journal of Urban economics.*

For non-economic incentives, we selected academic journals psychology and social science journals: *Transportation Research Part F, Journal of Environmental Psychology, Transportation Research Part A, Travel Behavior and Society, Social Indicators Research, Technological forecasting and Social change, Journal of transport Geography, and Transport Policy.*

- **Step 4: Selection of articles**

For the comparative study, we limited the analysis to 15 empirical reports or theory papers presenting quantified results in terms of effectiveness of economic incentives and significant positive results in terms of the effectiveness of non-economic incentives.

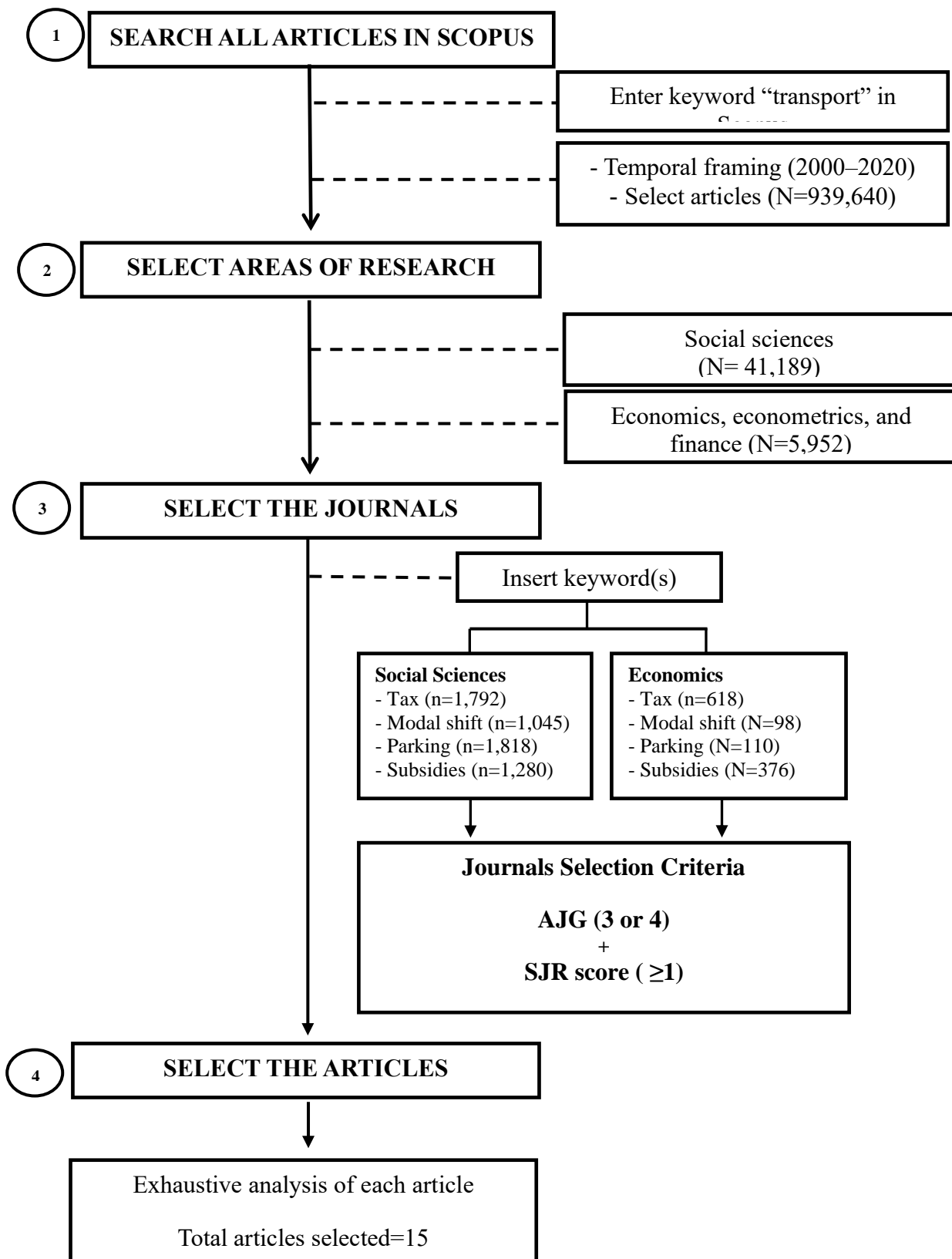


Figure 12: Methodology for the selection of articles (economic incentives)

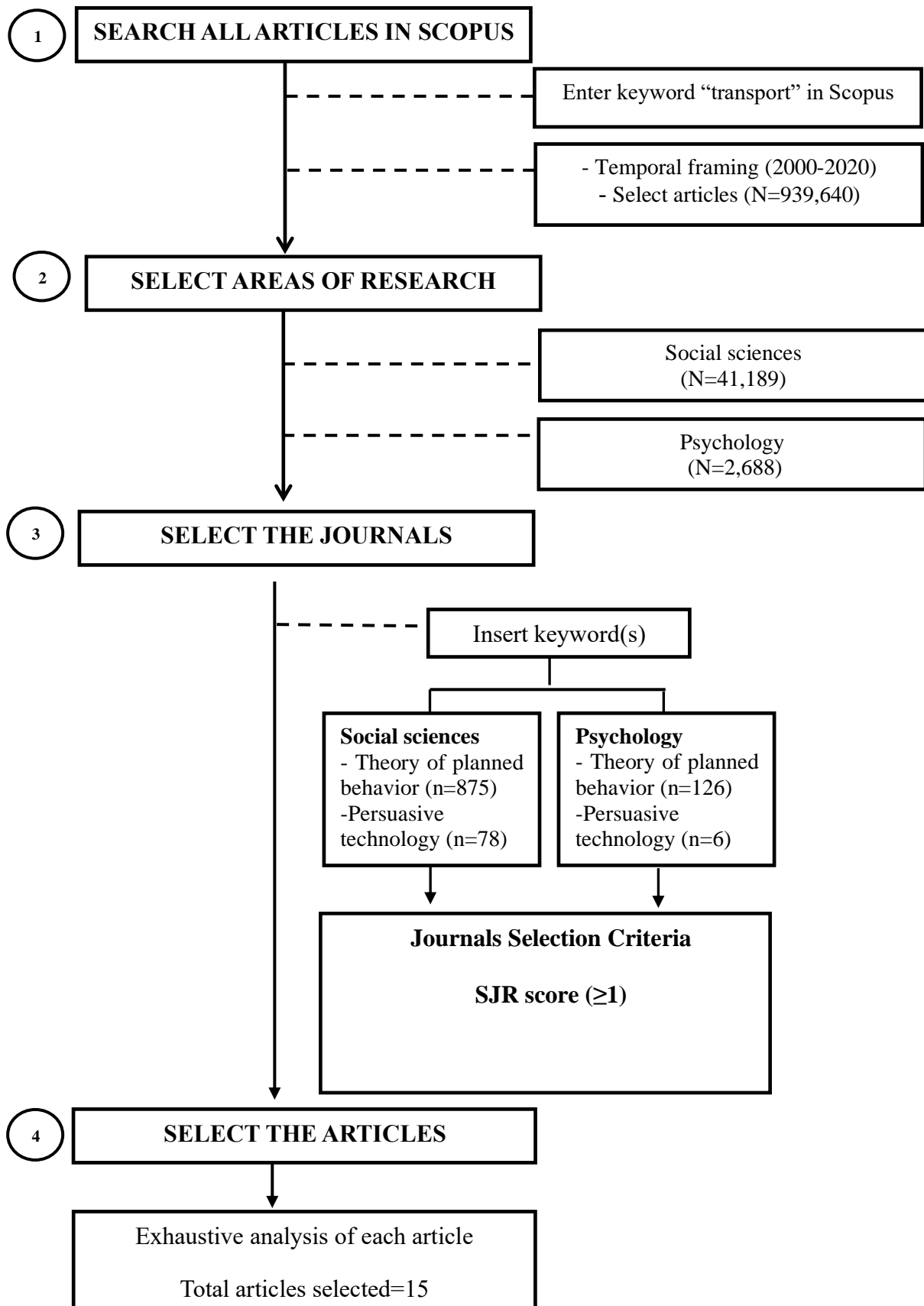


Figure 13: Methodology for the selection of articles (non-economic incentives)

4. COMPARISON AND DISCUSSION ON INCENTIVES FOR MODAL SHIFT TOWARDS SUSTAINABLE MOBILITY SOLUTIONS

Numerous studies have shown the contribution of economic and non-economic incentives in the modal shift towards sustainable mobility solutions. However, incentives (economic or non-economic) may prove less effective if applied independently. Comparing the two forms of incentives in terms of effectiveness thus gives an idea of which is more effective. These results have been drawn up in table 3 and 4 (appendix 1 and 2) which highlight:

- The author(s),
- The type of incentive,
- The method used,
- The sample size,
- The estimation period,
- The geographical perimeter,
- The variables observed,
- The results obtained in terms of modal shift towards sustainable mobility solutions.

The results were color-coded: green for a positive effect in terms of efficiency, and blue for a negative effect.

4.1. Effectiveness of economic incentives

Table 5 (see appendix 1) presents two main forms of economic incentives: taxes and subsidies. On taxes, there are environmental taxes imposed on the purchase of the vehicle, such as excise duty (Brand *et al.* 2013) and the tax linked to energy consumption (Ubbels *et al.* 2012). Then there are taxes related to private cars, such as the tax on gasoline (Hammadou & Papaix, 2015; Pavon & Rizzi, 2019). There are parking taxes (Evangelinos *et al.* 2018; Rotaris & Danielis, 2014; Hammadou & Papaix, 2015; Albalade & Gragera, 2020) and, finally, road pricing (Steininger *et al.*, 2007; Agarwal & Koo, 2016). All these pricing policies have had the expected effect of either reducing SOV use (Evangelinos *et al.* 2013), increasing the use of sustainable modes (Pavon & Rizzi, 2019), or both (Ubbels *et al.* 2012). However, as Hammadou & Papaix (2015) demonstrated, using a direct policy instrument that aims at reducing CO₂ emissions (fuel taxes) appears to be more effective in dense urban areas than using an indirect policy instrument that does not originally aim at reducing CO₂ emissions (parking management policies, cordon tools). The application of a 1.6-euro-cent tax on gasoline led to a 1.1% decrease in SOV use, a 14.2% increase in public transport use, and a 1.3% increase in walking, while a 50% increase in parking tax only led to a 0.8% decrease in SOV use, a 4.5% increase in public transport use, and a 1.7% increase in walking. The application of road pricing (1.2 euro per day) only reduced SOV use by 0.7%, increased

public transport use by 9.2%, and walking by 1%. This instrument is effective for those who depend on the car. Employees and managers are the main ones concerned in this study.

Some work has dealt with the effects of public transport subsidies on transport mode choice. Like pricing policies, public transport subsidies are useful for reducing SOV use (Rotaris & Danielis, 2014), increasing public transport use (De Witte *et al.*, 2006), or both (Bueno *et al.* 2017). For example, Bueno *et al.* (2017) showed that public transport subsidies for New York and New Jersey metropolitan areas for commuting led to a 16% reduction in SOV use and a 15% increase in public transport use. The effectiveness of this measures lies in commuters' proximity to public transportation and the non-ownership of cars.

Comparing pricing policies and public-transport subsidy policies shows that road pricing has a more significant impact on changing sustainable transport modes than subsidies. Rotaris & Danielis (2014) analyze the effectiveness of parking pricing policies and subsidies allocated to public transport in urban areas precisely at the University of Trieste, Italy. They showed that paying 1 euro per hour for parking reduced SOV use by 23% against only 17% with total one-month-long public transport subsidy. However, these parking pricing policies have a more significant impact on the mode choice of faculty than that of administrative staff and students. Pavon & Rizzi (2019) reached the same conclusion. The total public transport subsidy in Santiago, Chile, increased bus-run frequency during peak hours by a proportion roughly equal to that of the gasoline tax (12%). However, in off-peak hours, bus runs are more frequent (+3 buses/h) when a gasoline tax is implemented than when public transport is fully subsidized.

Globally, our analysis reveals that direct policy instruments such as the gas tax are more effective than indirect policy instruments such as parking management policies or cordon tolls in dense urban areas. The effectiveness of these policies on modal shift is for those dependent on the private car, mainly managers and employees. Public transport subsidy policies are effective in metropolitan areas for commuting, provided that the commuter is close to public transport and does not own a car. Comparing road pricing and subsidy policies in urban areas showed that road pricing is more effective than subsidies for managers and teachers. This effectiveness is not verified for students.

Effectiveness of non-economic incentives

Table 6 (see appendix 1) shows that transport mode choice can be influenced by three forms of incentives: psychological factors, persuasive technologies, and other means of persuasion, such as communication. Psychological factors include subjective norms (Shang-Yu Chen, 2016 ; Ingvaridsen & Nielsen, 2019), perceptions (De Vos *et al.* 2020 ; Shang-Yu Chen, 2016 ; Ingvaridsen & Nielsen, 2019 ; Gutierrez *et al.* 2020), and

individual characteristics such as habits and attitudes (Lind *et al.* 2015 ; De Vos *et al.* 2020; Stark *et al.* 2019 ; Gutierrez *et al.* 2020). Subjective norms and perceptions have a greater and more positive impact than other psychological factors for users and non-users of active modes such as cycling in urban areas (Shang-Yu Chen, 2016). Subjective norms or perceptions are perceived and felt social pressures to engage or not engage in a use behavior such as public bicycling. Psychological factors are attitudes and beliefs that explain the choice to ride a public bicycle (Ajzen 1991). However, when comparing the effect of all psychological factors on the transport mode choice, most of the scholarship shows that individual specificities are the most significant factor explaining sustainable mode choice. De Vos *et al.* (2020) showed that attitudes are more significant and positively affect choice of public transport in urban areas than perceptions related to satisfaction. For rural residents, the intention to use public transport is positively influenced by moving to urban areas because accessibility to the best transportation offered in rural areas is less straightforward. Stark *et al.* (2019) also showed, in urban areas, the significant and positive impact of attitudes on children's sustainable mode choice. Children's mode choice is related to feelings of well-being during the trip.

Persuasive technologies also have a significant and positive effect on sustainable mode choice (Bucher *et al.*, 2019; Tsirimpa *et al.*, 2019). However, their effect is more significant on users of sustainable modes than on non-users, as demonstrated by Piwek *et al.* (2015) on competitive cyclists in suburban and urban areas. The need for performance feedback and self-assessment explains the significant and positive influence on cycling. Geng *et al.* (2016) and Pangbourne *et al.* (2020) show how persuasive information can promote walking in urban and rural areas. Argument value and personality traits are relevant tools for promoting walking via persuasive technologies. For older people, health benefits are arguments that influence the choice of walking. Environmental awareness is a motive for walking for younger people.

Finally, comparative analysis of these different forms of incentives points to the conclusion that individual specificities are the most significant factor explaining sustainable mode choice and are more easily influenced to change behavior through persuasive technologies or through information. Moreover, Stark *et al.* (2019) have shown that attitudes towards environmental and health-friendliness are already influenced in childhood and can have positive effects on the choice of sustainable modes. In addition, specific attitudes related to transport modes, such as wellbeing felt during travel, also help to increase the use of sustainable modes.

Overall, we find that subjective norms and perceptions are more effective than psychological factors in urban areas. Attitudes are more effective for public transport choice in urban areas. Accessibility and improvement of public transport and the feeling of well-being during travel encourage modal shift among rural residents and children respectively. Persuasive technologies are more effective on sustainable mode

users than on non-users in urban and suburban areas. Personality traits such as environmental sensitivity and argumentative values such as health benefits may be useful in encouraging walking among young and older people, respectively, via persuasive technologies.

Comparative study between economic and non-economic incentives

Here, the comparative study between economic and non-economic incentives has shown that some economic policies are less effective than others, have limitations, and influence only specific categories of users. The same is true for non-economic incentives. Some work indicates that some non-economic measures are less effective than others (Shang-Yu Chen, 2016) or less effective in a particular context (Piwek *et al.*, 2015). Thus, combining the two forms of incentives could optimize policy efficiency in terms of a modal shift towards sustainable mobility solutions (Hilton *et al.* 2014, Bulteau *et al.* 2021).

5. Conclusion

The definition of sustainable transportation generally refers to all combinations of government policies, infrastructure, technologies, and behaviors that reduce negative externalities (environmental and social) while maintaining or improving economic outcomes (Stephenson *et al.*, 2018). Bannister's (2008) sustainable mobility paradigm presents actions such as reducing the need to travel, encouraging modal shift, reducing the trip length, and encouraging greater efficiency in the transportation system. All of these actions involve various policy measures. Complementing these interventions, Stephenson *et al.* (2018) propose fundamentals in the procurement systems of transportation finance, the structure and culture of funding agencies, and transportation legislation. The modal shift involves measures that can reduce car use by promoting other transport modes that are sustainable. This paper set out to analyze the relative effectiveness of economic and non-economic incentives to make a modal shift to sustainable mobility solutions as alternatives to SOV-based mobility to reduce the negative externalities associated with road transport. We have shown that economic incentives can prompt a modal shift towards sustainable mobility solutions. These economic measures are classified according to two instruments: price regulation (fuel tax, road pricing through the introduction of urban tolls, parking fees, bicycle mileage allowances, bonus-malus system) and quantity regulation (tradable emission permits). However, the implementation and effectiveness of economic incentives can be challenged by public and political acceptability (Francke and Kaniok, 2013). In addition, economic incentives are also linked to environmental benefits that are mitigated by rebound effects and uncertainty about how the desired results will be achieved. All of these problems lie in the fact that there are various conditions for applying economic incentives in terms of categories of users that can affect the desired efficiency. The literature shows that pricing policies are more effective than subsidy

policies. Our analysis has shown that direct policy instruments related to personal car use (fuel tax) are more effective in dense urban than indirect policy instruments (parking management policies, cordon tools) areas. Modal shift is observed among managers and employees. Subsidies are less effective than road pricing policies regarding modal shift for employees and managers, but not for students. These different variations in effectiveness of economic incentives suggest that psychological factors should be considered in policies providing incentives for sustainable mobility solutions.

Our analysis and discussion of non-economic incentives showed that transport mode choices are guided by psychological factors (attitudes, subjective norms, perceived behavioral control, habits), and persuasive technologies. Attitudes can potentially affect the choice of sustainable modes in rural and urban areas. This influence may be related to the accessibility of public transport provision, which is better in urban areas. Persuasive technologies encourage sustainable modes of transportation in urban, suburban, and rural areas through tools such as personality traits, value arguments, and competition. Self-assessment and performance feedback encourage cyclists to cycle more. Promotion of the health benefits of walking is effective among older people. Among younger people, sensitivity to environmental protection may help encourage walking. Overall, the literature shows that individual specificities (attitudes, habits) are more significant than other non-economic incentives as factors explaining the modal shift towards sustainable mobility solutions. However, the effectiveness of non-economic incentives depends on cultural context, collective policies, and economic environment. Furthermore, there is a boomerang effect that is associated with the ineffectiveness of these measures.

The comparative study between economic and non-economic incentives finds that there are limits to independently applying these different forms of incentives. Economic and non-economic incentives must be combined to prompt agents to adopt sustainable transport modes. Hilton *et al.* (2014) demonstrated this by analyzing the effects of a bonus-malus system and injunctive norms on transport choice in France, specifically in the urban area of Toulouse. Through two experiments in which students are confronted with the choice between traveling by train or by plane, they showed that intention to travel by train increases when a bonus-malus price is combined with injunctive norms (emojis, and information on CO₂ emissions). Bulteau *et al.* (2021) explored the importance of financial and psychological incentives in promoting the use of carpooling for commuting, as a driver and as a passenger in the Paris region. They empirically demonstrated that the determinants of carpooling as a driver and as a passenger differ, and that incentives to encourage carpooling vary by individual profiles. Their results suggest that a policy combining economic and psychological incentives could be more efficient to promote carpooling. Wall *et al.* (2017) confirm the need for a combination of hard and soft measures to enhance modal shift to sustainable mobility solutions. His study combines subsidies for sustainable transport modes (public transport, Bicycles) and public awareness of the problems associated

with private car use in Portsmouth (UK) for commuting. The hard measures are intended to change travel behavior by changing travel costs. These measures are consistent with utility maximization models (Eluru *et al.*, 2013). The objective of soft measures is to modify travel behavior via user preferences and attitudes. They correspond to models using the theory of planned behavior (Anable, 2005). One advantage of combining push measures with non-economic incentives is that it increases social acceptability (Eriksson *et al.*, 2008). However, integrating the behavioral dimension with restrictive economic measures requires a mix. Hilton *et al.* (2014) show that the condition for the effectiveness of this combination is that the financial incentive (bonus-malus) is low. A financial incentive that is too high would encumber the intrinsic motivation to choose a sustainable mode. Also, Eriksson *et al.* (2008) suggest that combinations of economic and non-economic policies need to be tailored according to the geographical context and the target automobilist. Riggs (2017) found contrasted results. In an analysis of the impact of financial (donations, monetary incentives) and human (altruistic sense) incentives on active transportation habits (cycling and walking) in American universities, he found that combining these two forms of incentives makes them less effective. Economic agents tend to perceive a non-economic incentive as coercive when it is combined with an economic incentive. Further research on this issue is needed to disentangle the mixed conclusions on combining economic and non-economic incentives. For example, a selection of combinations of economic and non-economic incentives on modal shift could be analyzed via discrete choice models (Ben-Akiva & Lerman, 1985). One could model economic quantity control measures with subjective norms and analyze the effectiveness of this combination on modal shift. A mixed multinomial logit model would be more appropriate for the datasets we have collected because this type of model considers individual variation. This is left for further research.

Appendix 1

Table 5: Economic incentives.

In green, the results showing the effectiveness of the measures. In blue, the results showing the ineffectiveness of the incentives.

Authors/Journal	Type of incentive	Method used	Number of observations	Geographic scope	Period	Variable observed	Results	
							PC	SM
Pavón & Rizzi (2019)	<ul style="list-style-type: none"> Fuel tax (2,237 CLP), CLP: Chilean Pesos 	Simulation analysis	21,000	Santiago, Chile		-Bus frequency, peak (bus/h) -Bus frequency, off-peak (bus/h)		PT (+12 bus/h) PT (+ 3 bus/h)
	<ul style="list-style-type: none"> Subsidies for public transport (100 %) 	Simulation analysis	21,000	Santiago, Chile		-Bus frequency, peak (bus/h) -Bus frequency, off-peak (bus/h)		PT (+13 bus/h) PT (+ 1 bus/h)
Brand et al. (2013)	Vehicle excise duty (for CO ₂ >255g CO ₂ /km, the tax is GBP 2 000)	Simulation analysis		England	2010–2050	Overall car use	PC (-1.7% in 2030) PC (-2.5% in 2050)	

Evangelinos et al. (2018)	Pricing workplace parking via cash-out.	Discrete choice modeling approach	690	Germany	2011	The decreasing probability of choice for SOV use	PC (from -41% to -43%)	
	<ul style="list-style-type: none"> daily cash-out option from €1 to €2 							
	<ul style="list-style-type: none"> daily cash-out option from €2 to €3 							
	<ul style="list-style-type: none"> daily cash-out option from €3 to €4 						PC (from -37% to -30%)	
Bueno et al. (2017)	Benefits such as toll payments, mileage reimbursements or free parking	Discrete choice modelling approach (multinomial logit model)	21,771	New York and New Jersey, United States	2010–2011	The likelihood of choosing the private car and other sustainable modes for commuting		PT (-82%)
	Private car benefits						PC (+12%)	PT (-12%)

	Car ownership						PC (+40%)	W (-10%) C (-2%) PT (-28%)
	Public transport subsidies						PC (-16%)	PT (+15%)
	Bike related transportation benefits							C (+2%)
Rotaris & Danielis (2014)	Increasing the cost of the annual permit from the current level of €40 to €80	Discrete choice modelling approach (multinomial logit model)	372	University of Trieste, Italy		Change of car use in % terms	PC (-6%)	
	Setting an hourly parking tariff equal to €1						PC (-23%)	
	Increasing the time needed to find a parking space by 15 seconds						PC (-4%)	

	Free monthly ticket						PC (-17%)	
	One-way ticket 60% of variable costs (increasing price of ticket)						PC (+2%)	
Guzman et al. (2020)	Provision of facilities for bicycles	Discrete choice modelling approach (mixed logit model)	475	Bogota, Colombia		Probability of choosing a mode	PC (-2%)	CP (-2%) PT (-2%) C (13%) W (-10%)
	Implementation of company bus services						PC (-1%)	CP (-1%) PT (4%) C (0%) W (-1%)
	+30% parking fee						PC (-8%)	CP (-3%) PT (3%) C (2%) W (2%)

De Witte et al. (2006)	Subsidies for public transport (100%)	Quantitative survey and analysis of the materials based on the structural method	3,162	Brussels, Belgium	2003–2004 (academic year)	Share of new users of public transport		T (17.55%) M (11.08%) B (13.69%)
De Borger & Wuyts (2011)	Optimal labor and congestion taxes (labor =86.45)	Numerical model		Belgium		Share of SOV use and public transport use	PC (-8.47%)	PT (+8.47%)
	Optimal labor and company car tax (labor =100)						PC (+2.38%)	PT (-1.38%)
	Optimal congestion tax and free public transport (labor=98.10)						PC (-2.82%)	PT (+2.82%)

Ubbels et al. (2012)	Complete abolition of fixed taxes and application of kilometer charges	Discrete choice modelling approach (multinomial logit model)			2008	Share of kilometers travelled per transport mode	PC (-10%)	PT (+2%)
	Tax on new cars modified to make it dependent on the car's environmental performance with an average level of fl 5000. (fl= Femtoliter; 1 fl= 10 ⁻¹⁵ liter.						PC (-8%)	PT (+1%)
	Kilometer charges+ incentive included to buy fuel-efficient cars						PC (-10%)	PT (+2%)
	Extra high level of a kilometer						PC (-9%)	PT (+9%)
Qi Sun et al. (2020)	Adoption of e-bikes	Econometrics of panel data	5,258	Netherlands	2013-2016	Modal share in distance travelled after the adoption of	PC (-5.6%)	E-bikes (100%) C-bikes (-38.3%)

						e-bikes		
Hammadou & Papaix (2015)	Carbon tax (1.6€/liter)	Discrete choice modelling approach (multinomial logit model)	8,990	Lille and Roubaix-Tourcoing, France	2006	Effect on modal shares (%)	PC (-1.06%) CP (-6.43%)	PT (+14.21%) W (+1.26%)
	Parking charges (10%)						PC (-0.19%) CP (-0.37%)	PT (+0.50%) W (+0.42%)
	Parking charges (50%)						PC (-0.77%) CP (-3.03%)	PT (+4.50%) W (+1.70%)
	Cordon toll (1.2 €/day)						PC (-0.70%) CP (-4.57%)	TP (+9.21%) W (+1.01%)
	In-vehicle travel time improvements of 10%.						PC (-0.04%) CP (-0.62%)	TP (+1.40%) W (-0.02%)

	Parking charge (50%) & Cordon toll (1.2 €/day)						PC (-1.69%) CP (-7.73%)	PT (+16.02%) W (+2.64%)
	Parking charge (50%) & Cordon toll (1.2 €/day) & in-vehicle travel time improvements of 10%.						PC (-1.91%) CP (-8.66%)	PT (+19.52%) W (+2.62%)
Agarwal & Koo (2016)	Congestion toll tax (increasing by \$1 in the morning)	Multiple regression	77	Singapore	2 months	Increasing bus use		B (+8%)
	Adjusting the tax from \$0.5 to \$1 in the evening							B (+10%)
Albalate & Gragera (2020)	Regulated spaces (Parking spaces per 1000 inhabitants: commercial, mixed-use, resident-exclusive)	Panel data modeling	72	Barcelona, Spain	2007-2014	Car ownership ratio measured by number of cars per thousand	PC (number of cars = +0,26)	

						inhabitants		
	Parking fee (average weighted curbside parking fee)						NS	
Steininger et al. (2007)	Road pricing 5 euro-cents/km without time differentiation	Computable general equilibrium model	1 country	Austria	2000	Modal shift (in terms of number of passengers/k m)	PC (-6.5%)	PT (+6.3%)
	10 euro-cents/km						PC (-14%)	PT (+15%)
Asensio et al. (2014)	Reduction of 5% in commuting and regional train fares	Panel regression	48 Spanish provinces	Spain	2008- 2011	Gasoline consumption (%)	PC (-2-3%)	

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Legend: AC=Active mode/B=bus/C=cycling/CP=carpooling/PC= private car/ PT=public transport/M=metro/NS=No significant /SM=sustainable mobility/S=scooter/T=tram/W=walking

Appendix 2

Table 6: *Non-economic incentives.*

In green, the results showing the effectiveness of the measures blue, the results showing the ineffectiveness of the incentives; (**) = low significance, (***) = high significance, NS=not significant.

Authors	Type of incentives	Method used	Number of observations	Period	Geographical area	Observed variables	Results	
							PC	SM
Ingvardson & Nielsen (2019)	Overall satisfaction	Structural equation modeling	38,537	2009–2015	Stockholm, Sweden; Oslo, Norway; Helsinki, Finland; Copenhagen, Denmark; Vienna, Austria; and Geneva, Switzerland.	The use of public transport		PT (***)
	Norms							PT (**)
	Recommendation to others							PT (*)

Shang-Yu Chen (2016)	Perceived green value of public bikes	The modified technology acceptance model (TAM) and structural equation modeling	522	August-September 2014	Taipei, Taiwan	Green loyalty to public bikes for non-users		C (**)	
	Perceived pleasure to use							C (***)	
	Perceived green usefulness							NS	
	Subjective norms							C (***)	
	Perceived behavioral control							NS	
Geng et al. (2016)	Information and communication	Questionnaires	452	November 2015	Xuzhou, China	Differences in attitudes towards transport modes before and after the experiment	NS	Green modes (+0,85%) ***	
De Vos et al. (2020)	Satisfaction with PT	Ordered logit model	986	2013	Canada	Desired frequency	PT	PT (1,73) odds ratio	
						Actual frequency	PT	PT (1,70) odds ratio	
	Attitudes towards PT						Desired frequency	PT	PT (27,83) odds ratio
							Actual frequency	PT	PT (4,58) odds ratio

Kroesen & Chorus (2018)	General attitudes	Structural equation model and cross-lagged panel model	1,082	July 2013–July 2014	Netherlands	Mode choice behavior	NS	NS
	Specific attitudes						(***)	SM (***)
Gutierrez et al (2020)	Habits to use bicycle (spontaneity)	Discrete choice modelling approach (hybrid ordinal logit model)	805	March–May 2018	Santiago, Chile	Significance on bicycle use		C (***)
	Perception of use of bicycle (Risk)							C (***)
	Bicycle facilities							C (***)
Stark et al. (2019)	Age (+) Kids	Descriptive-exploratory analyses	129		Vienna, Austria		PC (***)	B (***)
	Age (-) Kids						PC (***)	W (***)
	Attitude towards respect for the environment and health						PC (***)	W (***) C (***) S (***)
	Specific attitudes related to transport modes (wellbeing during a trip)						PC (***)	W (***) C (***) S (***)

Piwek et al. (2015)	Self-monitoring for competitive cyclists	Qualitative and quantitative methods	23	Five weeks	England	Frequency and long distances travelled by bicycle		C (***)
	Self-monitoring for non-engaged cyclists							C (*)
Bucher et al. (2019)	A more accurate tracking with eco-feedback via an application	Surveys	261	Six weeks	Zurich, Switzerland	Modal shift after use of application for systematic loops	PC (-24%)	PT (+7,9%) C (+12,5%) W (+5%)
Pangbourne et al. (2020)	type of argument in the persuasive message: 'Authority'	A linear mixed effect	406		England	Impact on behavioral change for walking adoption		W (***)
	Value of argument in the persuasive message: 'Health'							W (***)
Gardner (2009)	Intention	Surveys	102	2 weeks	Netherlands	Behavioral change for the use of a mode		C (***)
	Habit							C (***)
	Strong habit x low intention							C (***)
	Low habit x strong intention							C (***)
Kang et al. (2019)	Convenience	Structural equation modelling	307		Malaysia	Intention to switch to public transport		PT (**)
	Flexible service					Intention to switch to public transport		PT (**)

	Commuter impedance					Intention to switch to public transport		PT (*)
	Intention to switch for public transport					Behavioral readiness to adopt public transport		PT (***)
Tsirimpa et al. (2019)	Reward system via a mobile application	Discrete choice modelling approach	706	6 weeks	Vienna, Austria and Birmingham, UK	Average travel time by mode of transport for car users (Birmingham)		PT (+108 min) C (+15 min) W (+67 min)
Lois et al. (2015)	Social identity	Structural equation modelling	595	2012	Victoria-Gasteiz, Spain	Intention to begin cycling among car users		C (***)
Lind et al. (2015)	Personal norms	Structural equation modelling	1,043	2013	Norway	Predicting transport mode		PT (***) AC (**)
	Ascription of responsibility							PT (*) AC (***)

Legend: AC=Active mode/B=bus/C=cycling/CP=carpooling/PC= private car/ PT=public transport/M=metro/NS=No significant /SM=sustainable mobility/S=scooter/T=tram/W=walking

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CHAPTER 2

The impacts of combining incentives on carpooling for commuting in Paris Metropolitan area

Abstract: Carpooling is one solution to help reduce the negative externalities of solo driving. Several studies have set out to encourage carpooling through either economic or non-economic incentives. However, there is little research on combining economic and non-economic incentives to shift commuter behavior from solo driving to carpooling (to work or school). Here, 1502 respondents, including 509 car drivers, living in the Paris metropolitan area were surveyed by questionnaire, and econometric modeling was performed using multinomial logit (MNL) and binomial logit models. First, we analyzed the effect of non-economic incentives, such as nudges and trust in others, when carpooling is considered in isolation. Second, we analyzed the effect of the combination of nudges with employer subsidies for sustainable mobility on intention to carpool as driver or passenger for the home-to-work (or home-to-school) commute. The results show that nudges are more effective among younger and more educated people as a way to encourage them to carpool more. Applying nudges in isolation appears to be more effective at encouraging carpooling for commuting than combining nudges with employer subsidies for sustainable mobility.

Keywords: Carpooling for commuting, economic incentives, Non-economic incentives, Nudge, Sustainable mobility, Travel behavior.

1. INTRODUCTION

As of 1st January 2021, the number of private cars in circulation in France was 38.3 million (Données et études statistiques, 2021). In 2017, the modal share of car travel for commuting trips in France was 73.7% (Insee, 2021). Increasing use of private cars intensifies negative externalities such as air pollution, noise, congestion, and traffic accidents. In recent years, policymakers have agreed to progressively internalize these externalities by restricting the use of private cars and encouraging a modal shift to more sustainable mobility solutions. The promotion of daily carpooling (or ridesharing) is one of the solutions that the European Economic and Social Committee (2014) recommends as a way for local authorities to reduce the negative externalities associated with solo driving. However, the work of Coulombel *et al.* (2019) shows that behavioral changes (leading to modal shift) can lead to rebound effects that mitigate the environmental benefits of carpooling (or ridesharing). Carpooling involves two or more participants traveling in the same car, which reduces the number of single-occupancy vehicles on the roads (Neoh *et al.*, 2015).

Many studies have shown that carpooling can bring economic gains but also often faces social or psychological barriers. Economic gains can encourage carpooling through economic incentives to price solo driving (stick effect) or through economic assistance (carrot effect) (Bulteau *et al.*, 2021). For example, rising gasoline prices due to the Russia-Ukraine crisis have led to increased registrations on carpooling platforms. Economic incentives encompass taxes or fees, subsidies, and cap-and-trade systems for greenhouse gas emissions (Santos, 2018). However, several studies have challenged the effectiveness of economic incentives to encourage carpooling, and some of them have proven the ineffectiveness of the stick approach (Mcshane and Mayer, 1982; Peters and Gordon 2009) and the carrot approach (Ciari.2012) when applied independently.

The non-economic incentives considered here are psychological factors, which are critical elements in decisions on whether to carpool (Gardner & Abraham, 2007). The literature shows that Azjen's theory of planned behavior (Azjen, 1991) can successfully explain travel behavior, specifically carpooling for commuting (Bulteau *et al.*, 2021). Behavioral interventions can influence individual travel behavior (Gravert & Collentine. 2021). One of the tools used in the framework of behavioral interventions is 'nudges' (Thaler & Sunstein, 2009). Nudging aims to modify individual behaviors by adapting the decision environment to influence an individual's decision to take action (Thaler & Sunstein, 2009). Studies have demonstrated that nudging is effective in several areas of behavior, such as healthy consumption (Venema *et al.*, 2020), green purchasing (Becchetti *et al.*, 2020), waste reduction (Chakravarty & Mishra. 2019), and sustainable mobility (Hilton *et al.*, 2014). The types of nudges most frequently used in the environmental domain, as in sustainable mobility, are social norms, which can be descriptive (Carlsson *et al.*, 2021) or injunctive (Xinze *et al.*, 2022). For example, Bulteau *et al.* (2019) showed that the decision to carpool for commuting correlates with having family members or colleagues who carpool. Note that dispositional trust is an equally important determinant of intention to carpool. Individuals who trust strangers will see themselves as more capable of carpooling as either a driver or passenger (Bachmann *et al.*, 2018).

Despite all these reported benefits of nudges, other studies have shown them to be ineffective (Kristal & Willans, 2019) or insufficient (Gravert & Collentine, 2021). Given these limitations, it can be hypothesized that a combination of economic and non-economic incentives would effectively increase the modal shift from solo driving to sustainable mobility solutions, particularly carpooling for commuting (Bulteau *et al.*, 2021). Very few studies have investigated combined incentives for carpooling. Here we address this gap by conducting a study that explores how to encourage carpooling for commuting (or school) in the Paris metropolitan area (Ile-de-France region) via a combination of economic and non-economic incentives. The major contribution of this study is that we used data from a questionnaire on 1502 respondents including 509 motorists in the Ile-de-France region to separately test (1) the effect of non-economic incentives, such as nudge and carpooling with a stranger, on intention to carpool to work as either driver or passenger, and (2) the effect of the combination of nudge and

a economic incentives. The *nudge* used in this study is the injunctive standard used in Hilton *et al.* (2014). *The economic incentives* refers to employer subsidies for sustainable mobility (called 'Forfait mobilité durable', or FMD, in French). This subsidy is a scheme implemented in France that enables companies to provide their employees with a budget to cover the costs of commuting by bicycle, carpooling as a driver or passenger, and public transportation. In this paper, we measure the intention to shift travel behavior and adopt carpooling for commuting as a driver or passenger. Specifically, we test the hypothesis that a combination of specific economic and non-economic incentives would be more effective than these same incentives taken separately. To our knowledge, this is the first study to analyze the effect of the combination of FMD and nudge on shifting commuter behavior from solo driving to carpooling.

Section two of this paper reviews the literature on the impact of non-economic incentives such as nudges on sustainable travel behavior, trust in others for carpooling, and combining nudge with economic incentives. Section three discusses the methodology used, including the sample surveyed and the econometric models used, such as multinomial logit (MNL) and binomial models. Section four presents our results. Section five discusses our findings, and section six concludes.

2. LITERATURE REVIEW

2.1. Non-economic incentives for sustainable travel behavior

2.1.1. Nudges

Nudges as non-economic incentives are expected to play a similar role in transportation decisions to economic incentives (Riggs, 2017). As a trigger for new pro-environmental behaviors, social norms are the most studied nudges in the literature. Social norms can be considered either as a descriptive nudge (Carlsson *et al.*, 2021) or an injunctive nudge (Hilton *et al.*, 2014). Bicchieri & Dimant (2019) define a *descriptive nudge* as a nudge that aims to induce a desired behavior by influencing expectations about what most people in the same situation do. An *injunctive nudge* relates to perceptions of an individual's behaviors that are either approved or disapproved of in their sociocultural context (Cialdini, 2003). Hilton *et al.* (2014) showed the effect of the injunctive norm on sustainable mode choices. They used the injunctive norm as a simple message and included emoticons in a hypothetical scenario proposed to students from Toulouse who had to choose between the train and the plane to take a Toulouse–Paris trip (about 600 km) for a job interview. The message encouraged respondents to choose the train as a way to avoid significant disruptions at the airports, and the emoticons (happy/unhappy) were linked to the choices of each transport mode—a happy emoticon for choosing the train and an unhappy emoticon for choosing the plane. For the students, the choice of taking a train was linked to a lower environmental footprint than taking a plane. The study found that the nudge device increased preference for the train over the plane. Riggs (2017) also showed the effectiveness of social norms as non-economic incentives to choose sustainable transport modes on the Cal Poly campus in San Luis Obispo, US. Raux *et al.* (2021)

analyzed the effect of injunctive and descriptive norms and information on CO2 emissions (as non-economic incentives) plus a carbon tax and a bonus-malus fiscal system (as economic incentives) on transport mode choices long-distance leisure travel between bus, train, car, and plane in eight French metropolitan areas. An intervention providing CO2 emissions data on each mode was found to decrease the stated preference for the highest CO2-emitter modes, such as air travel, and increase the choices for the lowest-emitting mode, i.e. train. When the injunctive standard and the CO2 information were combined, choice of air travel decreased slightly. However, adding the descriptive standard to the other nudges appeared counterproductive, as choice of air travel increased.

Studies investigating the effect of nudges on carpooling choices give mixed findings, with some studies finding that nudges are effective for pro-sustainable mobility, and others that they are not. In a study to estimate end-to-end travel-time values for commuting in the Lyon metropolitan area, Le Goff *et al.*, (2022) showed that the individuals most likely to switch from carpooling as drivers to carpooling as passengers were those who are environmentally conscious and consider solo driving a significant source of air pollution.

Kristal and Whillans (2019) showed that nudges were ineffective in shifting choices towards carpooling from home to work or to study and suggested that nudges may be ineffective in changing habitual travel behaviors. Gravert & Collentine (2021) found no successful effect of descriptive nudges on public transport choice in Sweden, and they proposed adding a strong economic incentive to increase use of public transport through the formation of travel habits. Given the divergent results of recent studies, there is a need to continue testing the impact on sustainable travel behavior of nudges in isolation and in combination with other incentives, especially economic ones.

2.1.2. Increased trust in others for carpooling to work

Socializing with strangers such as carpoolers remains a challenge (Gardner & Abraham, 2007). Morency (2007) studied the evolution of the urban carpooling market in the Greater Montreal area and showed that social and value differences among potential carpoolers are barriers to adoption. Charles & Kline (2006) extended the analysis by singling out race as a social factor in carpooling. They also highlighted that individuals are more likely to carpool when they can carpool with passengers that share their values. Another determinant of carpooling is dispositional trust. Some drivers value their personal space and privacy, which deters them from carpooling (Correia & Viagas, 2011). Thus, the people most likely to carpool are those who trust strangers and see themselves capable of becoming passengers or drivers in the carpool crew (Bachmann *et al.*, 2018). Trust in carpooling also differs by gender. Studies have shown that women are less likely to carpool than men (Morency, 2007; Ciari, 2012), and the reason for this is believed to be a sense of insecurity. Thus, Bulteau *et al.* (2021) suggested that women would be more incited to carpool to work with a work colleague, which would remove this psychological barrier.

2.2. Nudges and economic incentives for sustainable travel behavior

Given the different limitations of economic and psychological incentives taken in isolation in terms of prompting a modal shift toward sustainable mobility solutions, some works advocate combining both these types of incentives (Hilton *et al.*, 2014; Raux *et al.* 2021; Bulteau *et al.* 2021, Le Goff *et al.*, 2022). Hilton *et al.* (2014) combined the bonus-malus as an economic incentive and the injunctive norm as a non-economic incentive and showed that the combination of incentives increased preferences for long-distance rail travel relative to air travel. However, this combination only proved effective when the economic incentives (bonus-malus) was low, as an over-high economic incentive erodes the intrinsic motivation to choose a sustainable transport mode. In contrast, Gravert & Collentine (2021) suggested that a higher and longer-lasting economic incentives (a free public transport card) combined with a descriptive norm as a non-economic incentive should lead individuals to change their travel behavior and opt for public transport. The descriptive standard they used was a message stating the modal share of public transport trips by neighbors relative to the sample respondents. Raux *et al.* (2021) showed that improving the provision of CO2 information through a tax incentive such as a bonus-malus reduces preferences for CO2-emitting transport modes. A formulation of the tax incentive in the form of personal carbon trading credit with the provision of CO2 information as a non-economic incentive reduced choice for air travel, but only moderately. Bulteau *et al.* (2021) suggested that combining economic and psychological incentives may effectively promote carpooling for commuting in the Paris metropolitan area.

Moreover, the determinants of carpooling differ for drivers versus passengers, and the incentives to encourage carpooling vary according to individual profiles. Eriksson *et al.* (2008) argued that combinations of economic and non-economic incentives must be analyzed according to geographic context and target motorist. Riggs' (2017) results do not support combining economic incentives with nudges as non-economic incentives. Riggs analyzed the impact of economic (donations) and human (altruistic action) incentives on active transportation habits (biking and walking) at U.S. universities and found that combining these two forms of incentives makes them less effective. Indeed, economic agents perceive a nudge as coercive when it is combined with an economic incentives. To summarize, the literature finds mixed results on the potential effect of combining economic and non-economic incentives to drive a modal shift towards sustainable mobility solutions, especially in carpooling. This review thus finds a need to continue testing the combination of nudges as non-economic incentives with other economic incentives for carpooling in various geographic contexts.

3. METHODOLOGY AND RESULTS

3.1. Study design and sampling

This study set out to measure intention to change travel behavior by adopting carpooling for commuting as a driver or passenger. We designed a questionnaire for

active individuals or students living and working (or studying) in the Paris metropolitan area (Ile-de-France region), or people in job search situation. The questionnaire was administered to 1502 respondents in June 2021 by the Dynata survey institute. The sample selected is representative of the Ile-de-France population in terms of variables such as the gender, age, and *Département* of residence. The *département* is a disaggregated territorial unit encompassed within the Ile-de-France region, at a higher tier than.

After cleaning the database and deleting missing values, we ended up with a final sample of 1326 respondents. We focused on respondents who reported using solo driving as their main mode of transport for daily commuting: 509 (44.50%) out of the initial set of 1326 respondents reported that they were the driver of the car used for their commute.

3.2. Individual, socio-demographic and transport-related variables

The questionnaire was divided into three parts. The first part addressed the socio-demographic characteristics of the respondents, such as age, gender, income, level of educational attainment, socio-professional category, household size, home address, and work address. The second part was related to the respondents' current travel habits (outside of lockdown periods, during the Covid-19 crisis). Each respondent was asked about:

- The mode of transport used to get to their place of work (or study)
- The distance of their commute
- The monthly budget allocated to commuting
- Possession of a driver's license
- Car ownership
- The availability of the transport mode (car, traditional bike, electric-assist bike, two-wheeled motorized, standing (kick scooter).

The third part consisted of questions designed to test the respondent's intention to carpool for commuting as a driver and/or a passenger.

The respondent was presented with a hypothetical scenario in which he/she had to choose between three transport alternatives such as solo driving, carpooling as a driver and carpooling as a passenger. The choice of each transport alternative was made based on general attributes (travel time, travel cost), which were different for each transport alternative, and on three specific attributes related to the incentives to be tested: (1) Employer subsidies for sustainable mobility (FMD) as a economic incentives, (2) nudges as non-economic incentives and (3) greater trust in others during carpooling as a non-economic incentives. We specified the distance traveled in the scenario and assumed that there were no practical obstacles (like detours) to carpooling for commuting.

3.3. Contextual variables

We accounted for geographic-context variables, such as the respondent's place of residence and place of work. Each individual's place of residence and place of work was

assigned to a *Département*: (1) central Paris (*Département* 75), (2) inner suburbs (*Départements* 92, 93, or 94), or (3) outer suburbs (*Départements* 77, 78, 91 or 95) and include the *Départements* located on the outskirts of the Ile-de-France region (Fig 14). The relevance of this geographical division is linked to the tension in the effectiveness of daily carpooling between (1) the prevalence of using private cars in the outer suburbs for commuting trips, as an opportunity for carpooling, and (2) the need to reach a critical mass of users to allow the formation of carpool crews, which requires achieving a certain level of human density which can be found in central Paris and the *Départements* of the inner suburbs, but not in the *Départements* of the outer suburbs which tend to be less urbanized.

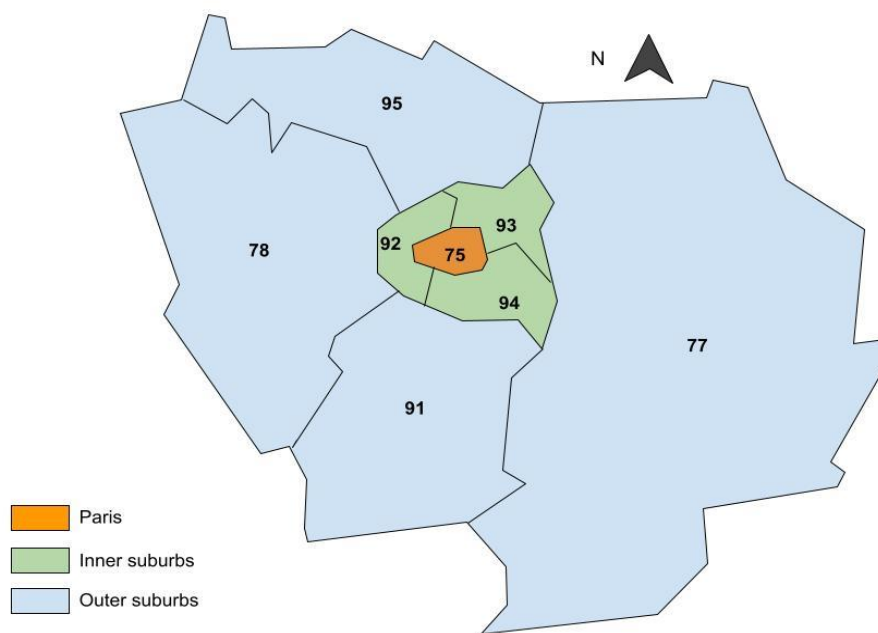


Figure 14: *The administrative organization of the Ile-de-France region*

3.4. Description of the sample

Other characteristics of the respondents are shown in Table 7. The final sample of 1326 respondents comprise 49.47% men and 50.45% women. Most respondents were between 35 and 49 years old (36.05% of the sample) and had a relatively high level of educational attainment, as 42.01% of the respondents had studied to undergraduate or graduate level. Concerning socio-professional category, a large proportion of respondents were employees (30.76%) or executives (29.18%). Concerning respondent socio-demographics, 45.70% of the respondents lived in the outer suburbs and 32.05% worked there. Only 20.29% of respondents did not own a car, and 23.83% owned at

least two cars. A large share of respondents (44.95%) commuted primarily using public transport, while 38.39% commuted by solo driving.

Table 7: Descriptive data on the sample (N=1326)

N= 1326		N= 509
Variables	Subsample (%)	Car Driver (%)
Individual and socio-demographic variables		
Gender	1.326	509
Female	669 (50.45%)	233 (46%)
Male	656 (49.47%)	276 (54%)
Age	1.326	
18–24	225 (16.97%)	38 (7.5%)
25–34	273 (20.59%)	134 (26%)
35–49	478 (36.05%)	205 (40%)
50 years and older	350 (26.40%)	132 (26%)
Income per household €	1.326	509
<500–1000	71 (5.35%)	15 (2.9%)
1001–2500	323 (24.36%)	109 (21%)
2501–4000	397 (29.94%)	160 (31%)
4001–9000	418 (31.52%)	193 (38%)
>9000	66 (4.98%)	16 (3.1%)
DWA *	51 (3.85%)	16 (3.1%)
Education level	1.326	509
<bac	129 (9.73%)	53 (10%)
Bac (high school diploma)	270 (20.36%)	78 (15%)
bac +2/3/4	557 (42.01%)	219 (43%)
≥ bac+5	370 (27.90%)	159 (31%)
Socio-professional category	1.326	509
Farmers	62 (4.68%)	28 (5.5%)
Inactives	47 (3.54%)	16 (3.1%)
Executives	387 (29.18%)	168 (33%)
Middle management	221 (16.67%)	102 (20%)
Employees	408 (30.76%)	165 (32%)
Workers	20 (1.51%)	7 (1.4%)
Retirees	27 (2.04%)	12 (2.4%)
Students	154 (11.61%)	11 (2.2%)
People per household	1.326	509
1	269 (20.29%)	77 (15%)
2	337 (25.41%)	121 (24%)
3	280 (21.12%)	115 (23%)
≥ 4	440 (33.18%)	196 (39%)
Number of cars owned by household	1.326	509
0	265 (20.29%)	6 (1.2%)
1	745 (56.18%)	327 (64%)
≥ 2	316 (23.83%)	176 (35%)
Contextual variables		
Place of residence	1.326	509
Paris	248 (18.70%)	80 (16%)
Inner suburbs	472 (35.60%)	139 (27%)
Outer suburbs	606 (45.70%)	290 (57%)
Place of work or study	11.26	
Paris	484 (36.50%)	122 (24%)
Inner suburbs	417 (31.45%)	249 (49%)

Outer suburbs	425 (32.05%)	138 (27%)
Travel habits		
Main mode of transport	1.326	509
Car as driver	509 (38.39%)	-
Car as passenger	33 (2.49%)	-
Public transport	596 (44.95%)	-
Motorized two-wheeler	30 (2.26%)	-
Walking	88 (6.64%)	-
Traditional bicycle	25 (1.89%)	-
DWA = Don't want answer		-

3.5. Econometric models

The econometric modeling is done in two steps. First, we modeled the choice of transport modes, i.e. solo driving, carpooling as a driver, and carpooling as a passenger, using MNL (Ben Akiva & Lerman. 1985). Theoretically, we assume that these modalities are nominal, and take solo driving as the reference. This model will be used as a baseline model, with no incentives (economic or nudges) considered, and the MNL estimation identifies respondents' mode choice without incentives (Table 8). The expression of the MNL model for nominal polytomous variables is written as follows (Greene, 2011):

$$p_{ij} = \frac{\exp(w'_i \beta_j)}{1 + \sum_{k=1}^J \exp(w'_i \beta_k)}, j = 0, 1, \dots, J. \quad (1)$$

where j is reference modality of the response variable, $j = 0, 1, \dots, J$, the w'_i explanatory variables and β_k is the k coefficient of the model.

Secondly, in order to analyze change in travel behavior through the economic and non- incentives proposed in the questionnaire, we used logit models. Initially, we have a polytomous variable with J modalities. We can transform the J variables into a set of $J-1$ dichotomous dummy variables, to thus obtain several binomial models (Bressoux, 2010). We consider only the individuals who responded by choosing solo driving in the first scenario (MNL model). Then, we analyze the effect of incentives on their intention to carpool from home to work or home to place of study as a passenger or as a driver by running three binary logistic regressions: (1) the effect of nudges as non-economic incentives (Table 9) (Hilton, 2014); (2) the effect of carpooling with a stranger as another non-economic incentive; (3) the combination of nudges and FMD as a economic incentive. As indicated in section 1, FMD is a subsidy granted in France by employers to employees to finance part of the cost of their commuting trips. This subsidization package rewards more sustainable modes of commuting than solo driving, such as public transport, carpooling, car-sharing services, and cycling.

The logit model is a dichotomous model that works to the premise that, for an explained variable, an individual will make the choice that brings them the greatest utility (Greene, 2011). A logit model defines the probability associated with an event $y_i = 1$ as the value of the distribution function of the logistic law considered at point $X'\beta$. The expression of the logit model is written as follows (Greene, 2011):

$$p(y_i = 1|x) = \frac{\exp(X'\beta)}{1 + \exp(X'\beta)} \quad (2)$$

where X' is a vector of variables that explain an event.

To summarize, four different models are estimated:

- *Model M1*: MNL model, which is the baseline model without incentives.
- *Model M2*: logit model with nudges as non-economic incentives.

- *Model M3*: logit model that tests commuting with a stranger.
- *Model M4*: logit model that tests the combination of FMD as a economic incentives and nudges as non-economic incentives.

The maximum likelihood estimation process was used to estimate the β parameters of the models (Greene, 2011). Multicollinearity was controlled by measuring variance inflation factors (VIF). All values are lower than 2. A Hosmer-Lemeshow test was used to check the overall significance of the models, and all the p-values were greater than 0.05, implying that the models fit the data.

Table 8: Scenario without incentives










Modes of transport	 Driving alone in the car	 Carpooling as the driver	 Carpooling as the passenger on board
Travel Time	15 min	18 min	20 min
Travel cost	4.80 €	1.60 €	1.60 €
Choice	Choice A	Choice B	Choice C

Table 9: Scenario with nudge as a non-economic incentive

"Research by scientific experts has shown that traditional road transport (car) is the main emitter of different types of pollution such as CO2 emissions, fine particles that negatively impact the environment. Driving alone negatively impacts the environment more than carpooling because the same amounts are emitted to transport one passenger instead of 3".

Modes of transport	 Driving alone in the car	 Carpooling as the driver	 Carpooling as the passenger on board
Travel Time	15 min	18 min	20 min
Travel cost	4.80 €	1.60 €	1.60 €
Nudges	 Negative impact on environment	 Less negative impact on environment	 Less negative impact on environment

Choice	Choice A	Choice B	Choice C
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4. RESULTS

4.1. Multinomial logistic model (M1. without incentives)

Multinomial model M1 considered all alternatives: solo driving (set as reference), carpooling as a driver, and carpooling as a passenger. This model represents scenario 1, as respondents are not subject to economic or non-economic incentives. The model's estimation identifies the respondent characteristics that play a significant role in the choice of driver and passenger carpooling. The results of this estimation are presented as odds ratios (OR) in Table 10.

4.1.1. Carpooling as a driver

- **Individual and sociodemographic variables**

Model M1 shows little correlation between individual sociodemographic variables and the probability of choosing carpooling as a driver. The probability of choosing carpooling as a driver was higher for households with an income between 1001–2500 euros (OR = 2.30, 95% CI = 1.25- 4.22) than for households with an income between 2501–4000 euros. Households consisting of four or more people (OR = 2.88, 95% CI = 1.36-6.12) have a higher probability of choosing driver carpooling than individuals living alone.

- **Contextual variables**

The results also show significant contextual variables. Living in central Paris (OR = 1.95, 95% CI = 0.90-4.24) increased the probability of choosing carpooling as a driver compared to living in the inner suburbs. Respondents who work in the outer suburbs are 0.53 times less likely to choose carpooling as a driver than respondents who work in the inner suburbs.

4.1.2. Carpooling as a passenger

- **Individual and sociodemographic variables**

Model M1 found some individual sociodemographic variables that were significant factors for carpooling as a passenger, such as the level of education, socio-professional category, and number of people in the household. Individuals with a bachelor's degree (OR = 0.30, CI = 0.10-0.93) and a master's degree or higher (OR = 0.29, CI = 0.09-0.90) were less likely to choose carpooling as a passenger than individuals with less than a bachelor's degree. The probability of choosing carpooling as a passenger was higher for households composed of four or more people (OR = 3.28, 95% CI = 1.21-8.87) than for individuals living alone. People who own a car (OR = 0.12, 95% CI = 0.01-1.30) or two cars (OR = 0.9, 95% CI = 0.01-1.09) were less likely to choose carpooling as a passenger compared to not owning a car.

- **Contextual variables**

For the contextual variables, respondents living in the outer suburbs were 0.45 times less likely to choose carpooling as a passenger than respondents living in central Paris.

Table 10: Multinomial Logit Model (M1)

Variables Units	Carpooling as a driver			Carpooling as a passenger		
	Odds ratio	95% CI	p-value	Odds ratio	95% CI	p-value
Individual and socio-demographic variables						
Age						
50 years and older (<i>Ref</i>)	—	—		—	—	
18–24	0.95	0.36–2.47	>0.9	1.44	0.42– 4.99	0.6
25–34	1.34	0.72–2.46	0.4	1.16	0.48– 2.83	0.7
35–49	1.11	0.66–1.88	0.7	1.21	0.58– 2.56	0.6
Gender						
Female (<i>Ref</i>)	—	—		—	—	
Male	0.80	0.53–1.21	0.3	1.00	0.57– 1.77	>0.9
Income per household €						
2501–4000 (<i>Ref</i>)	—	—		—	—	
500–1000	0.63	0.16–2.55	0.5	0.94	0.17–5.34	>0.9
1001–2500	2.30***	1.25–4.22	0.007	1.35	0.58–3.10	0.5
4001–9000	1.11	0.67–1.85	0.7	0.72	0.36–1.44	0.4
>9000	1.50	0.50–4.52	0.5	0.30	0.03–2.70	0.3
DWA*	0.90	0.27–2.94	0.9	0.45	0.05–3.92	0.5
Education level						
<bac (<i>Ref</i>)	—	—		—	—	
Bac (High school diploma)	1.27	0.56–2.90	0.6	0.30**	0.10–0.93	0.038
bac2-4	0.98	0.45–2.13	>0.9	0.46	0.17–1.21	0.11
>bac+5	0.83	0.34–2.00	0.7	0.29**	0.09–0.90	0.033
Socio-professional category						
Executives (<i>Ref</i>)	—	—		—	—	
Farmers	1.75	0.22–14.0	0.6	0.00***	0.00–0.00	<0.001

inactives	0.37	0.09–1.49	0.2	0.00***	0.00–0.00	<0.001
Artisans	0.45	0.17–1.19	0.11	0.26*	0.05–1.26	0.095
Middles management	0.85	0.46–1.57	0.6	0.88	0.38–2.01	0.8
Employees	0.74	0.40–1.35	0.3	0.59	0.25–1.36	0.2
Workers	0.47	0.08–2.91	0.4	0.37	0.03–4.26	0.4
Retirees	0.63	0.15–2.62	0.5	0.91	0.16–5.32	>0.9
Students	1.68	0.43–6.64	0.5	0.62	0.08–4.68	0.6
People per household						
1 (<i>Ref</i>)	—	—		—	—	
2	1.54	0.75–3.17	0.2	0.90	0.32–2.47	0.8
3	1.87	0.87–4.04	0.11	1.74	0.62–4.84	0.3
≥ 4	2.88***	1.36–6.12	0.006	3.28**	1.21–8.87	0.020
Number of cars owned by household						
0 (<i>Ref</i>)	—	—		—	—	
1	0.32	0.03–3.65	0.4	0.12*	0.01–1.30	0.081
≥ 2	0.44	0.04–5.14	0.5	0.09*	0.01–1.09	0.059
Contextual variables						
Place of residence						
Inner suburbs (<i>Ref</i>)	—	—		—	—	
Outer suburbs	1.50	0.85–2.62	0.2	0.45*	0.19–1.02	0.057
Central Paris	1.95*	0.90–4.24	0.092	1.58	0.59–4.21	0.4
Place of work or study						
inner suburbs (<i>Ref</i>)	—	—		—	—	
Outer suburbs	0.53**	0.30–0.92	0.024	1.33	0.56–3.17	0.5
Central Paris	0.61	0.31–1.17	0.14	0.95	0.39–2.33	>0.9

4.2. Binomial logistic models (M2–M3–M4)

4.2.1. Impact of non-economic incentives on carpooling for commuting: nudges (M2).

• Individual and sociodemographic variables

The objective of estimating this model was to measure the impact of nudges as non-economic incentives on respondents' choices that lead to choosing carpooling as a driver or as a passenger. The results of the M2 model show significant individual socioeconomic and sociodemographic variables (Table 11). Positive impact of the nudges appears to be highly and negatively correlated with age of the respondents. Respondents aged 18–24 were 4.42 times more likely to choose to carpool as a driver or a passenger than those aged 50 and over. We found that under the effect of nudges, these likelihoods decrease as age increases. The odds ratio for choosing carpooling for commuting goes from 4.04 for people aged 25–34 to 3.19 for people aged 35–49. Some education levels are also correlated with choosing carpooling as a driver or a passenger. For example, graduate-level respondents were 3.88 times more likely to carpool than respondents with undergraduate level or less. Also, the nudges seem to positively affect decision to carpooling among employees (OR = 1.94, 95%CI = 0.91–4.21) compared to executives.

4.2.2. Impact of a non-economic incentives on carpooling with a stranger (M3)

The results presented in Table 11 show significant individual, sociodemographic and contextual variables for carpooling with a stranger, as a driver or a passenger. The odds of carpooling with a stranger are Respondents aged 18–24 were 2.79 times more likely to choose to carpool with a stranger than respondents aged 50 and over. Also, the probability of carpooling with a stranger was 2.02 times higher for men than women. Households with an income level between 1001 and 2500 euros were 0.21 times less likely to choose to carpool from home to work or place of study than households with an income between 2501 and 4000 euros. Among the socio-professional categories, only employees (OR = 2.43, 95%CI = 0.96–6.25) were more likely than executives to choose to carpool with a stranger.

Concerning the contextual variables, individuals living in central Paris (OR = 2.47, 95%CI = 0.91–6.69) were more likely to carpool with a stranger than those living in the inner suburbs. Living in the outer suburbs was not a significant factor for carpooling with a stranger.



4.2.3. Combination of economic and non-economic incentives (M4)

The results in Table 11 show that individual-level variables, such as respondent's age, and contextual variables, such as place of residence, are significant factors when combining the nudges with the FMD granted by the employer. The odds of respondents choosing to carpool as a driver or a passenger were higher for respondents aged 18–24 (OR=3.40–95%CI =1.14–10.0) and respondents aged 25–34 (OR=2.75, 95%CI=1.24–6.43) compared to respondents aged 50 and over. Regarding

the contextual variables, individuals living in central Paris were 2.01 times more likely to carpool than those living in the inner suburbs.

Table 11: Binomial logit models (M2-M3-M4)

Variables	Non-economic incentives only: nudges (M2)			Carpooling with a stranger (M3)			Combination of incentives: nudges + FMD (M4)		
	Odds ratio	95% CI	p-value	Odds ratio	95% CI	p-value	Odds ratio	95% CI	p-value
Individual and socio-demographic variables									
Age									
50 years and older (Ref)	—	—		—	—		—	—	
18–24	4.42**	1.22–16.6	0.024	2.64	0.55–12.0	0.2	3.40**	1.14–10.0	0.026
25–34	4.04***	1.54–12.1	0.007	2.79*	0.98–8.91	0.066	2.75**	1.24–6.43	0.015
35–49	3.19**	1.30–9.07	0.017	1.65	0.60–5.07	0.4	1.78	0.85–3.94	0.14
Gender									
Female (Ref)	—	—		—	—		—	—	
Male	1.57	0.91–2.76	0.11	2.02**	1.04–4.09	0.042	1.45	0.88–2.43	0.2
Income per household €									
2501–4000 (Ref)	—	—		—	—		—	—	
500–1000	2.29	0.65–7.78	0.2	1.32	0.24–5.74	0.7	2.34	0.73–7.31	0.14
1001–2500	0.53	0.23–1.19	0.13	0.21**	0.04–0.70	0.021	0.61	0.28–1.27	0.2
4001–9000	1.13	0.58–2.22	0.7	1.02	0.47–2.23	>0.9	0.90	0.49–1.68	0.7
>9000	0.70	0.10–2.95	0.7	0.74	0.10–3.38	0.7	0.78	0.16–2.79	0.7
DWA*	0.00	0.00–0.00	>0.9	1.94	0.27–8.94	0.4	0.39	0.02–2.17	0.4
Education									
<bac (Ref)	—	—		—	—		—	—	
Bac (high school diploma)	2.88	0.66–20.3	0.2	1.44	0.28–10.9	0.7	0.98	0.33–3.18	>0.9
bac2-4	3.88*	0.99–26.1	0.088	1.74	0.41–12.2	0.5	1.12	0.42–3.41	0.8
>bac+5	3.06	0.71–21.6	0.2	2.74	0.58–20.4	0.2	1.37	0.46–4.51	0.6
People per household									
1	—	—		—	—		—	—	
2	1.57	0.60–4.39	0.4	1.95	0.53–9.48	0.3	1.67	0.70–4.17	0.3

3	1.04	0.38–3.04	>0.9	1.20	0.30–6.02	0.8	1.04	0.42–2.72	>0.9
≥ 4	1.12	0.42–3.22	0.8	1.62	0.43–7.97	0.5	0.93	0.37–2.43	0.9
Number of cars owned by household									
0 (<i>Ref</i>)	—	—		—	—		—	—	
1	1.10	0.15–22.4	>0.9	0.41	0.05–8.61	0.5	1.08	0.16–21.7	>0.9
≥ 2	0.52	0.07–10.9	0.6	0.32	0.04–6.94	0.3	0.87	0.12–17.9	>0.9
Contextual variables									
Place of residence									
inner suburbs (<i>Ref</i>)	—	—		—	—		—	—	
Outer suburbs	0.88	0.40–1.93	0.7	1.28	0.47–3.62	0.6	1.32	0.62–2.88	0.5
Central Paris	0.99	0.40–2.49	>0.9	2.47*	0.91–6.69	0.073	2.01*	0.91–4.39	0.081
Place of work or study									
Inner suburbs (<i>Ref</i>)	—	—		—	—		—	—	
Outer suburbs	1.42	0.63–3.39	0.4	0.59	0.24–1.44	0.2	0.75	0.37–1.51	0.4
Central Paris	1.83	0.78–4.31	0.2	0.57	0.20–1.66	0.3	0.66	0.28–1.56	0.3
Factor (socio-professional category)									
Executives (<i>Ref</i>)	—	—		—	—		—	—	
Farmers	0.00		>0.9	0.00		>0.9	0.00		>0.9
inactives	1.71	0.28–8.04	0.5	2.92	0.33–17.4	0.3	2.14	0.51–7.84	0.3
Artisans	0.94	0.25–2.91	>0.9	2.31	0.59–7.66	0.2	1.29	0.43–3.45	0.6
Middles management	0.89	0.34–2.15	0.8	1.76	0.58–4.97	0.3	0.85	0.36–1.91	0.7
Employees	1.94*	0.91–4.21	0.089	2.43*	0.96–6.25	0.062	1.49	0.73–3.05	0.3
Workers	0.00	0.00–2-009-943-625-222	>0.9	0.00	0.00–28-560-125	>0.9	0.00		>0.9
Retirees	2.27	0.11–17.2	0.5	1.98	0.09–15.9	0.6	0.71	0.04–4.55	0.8
Students	1.17	0.18–6.25	0.9	2.12	0.21–16.7	0.5	1.03	0.20–4.69	>0.9
1*p<0.1; **p<0.05; ***p<0.01									
OR = Odds Ratio, CI = Confidence Interval DWA = Do not wish to answer  reflects that respondents characterized by the variable have a low chance of choosing the mode of transport over the reference  reflects that respondents characterized by the variable have a high chance of choosing the mode of transport over the reference									

5. DISCUSSION

The results obtained from the MNL model (M1) show that the choice to carpool to work is associated with a handful of individual socioeconomic variables, as highlighted in the literature (Ferguson, 1997; Buliung *et al.*, 2010; Cannig *et al.*, 2010). These variables include (i) low-income level (i.e., 1001-2500 euros in this study for carpooling as a driver) and (ii) low education level (less than university entrance for that carpooling as a driver and as a passenger).

The relationship between low income and carpooling practice is confirmed by the literature. Vanoutrive *et al.* (2012) and Bulteau *et al.* (2021) provided evidence that the likelihood of carpooling for commuting is higher for low-income classes than for high-income classes. The results on the relationship between education level and carpooling choice are consistent with Ferguson (1995), Molina *et al.* (2013), Friman *et al.* (2020), and Bulteau *et al.* (2021), which converge to show that higher education level is related to higher income level, which in turn is negatively related to pro-carpooling choice.

Concerning the individual transportation variable, car ownership is also a significant factor in the choice of passage carpooling. Income associated with car ownership is an economic determinant of carpooling for commuting for low-income and least-educated households. In addition, workers that share a household are likely to carpool due to the ease of matching within the household and the limited number of cars (Vanoutrive *et al.*, 2012). Carpooling choice was also associated with contextual variables, such as place of residence. Here, individuals living in the outer suburbs were more likely to carpool to work than those living in the inner suburbs. This is probably due to the higher commuting distances to be covered on average in less-urbanized areas that makes commuting more expensive and raises intention to carpool. Olsson *et al.* (2019) found that intention to carpool is positively related to population density. Higher population density and greater perceived accessibility are associated with greater rates of carpooling to work, as they make it easier to find a carpooler (Friman *et al.* 2020).

Estimates from the binomial models (M2–M3–M4) testing the impact of nudges, trust when carpooling, and the combination of nudge and employer subsidization for sustainable mobility lead to the conclusion that nudges are effective in prompting younger (18–49 years old) and more educated (undergraduate-to-graduate) employees to choose to carpool to work. This is consistent with the literature showing the effectiveness of nudges on young people (Vermeir & Verbeke, 2006; Miesler *et al.* 2017) and the fact that younger people practice carpooling more than older individuals (Abrahamse & Keall, 2012; Bulteau *et al.*, 2021). Young people have a deeper awareness of environmental challenges and engage in ecological recovery through active green behaviors (Calculli *et al.*, 2021). The utility value of carpooling for employees lies in the spatial and temporal regularity of commuting, which facilitates the organization of shared trips (Aguilera & Pigalle, 2021).

Our study shows that those who choose to carpool with a stranger (M3) are more likely to be 25–34-year-old males in the category of employees that live in central Paris. These results are consistent with the literature (Morency, 2007; Bulteau *et al.*, 2021). Carpooling carries a degree of insecurity that does not encourage women and the elderly people to carpool (Ciari 2012). Monchambert (2020) found that women were more likely to carpool than men, unless they carpooled with at least two passengers. Bulteau *et al.* (2021) argued that women would intend to carpool from home to work or study if they carpooled with a coworker and if carpooling was supported by a high economic incentive (in the form of a subsidy).

The combination of nudges as non-economic incentives and FMD as an economic incentive (M4) was effective for young people aged 18–34 and those who lived in central Paris and favored the choice of carpooling for commuting. Compared to M2, the application of nudges alone appears more effective than the combination of nudging with an economic pro-sustainable mobility package. In the context of the Ile-de-France region, this important result highlights that non-economic incentives alone are more effective than the combination of economic and non-economic incentives in improving carpooling for commuting. Our hypothesis, i.e. that specific economic and non-economic incentives would be more effective in combination than in isolation, is therefore disconfirmed. Two reasons could explain this result:

(i) The first explanation, given by Hilton *et al.* (2014), would suggest that the level of the economic incentives (the sustainable mobility package) was perhaps too high. The authors suggested that the economic incentives should not be too high in order to not erode the intrinsic motivation to choose the sustainable mode.

ii) The second explanation, which comes from Riggs (2017), is that economic agents perceive nudges as coercive when they are combined with a economic incentives. Mobility demand management involving pricing schemes and subsidies has become common practice, and so economic incentives have become price-inelastic and lost their value. The under-representation of economic incentives in incentive portfolios suggests a need to refocus on individual travelers' social and cultural values.

6. CONCLUSION

This paper analyzed the combination of economic (subsidization packages for commuters) and non-economic incentives (nudges) to encourage car drivers in the Paris metropolitan area to carpool to and from work or school. Our study uses a questionnaire surveying a representative sample of 1502 respondents, including 509 drivers, from the Ile-de-France region (Paris metropolitan area) commuter community, together with multinomial and binomial logit econometric models. The environmental,

economic and social benefits of carpooling for commuting push mobility management policies to encourage it (Vanoutrive *et al.*, 2012). Thus, combining nudges as non-economic incentives with other economic incentives could be an option to encourage carpooling for commuting (Hilton *et al.*, 2014). Our study shows that nudges are most effective in encouraging carpooling for commuting among higher-educated people aged 18–49 in employee-level jobs. This effectiveness is explained by young people's strong environmental awareness and the ease of carpooling for commuting among employees from the same large companies. Furthermore, men are more likely to carpool from home to work or school with a stranger than women. However, as the issue of trust in others is crucial, women may be encouraged to carpool if they have opportunities to form a carpool crew with a colleague. Individuals living in central Paris and employees are also more likely to carpool to work with a stranger. However, the combination of economic (subsidization packages for commuters) and non-economic incentives (nudges) to increase intention to carpool to work is only effective for young people (the 18–34 age-bracket) and those living in central Paris. This important result highlights that the combination of non-economic nudges and economic incentive (FMD) to carpool for commuting only works on specific population.

Therefore, in terms of public policy implications, we conclude that:

- i) Mobility management policies should target young people by using 'nudges' to foster encourage them further to choose carpooling for commuting as an alternative to solo driving. The sensitivity of young people to environmental issues can serve as a useful asset to give them further incentive to carpool to work.
- (ii) Employers need to implement carpooling-for-commuting services within their companies to give their employees, especially women, further incentive to carpool. Women will be more likely to carpool if they are in the company of co-workers during the trip.

In this context, the generalization of the FMD package for every worker in every company (the measure was not mandatory when it was voted in in France in 2019) is not necessarily a pressing policy directive, at least for the promotion of carpooling for commuting, as it only works for certain categories of employees (the youngest), and only in combination with nudges for this specific category. Promoting trust in others within companies, such as through social events or rating systems, could work better as a way to promote greater adoption of carpooling.

Despite the results and policy recommendations, our study has limitations. (i) First, our results are valid only for the Île-de-France region. (ii) Second, we did not test the effect of the FMD in isolation on carpooling choices for commuting. This analysis would have allowed us to estimate the weight of the FMD in the basket of combined economic and non-economic incentives. Nonetheless, we tested the effect of nudges in isolation on

carpooling choices for commuting. (iii) Third, other types of combinations of economic and non-economic incentives could have been tested.

Future research is planned to incorporate public transport and cycling as a mode of transfer from the private car and test other forms of economic and non-economic combinations to enhance a modal shift from solo driving to more sustainable mobility solutions for commuting trips.

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CHAPTER 3

Which combinations of incentives for transitioning towards sustainable mobility solutions for medium and short commuting trips in Ile de France?

Abstract: Reducing the negative externalities of road transport requires a reduction in private car use and a modal shift to other sustainable modes. However, little research has been conducted on combining economic and non-economic incentives to change commuter behavior, from solo driving to carpooling, public transit, and electric bicycles for medium and short distances (to work or school). Based on a questionnaire conducted on 1502 respondents in Ile-de-France, we model the impact of economic incentives for sustainable and non-economic mobility and the combination of both incentives on modal shifts for medium and short distances through nested Logit models. We examine separately (1) the impact of non-economic incentives such as nudging on medium-distance commuting trips. We also study the effect on the health of various transportation modes and the social norm for short-distance travel. Similarly, we examine (2) the impact of an economic incentive alone and (3) the combination of economic and non-economic incentives separately. The economic incentives refer to the employer's subsidy for sustainable mobility (called "Forfait mobilité durable" or "FMD" in French) and the 250-euro carbon tax. The results show that the combination of the 250 Euro carbon tax and nudge is very effective in shifting the modal shift to carpooling and public transport among young adults, low-income households, and people with a high level of education for medium distances. For short distances, nudge is effective for the choice of carpooling and electric bicycles among young adults and for the choice of public transport among people with a high level of education.

1. Introduction

The energy crisis caused by the war in Ukraine and the efforts of energy sobriety requested by the French authorities confirm the fundamental issues related to the ecological transition. Transport and mobility are part of these real issues and need to be rethought through the efforts of all actors (mobility operators, local authorities, and mobility users). Thus, encouraging sustainable mobility implies tackling all forms of travel (long-distance, work, leisure, tourism, or goods transport) (Youmatter, 2021).

Sustainable mobility also means changing our travel habits by reducing the use of private cars and increasing the use of more sustainable modes of transport (carpooling, public transport, active modes, etc.). The private car is still the preferred mode of transportation regardless of the distance traveled. It was used by 74% of employed workers in 2017, in France (Insee, 2021). Commutes to work of more than one kilometer are mainly made by 56% of workers by car, 23% on foot, 6% by bicycle, 13% by public transport, and 2% by motorized two-wheeler. Car use increases with distance, and the number of long-distance commuters has increased in recent years (Sandow & Westin, 2009). Unfortunately, this increased car use generates negative externalities such as air pollution, congestion, road accidents, noise etc.

To reduce these negative externalities, literature has already proposed economic instruments (Walton, 1997; Bulteau, 2012; Bueno *et al.*, 2017; Pavon & Rizzi, 2019), non-economic instruments (Ajzen, 1991; Kroesen & Chorus, 2018; Ingvardson & Nielsen, 2019), and finally, the combination of economic and non-economic instruments (Hilton *et al.*, 2014; Raux *et al.*, 2021; Bulteau *et al.*, 2021; Le Goff *et al.*, 2022) to encourage a modal shift from solo driving to more sustainable mobility solutions. However, the application of these instruments has revealed limitations. Economic incentives such as taxes or subsidies have yet to be ready for public acceptance (Shade & Schlag, 2003). Also, implementing these measures on a large scale is not easily feasible (Schuitema *et al.*, 2009). Behavior change related to economic incentives can lead to rebound effects that mitigate environmental benefits (Coulombel *et al.*, 2019). The effectiveness of non-economic incentives at the individual level is limited if the cultural context, economic environment, and corporate policies encourage undesirable behavior. Non-economic incentives can negatively affect behavioral intention (Perkins *et al.*, 2005) through a boomerang effect.

As for the combination of economic and non-economic incentives, the effectiveness of the modal shift towards sustainable mobility solutions is mixed. The work of Hilton *et al.* (2014) shows the effectiveness of the combination of nudge (non-economic incentive) and bonus-malus (economic incentive) on train choice intentions, while Riggs (2017) shows the ineffectiveness of donations and human incentives (altruistic action) on active transport habits. These results from the literature lead us to ask the following questions: (1) Which combinations of incentives are effective for a modal shift in the case of medium (<80km) and short distances (<10 km) for commuting trips? (2) Which combinations are effective for which sustainable mode choices?

Based on these questions, for medium distances we analyze whether economic and non-economic combinations increase the modal shift from solo driving to sustainable mobility alternatives such as carpooling and public transport commuting trips. For short distances, we study the modal shift to the same sustainable transport alternatives in addition to the electric bicycle. In the literature, we had very few studies

that addressed the combination of economic and non-economic incentives to encourage a modal shift to carpooling, public transport, and electric bicycles. There needs to be more work combining economic and non-economic incentives. In our paper, we look for the intention to change behavior and adopt other sustainable modes of transport for commuting trips. Specifically, we test the hypothesis that combinations of economic and non-economic incentives will be more effective than these same incentives taken separately, and we compare the results for medium and short distance trips. Contributions of this paper analyses the impact of economic and non-economic incentives in isolation and the effect of the combination of the two types of incentives on mode choice in the case of medium and short-distance commuting. Also, a comparative analysis of the different incentives is made to determine which ones are effective and on which targets. The method we used proposes encouraging a modal shift towards sustainable mobility solutions via a questionnaire of 1502 respondents in the Ile-de-France region. We consider both medium-distance and short-distance homework (or study) trips. We separately test (1) the effect of non-economic incentives such as nudge for medium distance trips. For short distance trips, we also test the health impact of transport modes, and the social norm. Similarly, we separately test (2) the effect of an economic incentive and (3) the combination of economic and non-economic incentives. The economic incentives refer to the employer's subsidy for sustainable mobility (called 'Forfait mobilité durable' or FMD in French) and the carbon tax of €250. FMD is a scheme set up in France allowing employers to cover part of the travel made by carpooling, public transport, or cycling.

Section two reviews the literature on the impact of financial, non-financial, and combined the both incentives on the choice of sustainable modes for medium-distance and short-distance commuting. For medium-distance trips, we emphasize carpooling and public transportation, while for short-distance travel, we consider active modes such as cycling and walking. Section three presents the methodology used, including the sample surveyed and the econometric models used, which are Nested logit models (NL). Section four presents our results. Section five discusses our findings, and section six concludes.

2. LITERATURE REVIEW

2.1. Economic incentives

- **Medium distances**

Medium and Long-distances travel have increased and have been a strategic mobility choice for households rather than a short-term solution for a few years for any trip purpose (Sandow & Westin, 2010). The literature proposes several economic instruments to reduce Single-occupancy vehicle (SOV) on long-distance trips. These instruments can be categorized into two forms of regulation: price regulations (Menon *et al.*, 1993; Storchmann, 2001; Nash & Matthews, 2005; Ang and

Marchal, 2013, Cats *et al.*, 2017); quantity regulations (Walton, 1997; Bulteau, 2012; Guensler *et al.*, 2019). Economic incentives for quantity regulation to encourage carpooling include high-occupancy-vehicle (HOV) lanes. These are lanes where SOV's cannot travel. In other words, they are only for carpools and transit. They are intended to reduce highway congestion (Guensler *et al.*, 2020, a). Cohen *et al.* (2022) showed that introducing HOV lanes in Israel positively impacted the intention to carpool by bringing new drivers to the carpooling platform. Li *et al.* (2007), interviewing Texas commuters, found that most carpooled because of the availability of an HOV lane. Another instrument to reduce congestion is the implementation of High-occupancy toll (HOT) lanes. These are toll lanes that generally allow carpools of three people to ride for free and others who do not carpool to ride for a fee (Guensler *et al.*, 2020, b). Pessaro *et al.* (2013) showed in their study that implementing HOT lanes contributed to an increase in transit ridership of 23% in Minneapolis and 53% in Miami. Other economic instruments, such as gasoline price increases, have also been shown to be effective in several studies. Using a theoretical model, Bento *et al.* (2013) showed that a 10% increase in fuel price implied ten additional carpools per hour in the traffic flow in Los Angeles. The meta-analysis by Olsson *et al.* (2019) identifies studies showing positive correlations between carpooling with increased fuel prices. According to the findings of a meta-analysis conducted by Goowin *et al.* (2004), a 10% rise in gasoline prices in numerous nations was related with a 3% decrease in road traffic and a 2.5% decrease in car ownership.

The economic instrument most discussed in the literature for public transport is the subsidy. Applied mainly to public transport, subsidies have both an economic and a social justification (Tirachini and Proost, 2021). Cats *et al.* (2017) showed that free public transport in Tallinn, Estonia, increased public transport use by 14%. Pavon and Rizzi (2019) analyze the implementation of a 100% public transport subsidy in Santiago, Chile. The implementation of this policy increased bus ridership during peak hours. The results of Buenos *et al.* (2017) are in the same direction. Subsidized public transport in New York and New Jersey increased the probability of choosing public transport by 15%. Other research refutes the effectiveness of public transportation subsidies. Basso *et al.* (2011) state that the deficient cross-price elasticity between transportation expenses and car use makes bus lanes more effective than fare subsidies. Parking policies and road pricing are also economic instruments to encourage a modal shift to public transport. The work of Agarwal and Koo (2016) shows that implementing a congestion charge (\$1/day) in Singapore increases bus use by 8%. As shown in Chapter 1, the work of Hammadou and Papaix (2015) showed that the application of road pricing in the form of a toll cordon estimated at 1.2€/day increased public transport use by 1.01% in three

French cities. The combination of road pricing (€1.2/day) and a 50% parking fee increased public transport use by 16.02%. They also show the carbon tax's effectiveness in increasing public transport use. The carbon tax of 1.6 €/liter increases the use of public transport by 14.21%. Subsidies, road pricing, and carbon tax are excellent prove to be good economic incentives for encouraging modal shift to public transport.

- **Short distance**

The focus is on active modes such as cycling and walking for short distances. When walking and cycling are encouraged, the transport sector can positively affect the health and environment of individuals and society (Hemmingsson *et al.*, 2009; Finkelstein *et al.*, 2008). Several studies have shown the positive impact of economic incentives on promoting active modes. Ciccone *et al.* (2021) investigate the impact of a fixed fare and a conditional lottery on cyclists in Norway. The economic incentive was NOK 2 per km cycled. The cyclist drawn at the end of the experiment wins a lottery ticket worth NOK 90 000. Participants who received a economic incentive cycled 36% more compared to the control group. The conditional lottery is a cost-effective and the only treatment with a long-term effect after removing the incentives. A randomized control trial in Sweden showed that a moderate-intensity program with free bicycles increased cycling among obese women (Hemmingsson *et al.*, 2009). Finkelstein *et al.* (2008) show that a payment conditioned on exercise level increased walking and running among older adults in the United States. In Norway, a subsidy program for electric bicycles was found to nearly double the bicycle share (share of bicycles in total miles traveled) among people who replaced their regular bicycles with electric bicycles (Institute of Transport Economics, 2016). The Danish "Bikerbusters" program, which provided free bicycles, increased bicycle use from 9% to 28% (Martin *et al.*, 2012). Rising gasoline prices may also have an impact on bicycle selection. Rashad (2009) explores the influence of urban expansion and growing fuel costs in major locations in the United States. His findings revealed that a one dollar rise in fuel costs increased the chance of cycling by 4.3 to 4.7 percentage points for males and 2.9 to 3.5 percentage points for women. Parking fees are another effective economic tool for encouraging a modal shift to cycling. Rye (2002) discovered that parking charges and increased access and facilities for cyclists tripled bicycle use at Manchester Airport in England.

2.2. Non-economic incentives

- **Medium distances**

Some research has noted that early studies on carpooling did not focus on psychological factors, although these factors influence individuals' decisions to carpool (Amirkiaee & Evangelopoulos, 2018; Canning *et al.*, 2010; Correia *et al.*, 2013). Two theories are often used as fundamental theories to explain individual motivations for choosing a mode of transportation. These are the Theory of Reasoned Action (TRA) and the Theory of Planned Behavior (TPB) (Schawanen and Lucas, 2011; Thøgersen, 2006,2009, Julagasigorn *et al.*,2021). These two theories imply that behavioral intention impacts actual behavior, but an individual's intention is determined by attitude, subjective norm, and perceived behavioral control (Ajzen, 1991). Bachmann *et al.* (2018) found that people carpool because it's their personal norm or moral obligation. So, they combine Norm Activation Model (NAM) and TPB carpooling norms. NAM model is a vested model that explains altruistic and environmentally friendly behavior (Schwartz, 1977; Onwezen *et al.*, 2013). Sometimes the means of transport are chosen depending on their abilities (knowledge, experience, resources, habits, etc.) and external factors (transport availability, performance and quality, time consumption in certain transport means, locations, distance and price policy) (Thøgersen, 2006, 2009). Thus, the TPB model includes individual skills (and limits) and environmental opportunities. It is MOA model (Olander and Thøgersen, 1995). According to the Motivation-Opportunity-Ability (MOA) model are critical in predicting behavior change (Binney *et al.*, 2007). Bachmann *et al.* (2018) conduct a study with 342 respondents in Switzerland. Their findings revealed that descriptive and personal norms, in combination with perceived behavior control, have a positive effect on the intention to carpool drivers or passengers, whereas attitude does not. Si *et al.* (2022) discovered that advertising information on carpooling behavior influences the intention to carpool, particularly among the elderly. The findings of Cheah *et al.* (2020) in New Zealand and Australia revealed that perceived usefulness and word of mouth have a significant influence on consumers' attitudes toward carpooling.

Some researchers find nudges useful for pro-sustainable mobility, whereas others don't. Le Goff *et al.* (2022) estimated end-to-end journey times for commuting in the Lyon metropolitan region. They found that environmentally concerned people who consider solo driving a major cause of air pollution are more likely to convert from carpooling as drivers to carpooling as passengers.

Several studies also show the role of psychological factors in the choice of public transport. Ingvardson and Nielsen's (2019) work in several European cities has shown that satisfaction with public transport services and social norms significantly and positively affects public transport use. De Vos *et al.* (2020) show the significant impact of attitudes on the desired frequency of public transport. Liming and Leibao (2022), in a study of 341 respondents in Hangzhou, China, show that perceived accessibility to public transport could strengthen the relationship between behavioral intention and actual public transport use behavior.

- **Short distances**

Several studies have found that non-monetary incentives play a role in selecting active modes, such as cycling for short distances. Shang-Yu Chen's (2016) research demonstrates the impact of psychological factors on bicycle utilization. In Taiwan, he proves that perceived happiness of perceived use and subjective norms enhance bicycle use. Gutierrez *et al* (2020) show that cycling patterns and facilities for cyclists increase cycling in Santiago, Chile. Stark *et al.* (2019) show that attitudes toward environmental friendliness and health, as well as mode-specific attitudes (well-being during a trip), promote cycling in the Vienna, Austria population. Gardner's (2009) study in Holland shows the role of intentions and habits in promoting cycling.

In addition to psychological factors, persuasive technologies are also effective ways to encourage cycling. Bucher *et al.* (2019) conducted six-week surveys in Zurich, Switzerland. Their study found that more accurate tracking with green feedback via a smartphone app increased bicycle use by 12.5%. Piwek *et al.* (2015) also have the significant and positive impact of self-monitoring for competitive cyclists on bicycle use in England.

2.3. Combination of economic and non-economic incentives

There are hardly any studies that integrate economic and non-economic incentives for a modal shift to sustainable modes, particularly carpooling. This is a gap in the research that needs to be filled. However, Bulteau *et al.* (2021) underline the necessity of combining economic incentives and psychological variables to induce a modal shift to carpool for commuting in the Paris region. This was done to reduce the number of people who commute alone. The work of Hilton *et al.* (2024) is consistent with this. The authors paired a economic incentive known as the bonus-malus with a non-economic incentive known as the injunctive norm. They found that the combination of incentives enhanced preferences for rail travel compared to air travel. On the other hand, this combination was only successful when the economic incentive (bonus-malus) was minimal. This is because an excessively high economic incentive erodes the intrinsic drive to select a sustainable mode of transportation. Instead, Gravert and Collentine (2021) propose increasing the economic incentive and duration when combined with a descriptive standard to encourage the use of public transport. Raux *et al.* (2021) found that providing CO₂ information through a tax incentive like a bonus-malus reduced CO₂-emitting transport mode preferences. Tax incentives in the form of personal carbon trading credits with CO₂ information as a non-economic incentive reduced air travel choice, but only slightly.

Regarding the combination of economic and non-economic incentives for a modal shift to bicycle use, there is only one study by Riggs (2017). In an analysis of the impact of economic (donations, monetary incentives) and human (i.e., generous) incentives on active transportation habits (biking and walking) at universities in the United States,

the author demonstrates that combining these two forms of incentives results in a reduction in their effectiveness. When combined with an economic incentive, non-economic rewards tend to be perceived by economic agents as punitive. This lack of knowledge about the combination of economic and non-economic incentives in the context of short-distance travel prompts us to investigate this part of our study further.

3. Methodology

3.1. Study design and sampling

This study aims to measure the intention to modify one's travel behavior by adopting carpooling and public transport for medium distances in commuting. For short distances, we aim to measure the intention to adopt the same modes of transport as in the case of medium distances, in addition to the electric bicycle for commuting trips. We designed a questionnaire aimed at active individuals or students living and working (or studying) in the Paris metropolitan area (Île-de-France region), or at people looking for work. We use the same database as described in chapter 2. Study design and sampling and descriptive analysis were discussed in sections 3.1 and 3.4 of Chapter 2 respectively.

3.2. Individual, socio-demographic and contextual variables

The socio-demographic variables are the same as those used in chapter 2, except that the socio-professional category is not included in the estimation of the models in that chapter (see section 3.2 of chapter 2). For medium distances (20 km), the respondent is placed in a hypothetical situation where he/she has to choose between four modes of transport (driving alone, carpooling, passenger carpooling, and public transport). For short distances (7 km), the respondent is asked to choose between five modes of transport (driving alone, carpooling, car sharing and public transport, and electric bicycle).

Each mode of transport was selected on the basis of general attributes such as cost and travel time and also on the basis of specific attributes (incentives) specified in Table 12. Table 13 and 14 are sample scenarios presented to respondents to choose a mode based on the various attributes.






For contextual variable, we only considered one geographical variable, the respondent's place of residence. Each person's domicile was assigned to one of three *départments*: (1) the core of Paris (*département* 75), (2) the inner suburbs (*départments* 92, 93, or 94), or (3) the outer suburbs (*départments* 77, 78, 91, or 95), which include *départments* on the outskirts of the Ile-de-France area (Appendix 1).

Table 12: Specific attributes

Incentives	Medium distance commuting trips (20 km)	Short distance commuting trips (7 km)
Economic incentives	- Employer subsidies for sustainable mobility (FMD) as an economic incentive	- Employer subsidies for sustainable mobility (FMD) as an economic incentive
Non-economic incentives	- Nudges, as a non-economic incentive	- Nudges, as a non-economic incentive - Social norms, as a non-economic incentive - Health impact, as a non-economic incentive
Combination	- The combination of carbon tax €250 as economic incentives and nudge as non-economic incentives	- The combination of carbon tax €250 as economic incentives and nudge as non-economic incentives

Table 13: Nudge scenario for short distance commuting trips (7 km)

“Research conducted by scientific experts has shown that traditional road transport (car) is the main emitter of different types of pollution such as CO2 emissions, fine particles that have negative impacts on the environment, driving alone has a more negative impact on the environment than other modes of transport”.

Modes of transport	 Driving alone in the car	 Carpooling as the driver	 Carpooling as the passenger on board	 Taking public transports	 Electric bike
Travel time	5 min	8 min	9 min	12 min	22 min
Travel cost	1,7 €	0,2 €	0,4 €	1 €	< 0,01 €
















Nudges	 Negative impact on environment	 Less negative impact on environment	 Less negative impact on environment	 Positive impact on environment	 Positive impact on environment
Choice	Choice A	Choice B	Choice C	Choice D	Choice E

Table 14: Health impact scenario for short distance commuting trips (7 km)

“Experts have scientifically demonstrated that the practice of daily active mobility has a significant impact on human health. Indeed, daily physical activity helps prevent many chronic diseases while improving physical condition and has a powerful impact on mental health”.

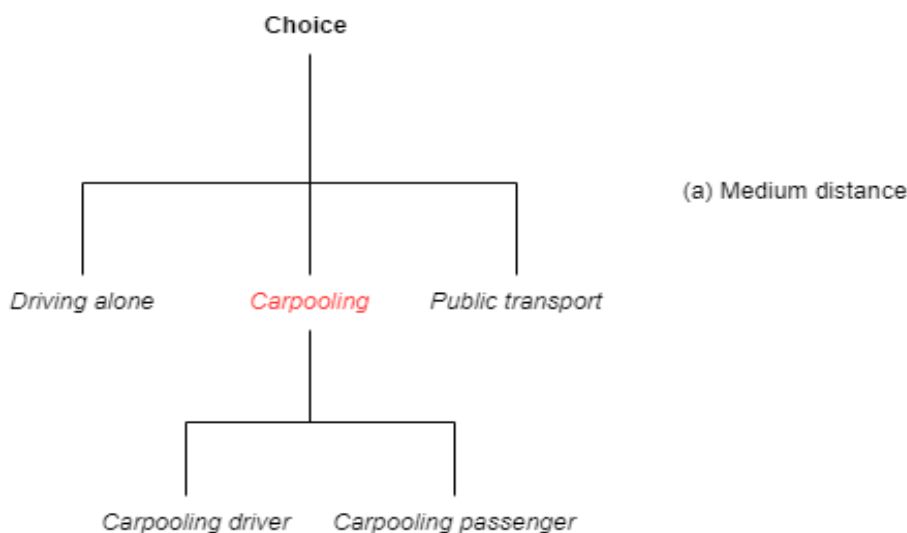
Modes of transport	 Driving alone in the car	 Carpooling as the driver	 Carpooling as the passenger on board	 Taking public transports	 Electric bike
Travel time	5 min	8 min	9 min	12 min	22 min
Travel cost	1,7 €	0,2 €	0,4 €	1 €	< 0,01 €
Health impact	 No impact on health	 No impact on health	 No impact on health	 Positive impact on health	 Very positive impact on health
Choice	Choice A	Choice B	Choice C	Choice D	Choice E

3.3. Econometric models

Unlike Chapter 2, where we have MNL and binomial models because of the objective of measuring intentions to choose between driving alone and carpooling, we switch to Nested models to answer the research question of this chapter. Indeed, the NL models allow the creation of branches associated with subgroups. For medium distances, we model (1) the effect of FMDs as an economic incentive, (2) the effect of nudges as a non-economic incentive (Hilton *et al.*, 2014), and (3) the effect of a combination of the €250 carbon tax as an economic incentive and

nudges as a non-economic incentive. For short distances, we also analyze (1) the effect of FMDs as an economic incentive, (2) the effect of nudges as a non-economic incentive, (3) the effect of social norms as a non-economic incentive, (4) the effect of health impact as a non-economic incentive, (5) the effect of a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive. As stated in Section 1, FMD is a French subsidy given to employees to help pay for work-related travel. This subsidy scheme rewards more sustainable forms of transportation than solo driving, such as public transit, carpooling, and biking.

The nested logit model can account for different levels of dependence between subgroups of options in a decision set is an advantage (Hemcher & Greene, 2002). The various options can be divided into subgroups, enabling the variance to differ across them while keeping the IIA hypothesis within the groupings. Thus, the options J can be organized in B subgroups (branches). In our study, we have three branches for medium distances and four branches for short distances, with the carpooling branch including driver and passenger carpooling (Figure 15).



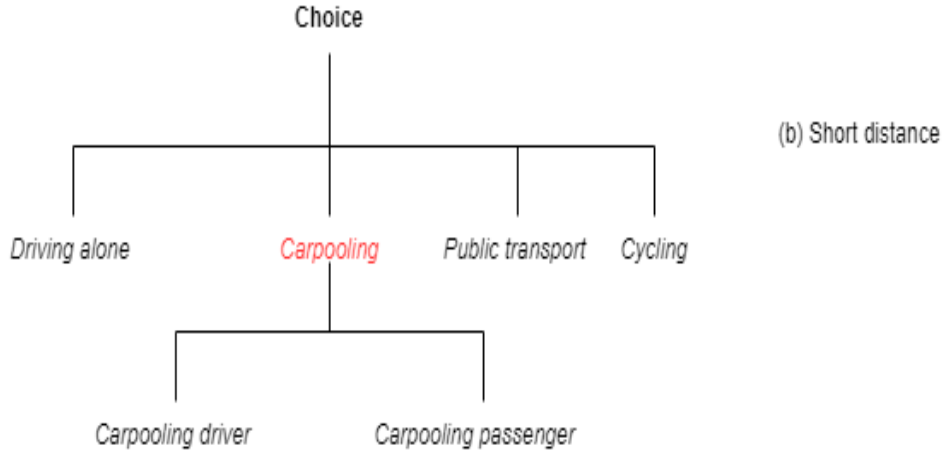


Figure 15: Nested structures

If we assume that the data contain observations on the attributes of the choices $x_{ij|b}$ and choice sets z_{ib} , the probability is in the form (Greene, 2011):

$$P_{ij|b} = \frac{\exp(x'_{ij|b}\beta)}{\sum_{j=1}^{j_b} \exp(x'_{ij|b}\beta)} \quad \text{et} \quad P_b = \frac{\exp[\tau_b(z'_{ib}\gamma + VI_{ib})]}{\sum_{b=1}^B \exp[\tau_b(z'_{ib}\gamma + VI_{ib})]} \quad (2)$$

where the new parameters' values τ_l is equal to 1 in the initial model.

To summarize, three NL models were estimated for medium distance commuting trips:

- *Model M1:* NL model, the effect of FMDs as an economic incentive.
- *Model M2:* NL model, the effect of nudges as a non-economic incentive.
- *Model M3:* NL model, the effect of a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive.

For the short distance commuting trips, we estimated five NL model:

- *Model M4:* NL model, the effect of FMDs as an economic incentive.
- *Model M5:* NL model, the effect of health impact as a non-economic incentive.
- *Model M6:* NL model, the effect of nudges as a non-economic incentive.
- *Model M7 :* NL model, the effect of social norms as a non-economic incentive.
- *Model M8:* NL model, the effect of a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive.

To estimate the model parameters, the maximum likelihood estimation procedure was utilized (Greene, 2011). To control multicollinearity, the variance inflation factors were used (VIF). The values for all explanatory variables are less than 2.

4. RESULTS

4.1. The impact of incentives for modal shift to carpooling and public transport in the context of medium distance commuting.

4.1.1. The effect of FMD

- **Nested logit model (M1)**

The nested logit model of the impact of the FMD on transport mode choice is presented in appendix 2. Individual variables such as household income, education level, car ownership, and the number of people per household are significant variables for **carpooling** choice when the FMD is applied. Respondents aged 18 to 24 are 2,877 times more likely to carpool than respondents aged 50 and over. Respondents aged 25 to 34 are 2,660 times more likely to carpool than those aged 50 and over. For income, households with incomes between €1001 and €2500 are 1,461 times more likely to choose to carpool than households with incomes between €2501 and €4000. At the same time, households with an income above 9000€ are 0.497 times less likely to choose to carpool than households with an income between 2501 and 4000€. For the level of education, respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.612 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. For car ownership, those with a car are 0.354 times less likely to choose to carpool. The odds of choosing carpooling decrease with increasing car ownership to 0.291 when respondents own two or more cars. Two-person households are 1,967 more likely to choose to carpool than single respondents. Three-person households are 1.725 times more likely to carpool. Households of 4 or more people are 2,875 times more likely to choose to carpool.

For **public transport**, individual and socio-demographic variables such as the level of education, car ownership, people per household and place of residence have a significant impact. For education level, respondents with a bachelor's degree are 2.521 times more likely to choose public transportation than those without a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 2.635 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport increases to 2,831 when the respondent's level of education is higher than a master's degree. Households with a car are 0.180 times less likely to choose public transport than those without a car. Households with two or more cars are 0.066 times less likely to choose public transport. Two-person households are 2.116 more likely to choose public transport than single respondents. Three-person households are 2.039 times more likely to choose public transport. Households of 4 or more people are 2.190 times more likely to choose public transport. For the contextual variable, respondents living in the inner suburbs are 1.474 times more likely to choose

public transport than respondents living in Paris (75).

4.1.2. The effect of nudges

- **Nested logit model (M2)**

The nested logit model of the impact of nudges on transport mode choice is presented in appendix 2. Individual variables such as age, household income, education level, car ownership, and the number of people per household are significant variables for **carpooling** choice when nudges are applied. Respondents aged 18 to 24 are 3.293 times more likely to carpool than respondents aged 50 and over. Respondents aged 25 to 34 are 2.199 times more likely to carpool than those aged 50 and over. For respondents between the ages of 35 and 49, the odds of choosing to carpool are 1,633. For income, households with incomes between €1001 and €2500 are 1.811 times more likely to choose to carpool than households with incomes between €2501 and €4000. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.687 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. The chance of choosing to carpool increases to 1.702 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.380 times less likely to choose to carpool. The odds of choosing carpooling decrease with increasing car ownership to 0.285 when respondents own two or more cars. Two-person households are 1.732 more likely to choose to carpool than single respondents. Three-person households are 1.591 times more likely to carpool. Households of 4 or more people are 2.456 times more likely to choose to carpool.

For **public transport**, individual and socio-demographic variables such as gender, age, income per household, level of education, car ownership, people per household, and contextual variable as place of residence are significant. Men are 0.737 times less likely to choose driver carpooling than women. Respondents aged 18 to 24 are 1.837 times more likely to choose public transport than respondents aged 50 and over. However, Respondents aged between 24 and 34 years are 0.601 times less likely to choose public transport than those aged 50 years or older. Households with an income between €1001 and €2500 are 1.734 times more likely to choose public transport than those with an income between €2501 and €4000.

For education level, respondents with a bachelor's degree are 2.921 times more likely to choose public transportation than those without a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 2.809 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport increases to 3.002 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.184 times less likely to choose public transport. The odds of choosing public transport decrease with increasing car ownership to 0.088 when respondents own two or more cars. Two-person households

are 1.959 more likely to choose public transport than single respondents. Three-person households are 1.815 times more likely to choose public transport. Households of 4 or more people are 2.407 times more likely to choose public transport. For the contextual variable, respondents living in the inner suburbs are 1.671 times more likely to choose public transport than respondents living in Paris (75).

4.1.3. The effect of a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive.

- **Nested logit model (M3)**

The nested logit model of the impact of nudges on transport mode choice is presented in appendix 2. Individual variables such as age, household income, education level, car ownership, and the number of people per household are significant variables for **carpooling** choice when a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive is applied. Respondents aged 18 to 24 are 2.983 times more likely to carpool than respondents aged 50 and over. Respondents aged 25 to 34 are 2.153 times more likely to carpool than those aged 50 and over. For respondents between the ages of 35 and 49, the odds of choosing to carpool are 1.395. For income, households with incomes between €1001 and €2500 are 2.064 times more likely to choose to carpool than households with incomes between €2501 and €4000. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.908 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. The chance of choosing to carpool increases to 1.800 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.296 times less likely to choose to carpool. The odds of choosing carpooling decrease with increasing car ownership to 0.215 when respondents own two or more cars. Two-person households are 2.738 more likely to choose to carpool than single respondents. Three-person households are 2.129 times more likely to carpool. Households of 4 or more people are 3.676 times more likely to choose to carpool.

For **public transport**, individual and socio-demographic variables such as age, income per household, level of education, car ownership, people per household, and contextual variable as place of residence are significant. Respondents aged 18 to 24 are 2.393 times more likely to choose public transport than respondents aged 50 and over. Households with an income between €1001 and €2500 are 1.687 times more likely to choose public transport than those with an income between €2501 and €4000. For education level, respondents with a bachelor's degree are 3.596 times more likely to choose public transportation than those without a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 3.361 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport increases to 3.546 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.180 times less likely to choose

public transport. The odds of choosing public transport decrease with increasing car ownership to 0.080 when respondents own two or more cars. Two-person households are 2.058 more likely to choose public transport than single respondents. Households of 4 or more people are 2.718 times more likely to choose public transport. For the contextual variable, respondents living in the inner suburbs are 1.717 times more likely to choose public transport than respondents living in Paris (75).

4.2. The impact of modal shift incentives to carpooling and public transport in the context of short-distance commuting.

4.2.1. The effect of FMD

- **Nested logistic model (M4)**

The nested logit model of the impact of the FMD on transport mode choice for short distance is presented in appendix 3. **For carpooling**, individual socio-demographic variables such as age, income per household, level of education, car ownership, people per household and contextual variable such as place of residence are significant. Respondents aged 18 to 24 are 2.171 times more likely to choose carpooling than respondents aged 50 and older as age increases from 25 to 34, the likelihood of choosing carpooling decreases to 2.173. For income, households with incomes between €1001 and €2500 are 2.112 times more likely to choose to carpool than households with incomes between €2501 and €4000. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.886 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. The chance of choosing to carpool increases to 1.833 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.334 times less likely to choose to carpool. The odds of choosing carpooling decrease with increasing car ownership to 0.209 when respondents own two or more cars. Two-person households are 2153 more likely to choose to carpool than single respondents. Three-person households are 1.668 times more likely to carpool. Households of 4 or more people are 3.299 times more likely to choose to carpool. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.571 times more likely to choose to carpool than those living in Paris (75). Those living in the outer suburbs are 1.493 times more likely to choose to carpool than those living in Paris (75).

For **public transport**, individual and socio-demographic variables such as income per household, the level of education, car ownership, people per household and place of residence have a significant impact. For income, households with incomes between €1001 and €2500 are 2.117 times more likely to choose to public transport than households with incomes between €2501 and €4000. Households with an income above 9000 € are 2.379 times more likely to choose public transport than those with an income between 2501 and € 4000. Respondents with a level of education equivalent to a bachelor's degree are 2.993 times more likely to choose public transport than those with a level of education below a bachelor's degree. Respondents with a level of

education between the second year and the fourth year of a bachelor's degree are 3,508 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport decreases to 3.158 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.164 times less likely to choose to carpool. The odds of choosing public transport decrease with increasing car ownership to 0.069 when respondents own two or more cars. Two-person households are 1.883 more likely to choose public transport than single respondents. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.590 times more likely to choose public transport than those living in Paris (75).

For **cycling**, individual socio-demographic variables such as age, level of education, car ownership and people per household are significant. Respondents aged 18 to 24 are 2.488 times more likely to choose cycling than respondents aged 50 and older; as age increases from 25 to 34, the likelihood of choosing cycling decreases to 2.362. Respondents with a level of education equivalent to a bachelor's degree are 1.755 times more likely to choose cycling than those with a level of education below a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.734 times more likely to choose cycling than respondents with a level of education below the bachelor's degree. For car ownership, those with a car are 0.256 times less likely to choose cycling. The odds of choosing cycling decrease with increasing car ownership to 0.199 when respondents own two or more cars. Households of 4 or more people are 1.655 times more likely to choose cycling than single respondents.

4.3.2. The effect of health impact

- **Nested logistic model (M5)**

The nested logit model of the impact of health impact on transport mode choice for short distance is presented in Appendix 3. For **carpooling**, individual socio-demographic variables such as age, income per household, car ownership and people per household are significant. Respondents aged 18 to 24 are 1.742 times more likely than respondents aged 50 and older to choose to carpool as age decreases from 25 to 34, the likelihood of choosing carpooling decreases to 1.706. In terms of income, households earning between €1001 and €2500 are 1.916 times more likely to carpool than households earning between €2501 and €4000. Those who own a car are 0.525 times less likely to carpool; when respondents own two or more cars, the likelihood of choosing to carpool decreases to 0.343. Carpooling is 2.718 times more likely in households with four or more people.

For **public transport**, individual and socio-demographic variables such as age, income per household, the level of education, car ownership and people per household and contextual variable such as place of residence are significant. Respondents between

the ages of 25 and 34 are 0.602 times less likely to choose public transit than those 50 years and older. In terms of income, households with incomes between €1,001 and €2,500 are 1.740 times more likely to choose public transport than households with incomes between €2,501 and €4,000. Respondents with a level of education equivalent to a bachelor's degree are 3.304 times more likely to choose public transport than those below a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 3.092 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport decreases to 3.395 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.240 times less likely to choose to carpool. The odds of choosing public transport decrease with increasing car ownership to 0.091 when respondents own two or more cars. Two-person households are 1.571 more likely to choose public transport than single respondents. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.626 times more likely to choose public transport than those living in Paris (75).

For **cycling**, individual socio-demographic variables such as age, car ownership and level of education are significant. Respondents aged 18-24 are 4.449 times more likely to choose cycling than those aged 50 and older; the likelihood of choosing cycling decreases to 1.969 as age increases from 25-34. Respondents with a bachelor's degree or higher are 1.738 times more likely to choose cycling than those without a bachelor's degree. Those who own a car are 0.275 times less likely to choose cycling. When respondents own two or more cars, the likelihood of choosing cycling decreases to 0.231.

4.2.3. The effect of nudges

- **Nested logistic model (M6)**

The nested logit model of the impact of nudges on transport mode choice for short distance is presented in Appendix 3. For **carpooling**, individual socio-demographic variables such as age, income per household, car ownership, people per household and contextual variable such as place of residence are significant. Respondents aged 18 to 24 are 2.516 times more likely to choose carpooling than respondents aged 50 and older as age increases from 25 to 34, the likelihood of choosing carpooling decreases to 2.074. For income, households with incomes between €1001 and €2500 are 1.883 times more likely to choose to carpool than households with incomes between €2501 and €4000. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 2.077 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. The chance of choosing to carpool decreases to 1.738 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.384 times less likely to choose to carpool. The odds of choosing

carpooling decrease with increasing car ownership to 0.273 when respondents own two or more cars. Households of 4 or more people are 2.234 times more likely to choose to carpool. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.773 times more likely to choose to carpool than those living in Paris (75). Those living in the outer suburbs are 1.661 times more likely to choose to carpool than those living in Paris (75).

For public transport, individual and socio-demographic variables such as age, income per household, the level of education, car ownership and people per household have a significant impact. Respondents between the ages of 18 and 24 are 1,738 more likely to choose public transit than respondents aged 50 and over. For income, households with incomes between €1001 and €2500 are 2.004 times more likely to choose to public transport than households with incomes between €2501 and €4000. Respondents with a level of education equivalent to a bachelor's degree are 4.151 times more likely to choose public transport than those with a level of education below a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 4.080 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport decreases to 3.594 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.195 times less likely to choose to carpool. The odds of choosing public transport decrease with increasing car ownership to 0.069 when respondents own two or more cars. Two-person households are 1.696 more likely to choose public transport than single respondents.

For **cycling,** individual socio-demographic variables such as age, car ownership, level of education, and people per household are significant. Respondents aged 18 to 24 are 5.014 times more likely to choose cycling than those aged 50 and older; as age increases from 25 to 34, the likelihood of cycling decreases to 2.082. Respondents with a level of education equivalent to a bachelor's degree are 2.410 times more likely to choose cycling than those below a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.992 times more likely to choose cycling than respondents with a level of education below the bachelor's degree. The chance of choosing to cycle increases to 1.707 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.262 times less likely to choose cycling. The odds of choosing cycling decrease with increasing car ownership to 0.209 when respondents own two or more cars. Households of 4 or more people are 1.655 times more likely to choose cycling than single respondents.

4.2.4. The effect of social norms

- **Nested logistic model (M7)**

The nested logit model of the impact of social norms on transport mode choice for short distance is presented in Appendix 3. For **carpooling**, individual socio-demographic variables such as age, income per household, level of education, car ownership, people per household and contextual variable such as place of residence are significant. Respondents aged 18 to 24 are 2.507 times more likely to choose carpooling than respondents aged 50 and older as age increases from 25 to 34, the likelihood of choosing carpooling decreases to 1.820. For income, households with incomes between €1001 and €2500 are 2.011 times more likely to choose to carpool than households with incomes between €2501 and €4000. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 1.715 times more likely to choose to carpool than respondents with a level of education below the bachelor's degree. For car ownership, those with a car are 0.483 times less likely to choose to carpool. The odds of choosing carpooling decrease with increasing car ownership to 0.308 when respondents own two or more cars. Two-person households are 1.635 more likely to choose to carpool than single respondents. Households of 4 or more people are 2.310 times more likely to choose to carpool. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.515 times more likely to choose to carpool than those living in Paris (75). Those living in the outer suburbs are 1.514 times more likely to choose to carpool than those living in Paris (75).

For **public transport**, individual and socio-demographic variables such as age, income per household, the level of education, car ownership and people per household and contextual variable such as place of residence are significant. Respondents aged 18-24 are 1.659 times more likely to choose public transportation than respondents aged 50 and older. Respondents aged 35-49 are 0.648 times less likely to choose public transportation than those aged 50 and older. In terms of income, households with incomes between €1,001 and €2,500 are 1.794 times more likely to choose public transport than households with incomes between €2,501 and €4,000. Households with an income above 9000€ are 2.327 times more likely to choose public transport than those with an income between 2501 and 4000€. Respondents with a level of education equivalent to a bachelor's degree are 3.023 times more likely to choose public transport than those below a bachelor's degree. Respondents with a level of education between the second year and the fourth year of a bachelor's degree are 3.944 times more likely to choose public transport than respondents with a level of education below the bachelor's degree. The chance of choosing public transport decreases to 3.733 when the respondent's level of education is higher than a master's degree. For car ownership, those with a car are 0.238 times less likely to choose to carpool. The odds of choosing public transport decrease with increasing car ownership to 0.079 when respondents own two or more cars. Two-person households are 1.944 more likely to choose public

transport than single respondents. For the contextual variable, such as place of residence, respondents living in the inner suburbs are 1.469 times more likely to choose public transport than those living in Paris (75).

For **cycling**, individual socio-demographic variables such as age, level of education and car ownership are significant. Respondents aged 18-24 are 3.253 times more likely to choose cycling than those aged 50 and older; as age increases from 25-34, the likelihood of choosing cycling decreases to 1.881. Respondents with an education equivalent to a bachelor's degree are 1.867 times more likely to choose bicycling than those with less than a bachelor's degree.

For car ownership, those with a car are 0.320 times less likely to choose cycling. The odds of choosing cycling decrease with increasing car ownership to 0.297 when respondents own two or more cars.

4.2.5. the effect of a combination of the €250 carbon tax as a economic incentive and nudges as a non-economic incentive.

- **Nested logistic model (M8)**

The nested logit model of the effect of a combination of the €250 carbon tax as an economic incentive and nudges as a non-economic incentive on transport mode choice for short distance is presented in Appendix 3. For **carpooling**, individual socio-demographic variables such as age, income per household, car ownership and people per household are significant. Respondents aged 18 to 24 are 2.388 times more likely to choose carpooling than respondents aged 50 and older; as age decreases from 25 to 34, the likelihood of choosing carpooling decreases to 1.559. Carpooling is 2.312 times more likely in households earning between €1,000 and €2,500 than in households earning between €2,501 and €4,000. Those who own one car are 0.487 times less likely to carpool; those who own two or more cars are 0.377 times less likely to carpool. Two-person households are 2.149 times more likely to carpool than single respondents. Three-person households are 1.760 times more likely than single respondents to choose to carpool. In households with four or more people, carpooling is 3.740 times more likely.

For **public transport**, individual and socio-demographic variables such as age, income per household, the level of education, car ownership and people per household have significant impact. Respondents between 18 and 24 are 1.816 times more likely to choose public transportation than respondents 50 years and older. When respondents are between 25 and 34 years old, they are 0.651 times less likely to choose public transport than those aged 50 and over. In terms of income, households with incomes between €1,001 and €2,500 are 2.008 times more likely to choose public transport than

households with incomes between €2,501 and €4,000. Respondents with a level of education equivalent to a bachelor's degree are 4.210 times more likely to choose public transportation than those without a bachelor's degree. Respondents with education levels between the second year and fourth year of a bachelor's degree are 3.944 times more likely to choose public transportation than respondents with education levels below a bachelor's degree. The probability of choosing public transportation decreases to 3.733 when the respondent's education level is above a master's degree. Concerning car ownership, those who own a car are 0.197 times less likely to choose public transport. The probability of choosing public transportation decreases with increasing car ownership, reaching 0.076 when respondents own two or more cars. Two-person households are 2.045 times more likely to choose public transportation than single persons. Households consisting of four or more people are 2.098 times more likely to choose public transport than those living alone.

For **cycling**, individual socio-demographic variables such as age, level of education, car ownership and people per household are significant. Respondents aged 18 to 24 are 4.710 times more likely to choose bicycling than those aged 50 and older; as age increases from 25 to 34, the likelihood of bicycling drops to 1.808. Respondents with the equivalent of a bachelor's degree in education are 1.753 times more likely to choose the bicycle than those without a bachelor's degree. Respondents who own a car are 0.278 times less likely to choose bicycling than those who do not. Respondents who own two or more cars are 0.248 times less likely to choose bicycles than those who do not own a car. Households of 4 or more people are 1.699 times more likely to choose bicycles than single people.

4.2.6. Comparison of different incentives.

This section compares the effectiveness of different incentives (economic, non-economic, or a combination of both) depending on the socioeconomic profile of the user. Incentives are compared when they have a significant and positive impact on mode choice, i.e., when the odds ratios are greater than 1. The objective is to determine for which respondents the incentives work best. The impacts of the incentives are presented in figures with the odds ratios on the ordinates and the respondents impacted by the abscissa.

- **Concerning medium distance trip**

For carpooling, the individual socio-demographic variables such as age, household income, level of education, and number of people per household are significant. All incentives tested are effective regardless of the age category of the respondents. However, nudges are the best incentive among respondents aged 18 and 24 and 35 and 49, with odds ratios of 3.293 and 1.63, respectively. While

among respondents aged 25 to 34, the FMD is the best incentive for carpooling, with an odd ratio of 2.66 (figure 16). The combination of the €250 carbon tax and the nudge would be efficient to promote carpooling among low-income population (i.e. highest odd ratio for respondents with an income between 1001 and 2500€) (figure 17), having at least a bac+2 level of study (figure 18). The odds ratios are 1.908 and 1.8, respectively. The odds ratio for the combination of the €250 carbon tax and the nudge is very high among households with two people (2.738), three people (2.129), and more than four people (3.676) for the carpooling choice (figure 19).

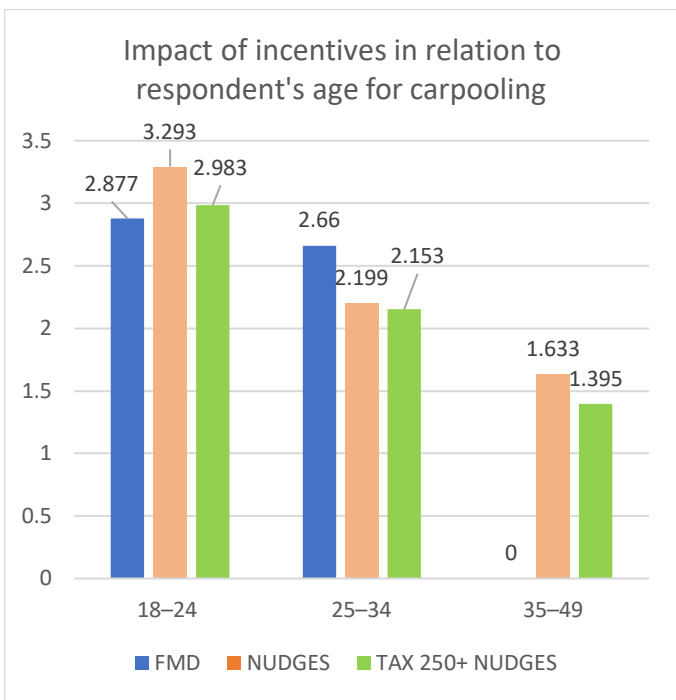


Figure 16: Impact of incentives in relation to respondents' age household for carpooling

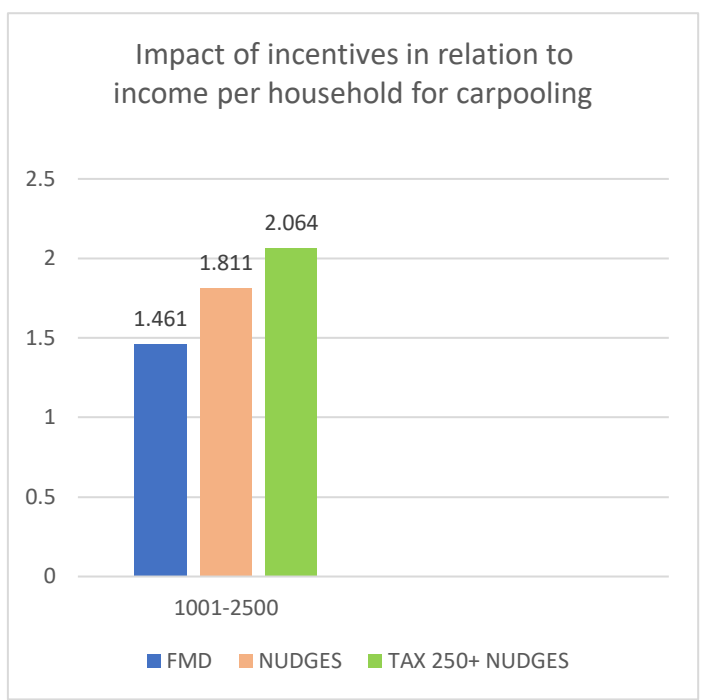


Figure 17: impact of incentives in relation to income per household for carpooling

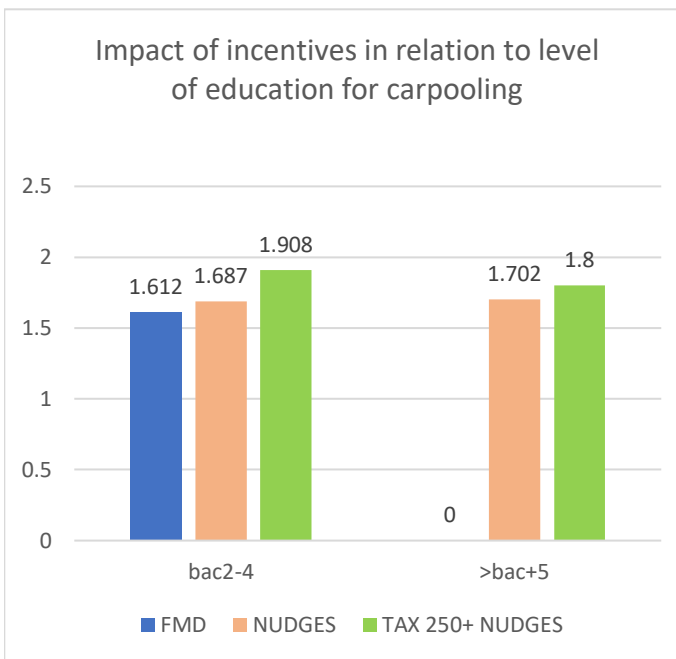


Figure 18: Impact of incentives in relation to level of education for carpooling

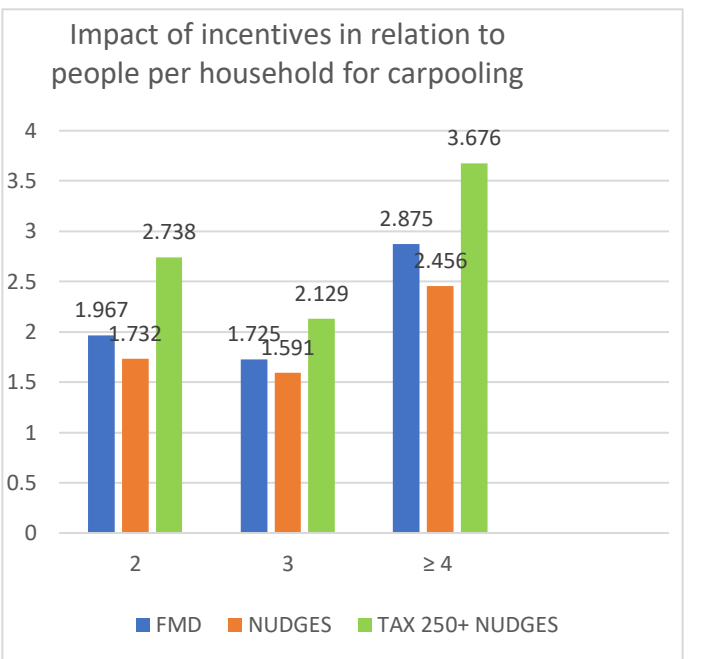


Figure 19: Impact of incentives in relation to people per household for carpooling

Incentives have a positive impact only among young respondents (i.e., 18 to 24) for the choice of **public transport**. The €250 carbon tax and nudge combination is the best incentive to encourage these respondents, with an odds ratio of 2.393 (Figure 20). The nudge is the best incentive for households with an income between 1001 and 2500 euros with an odds ratio of 1.734 (figure 21). The odds ratios for the combination of the €250 carbon tax and the nudges are highest for respondents with a level of education equivalent to a bachelor's degree (3.596), respondents with a level of education between the second and fourth years of a bachelor's degree (3.361), and finally respondents with a level of education higher than the second year of a master's degree (3.546). Regardless of education level, the combination of the €250 carbon tax and the nudge is more effective (Figure 22). The FMD is the incentive with the highest odds ratio for choosing public transportation for 2-person and 3-person households, at 2.116 and 2.039, respectively. Finally, the combination of the €250 carbon tax and the nudge is the best incentive for households with more than four people (figure 23) and living in the inner suburbs (figure 24), with respectively odds ratio of 2.718 and 1.717.

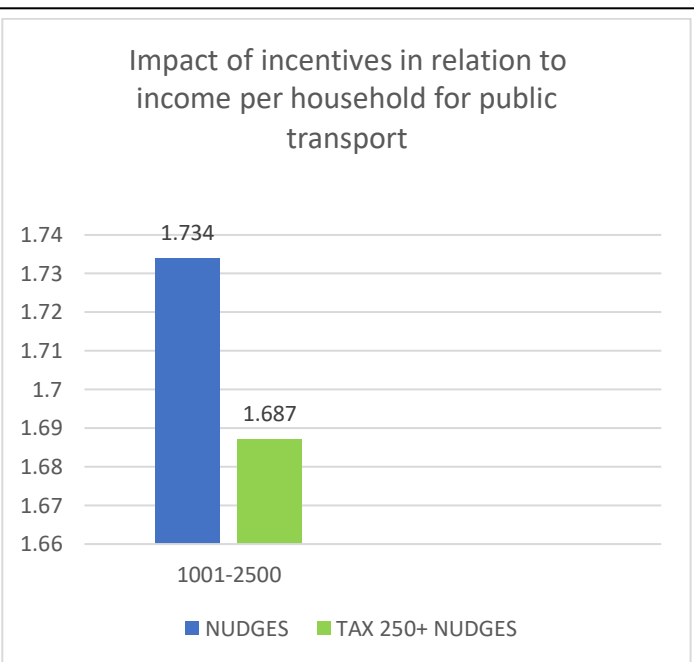
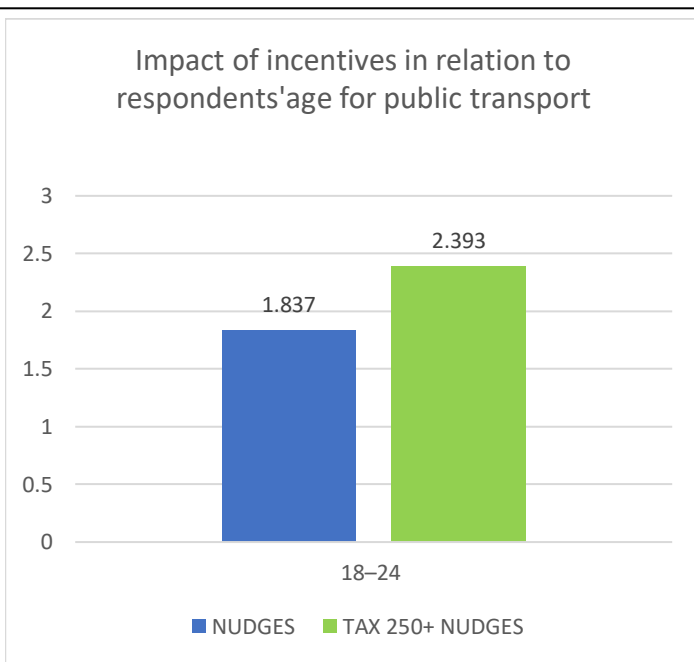


Figure 20: Impact of incentives in relation to respondents' age per household for public transport

Figure 21: Impact of incentives in relation to income per household for public transport

Impact of incentives on level of education public transport

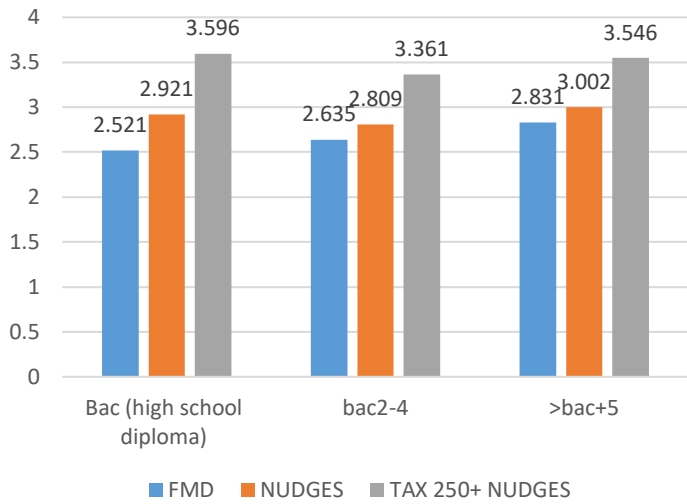


Figure 22: Impact of incentives in relation to level of education for public transport

Impact of incentives in relation to people per household for public transport

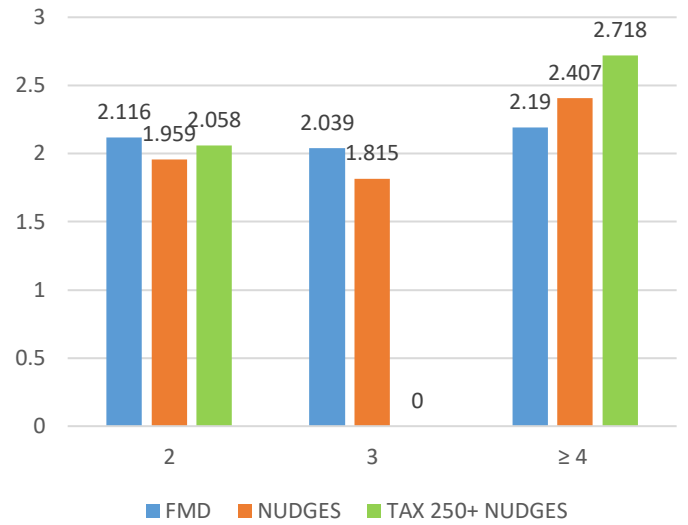


Figure 23: Impact of incentives in relation to people per household for public transport

Impact of incentives in relation to place of residence for public transport

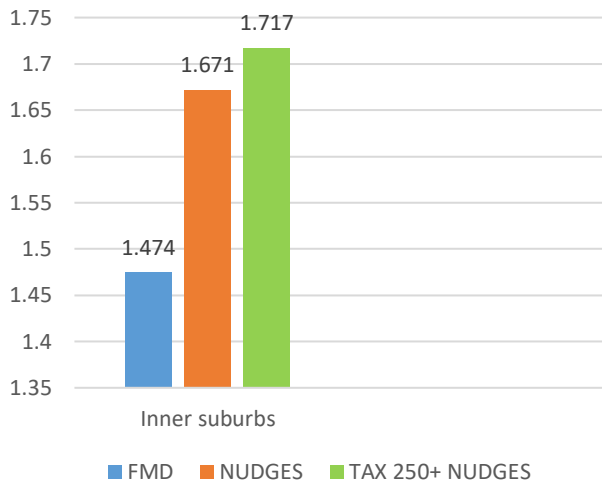


Figure 24: Impact of incentives in relation to Place of residence

- **Concerning short distance trips**

For **carpooling**, nudges and social norms appear to be the most incentivized measures, with respective odds ratios of 2.516 and 2.507 for respondents aged 18-24. For respondents between the ages of 25 and 34, the FMD is the most incentivized measure, with a score of 2.173 (figure 25). Household with an income bracket between 1000 € and 2500 € is the most sensitive to incentives (figure 26). The combination of the carbon tax of 250 € and the nudge is the best measure that works with an odds ratio of 2.312. The nudge works best on respondents in the second to fourth year of graduate school with an odds ratio of 2.077. The FMD is most effective among respondents at the graduate level to the fifth year of a master's degree with an odds ratio of 1.833 (figure 27). With an odds ratio of 2.153, FMD has a greater impact in two-person households. While the combination of the €250 carbon tax and the nudge has a greater impact on households of three or more people, with odds ratios of 1.76 and 3.74, respectively (figure 28). For those living in the inner and outer suburbs, the nudge is the best incentive to carpool, with respective odds ratios of 1.773 and 1.661 (figure 29).

Only respondents between 18 and 24 years old are sensitive to incentives for **public transport**. The €250 carbon tax and nudge combination have the most significant impact, with a score of 1.837 (figure 30). Households with an income between €1001 and €2500 and those with an income above €9000 are more sensitive to the FMD with a respective odds ratio of 2.117 and 2.379 (figure 31). Respondents with a level of education equivalent to a bachelor's degree were sensitive to the combination of the €250 carbon tax and the nudge, with a score ratio of 4.21. The nudge is the best incentive for respondents with a level of education between the second and fourth year of a bachelor's degree, with a score of 4.08. For respondents with a level of education higher than the fifth year of a master's degree, the combination of the €250 carbon tax and the nudge seems to be the best quote with an odds ratio of 3.733 (figure 32). The combination of the 250-euro carbon tax and nudge has the greatest impact on households of two or more people, with odds ratios of 2.045 and 2.098, respectively (figure 33). The health impact is the best incentive for choosing public transport for those living in the inner suburbs, with an odds ratio of 1.626 (figure 34).

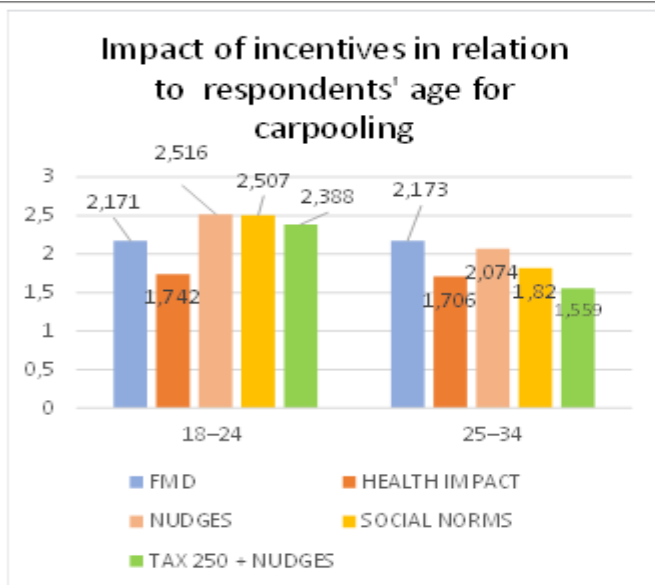


Figure 25: Impact of incentives in relation to respondent's age for carpooling

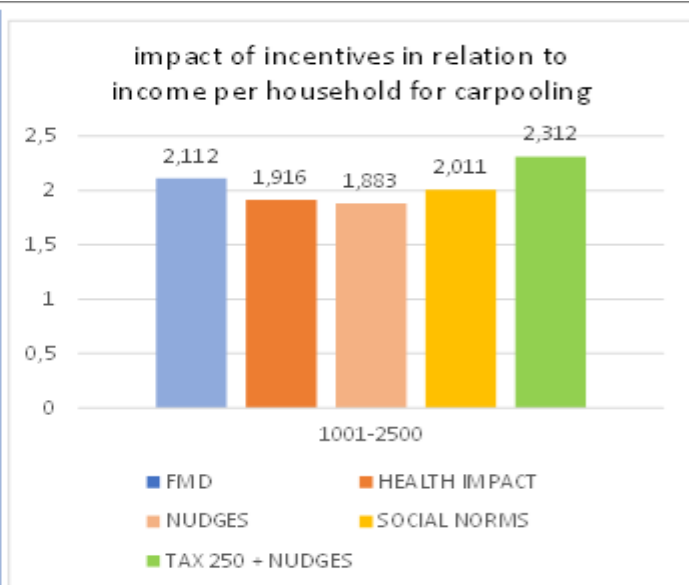


Figure 26: Impact of incentives in relation to income per household for carpooling

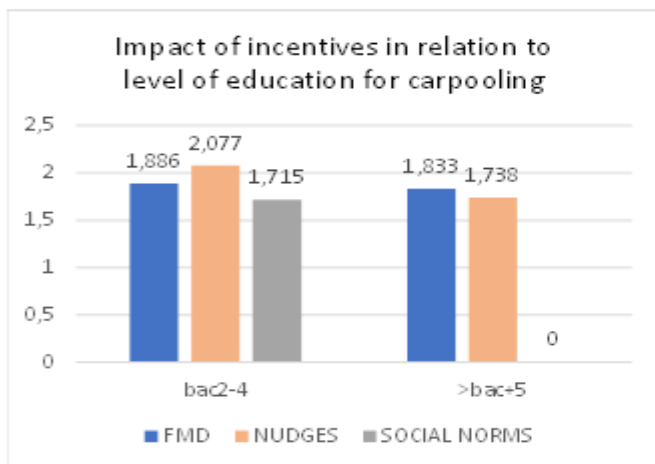


Figure 27: Impact of incentives in relation to level of Education for carpooling

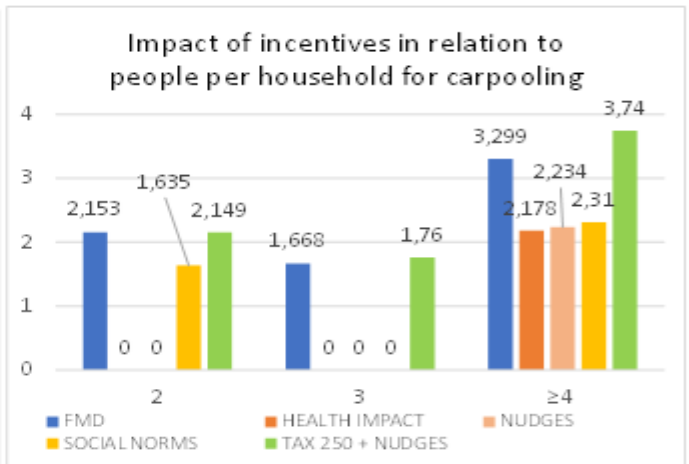


Figure 28: Impact of incentives in relation to people per household for carpooling

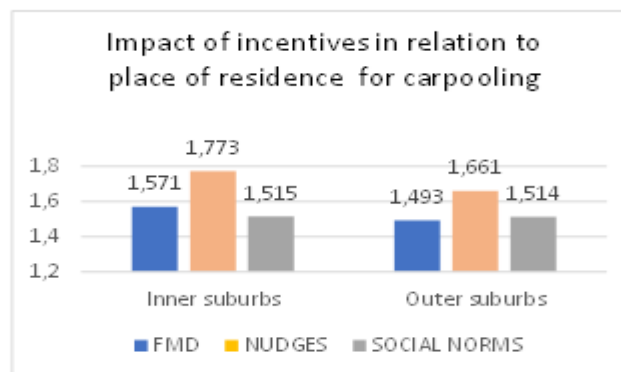


Figure 29: Impact of incentives in relation to place of residence for carpooling

Impact of incentives in relation to respondents' age (18–24) for public transport

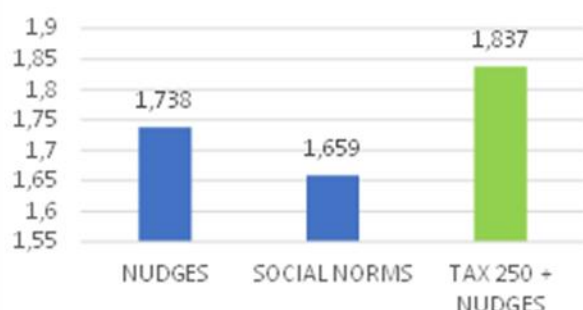


Figure 30: Impact of incentives in relation to respondents' age for public transport

Impact of incentives in relation to income per household for public transport

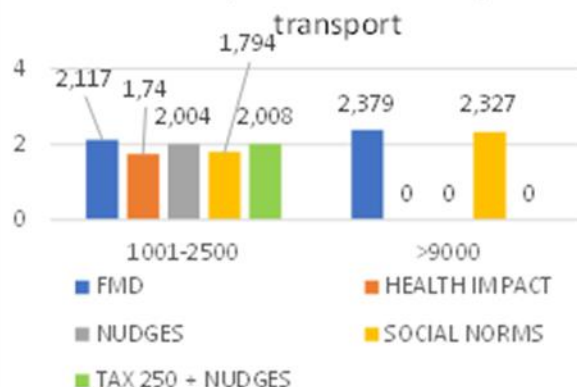


Figure 31: Impact of incentives in relation to income per household for public transport

Impact of incentives in relation to level of education for public transport

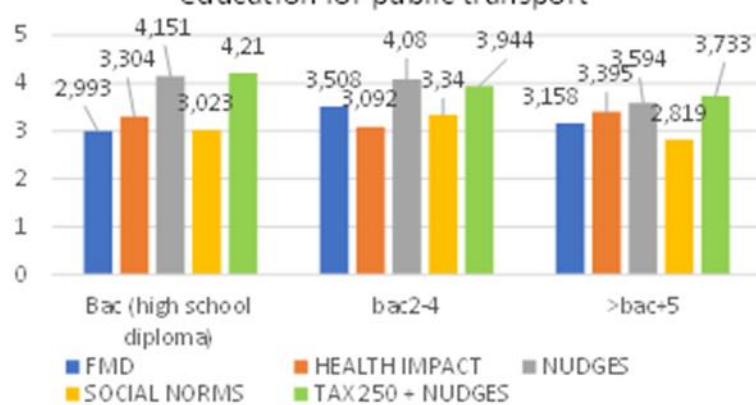
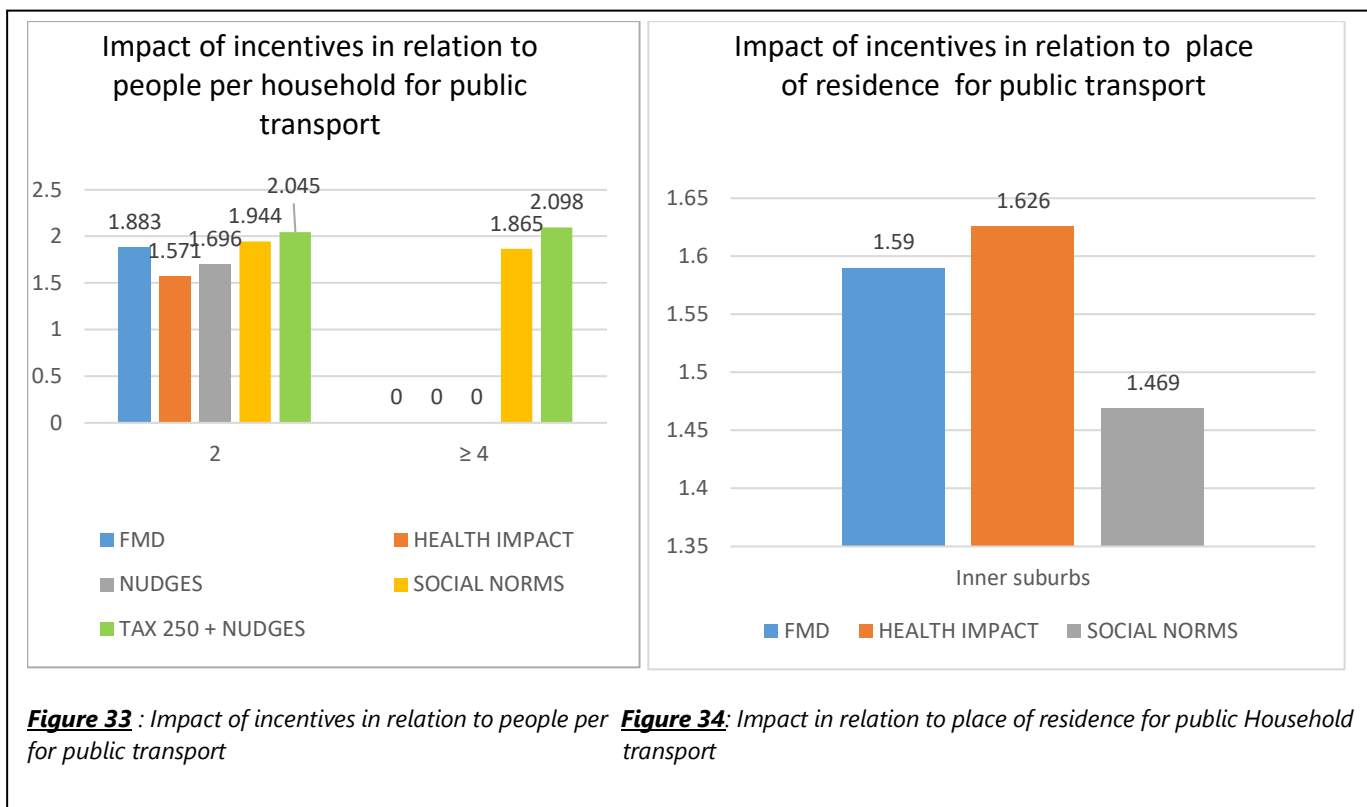


Figure 32: Impact of incentives in relation to level of education for Public transport



Regarding **cycling**, the nudge has a more significant impact than the other incentives for respondents aged 18 to 24, with an odds ratio of 5.014. The FMD has a more significant impact than other incentives for respondents aged 25 to 34, with an odds ratio of 2.362 (figure 35). The nudge is the incentive that has the most impact on the respondent with a level of education equivalent to the bachelor's degree, at the level of education between the second year and the fourth year of the bachelor's degree, and a level of education higher than the fifth year of the master's degree, with respective count ratios of 2.41; 1.992 and 1.707 (figure 36). Only households with four or more people are sensitive to bicycle-choice incentives. With an odds ratio of 1.699, the combination of the €250 carbon tax and the nudge has the greatest impact on bicycle choice (Figure 37).

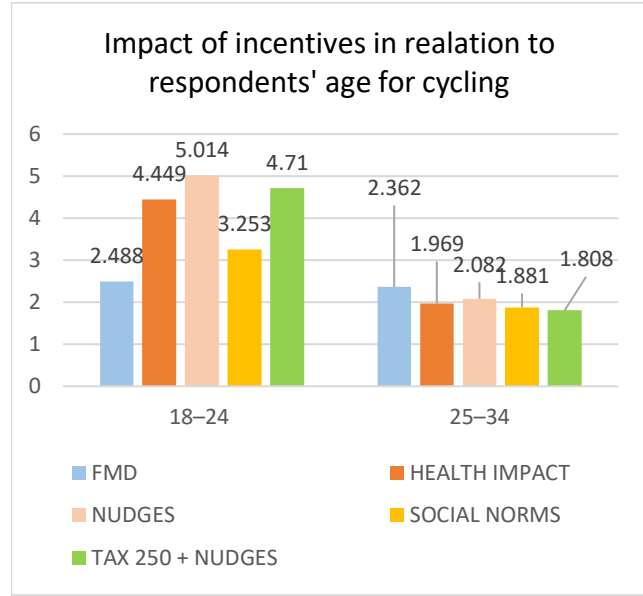


Figure 35: Impact of incentives in relation to Respondents' age for cycling

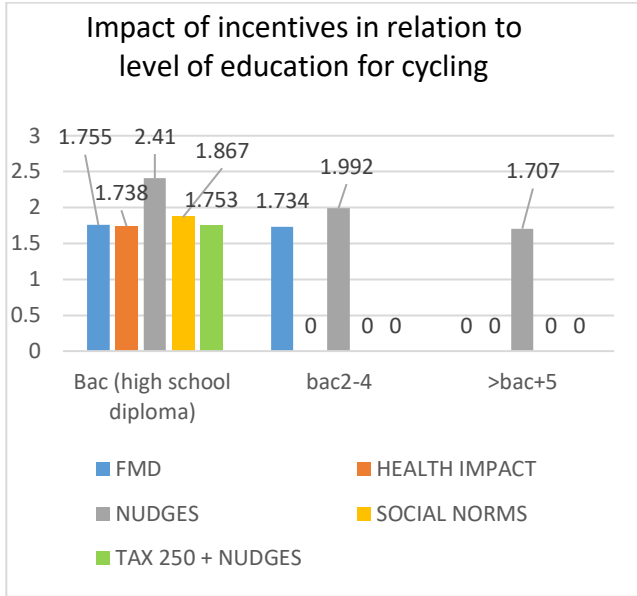


Figure 36 : Impact of incentives in relation to level of education for cycling

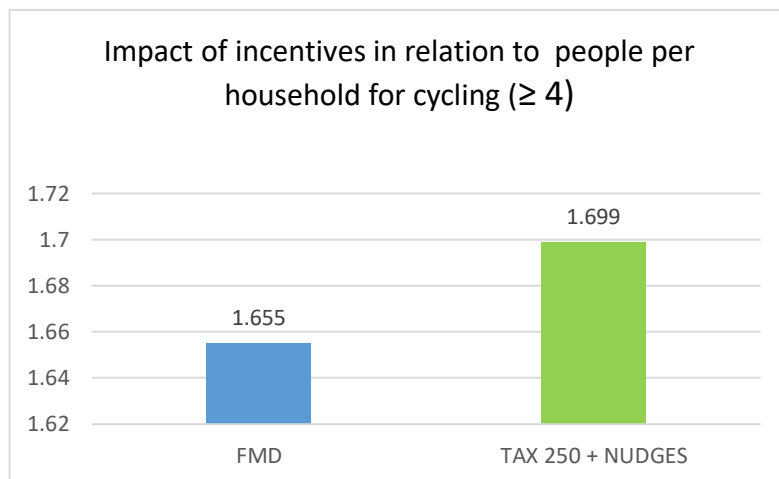


Figure 37: Impact of incentives in relation to people per household for cycling

Tables 15 and 16 summarize the results of comparisons between different incentives for respectively medium and short distance trips. They indicate the sociodemographic characteristics that are sensitive to evaluated incentives for each considered mode.

Table 15: Summary of profiles that are sensitive economic and non-economic incentives to use carpooling and public modes for medium-distance trips.

Incentives	Transport mode choice	
	Carpooling	Public transport
FMD	Age (25-34)	-People per household (2,3)
Nudges	Age (18-24; 34-49)	-Income per household (1001-2500)
Carbon Tax 250€ + Nudges	<ul style="list-style-type: none"> - Income per household (1001-2500) - Education level (bac +2/3/4; > bac+5) - People per household (2;3; ≥ 4) 	<ul style="list-style-type: none"> -Age (18-34) -People per household (≥ 4) -Place of residence (Inner suburbs)

Table 16 :Summary of profiles that are sensitive economic and non-economic incentives to use carpooling, public transport and electric bikes for short distance trips

Incentives	Transport mode choice		
	Carpooling	Public transport	Electric bike
FMD	<ul style="list-style-type: none"> -Age (18-24) -Education level(> bac+5) -People per household (2) 	<ul style="list-style-type: none"> - Income per household (1001-2500; >9000) 	Age (25-34)
Health impact	-	Place of residence (Inner suburbs)	-
Nudges	<ul style="list-style-type: none"> -Age (18-24) -Education level (bac +2/3/4) -Place of residence (Inner suburbs, Outer suburbs) 	-Education level (bac +2/3/4)	<ul style="list-style-type: none"> -Age (18-24) -Education level (bac +2/3/4; > bac+5)
Social norms	Age (18-24)	-	-
Carbon Tax 250€ + Nudges	<ul style="list-style-type: none"> - Income per household (1001-2500) - People per household (3; ≥ 4) 	<ul style="list-style-type: none"> -Age (18-24) - Education level (bac; > bac+5) 	-People per household (≥ 4)



5. DISCUSSION

5.1. Modal centered results

First, the results of NL models are discussed mode by mode regardless of the incentives. In particular, the choice of carpooling is found to be with individual and socio-demographic variables such as:

- Age (18 to 49 years old)
- Low household income (1001-2500 €)
- The respondent's level of education (baccalaureate 2-4 and >bac+5).
- Low level of car ownership
- The high number of people in the household.

These findings are consistent with the carpooling literature. Indeed, Vine *et al* (2014) show the relationship between young adults and carpooling usage. Younger generations are presumably more likely to share cars than older generations since their attitudes toward the automobile differ. According to Miller (2001), this can be interpreted as a new form of car culture. The relationship between income and carpooling has already been demonstrated in the literature. The works of Vanoutrive *et al.* (2012), Efthymiou & Antoniou (2016), and Bulteau *et al.* (2021) emphasize that people with middle or low incomes are more willing to carpool. Also, several studies have shown the relationship between education level and carpooling. Ballus-Armet *et al.* (2014) and Prieto *et al.* (2017) have shown that higher levels of education are positively associated with carpooling use. The literature has shown a negative relationship between car ownership and carpooling (Martin *et al.*, 2010; Clewlow, 2016). Gheorghiu and Delhomme (2018) also showed a positive relationship between the number of people in the household and carpooling usage.

For public transport, the results of NL models showed that the choice of public transport is associated with individual and socio-demographic variables such as:

- Age (18-24 years)
- Low household income (1001-2500 euros)
- Level of education (Bac, bac2-4, >bac+5)
- Low level of car ownership
- Number of people per household
- Contextual variables such as place of residence (inner suburbs).

In relation to the relationship between age and public transport, the findings of Dieleman *et al.* (2002) are consistent with ours in demonstrating that younger individuals are more likely to utilize public transportation, whereas middle-aged individuals are more likely to drive. The relationship between income and public transport use has been demonstrated in the literature. Income affects the demand for public transport through increased car ownership. Several studies state that as income

increases, transportation demand decreases (Holmgren, 2013). Schwanen *et al.* (2001) showed that high education levels could positively correlate with public transport choice. Education and learning are decisive factors in shaping society and assessing the level of sensitivity of people to current issues such as sustainable mobility. Thus, increased education can lead to behavioral change by decreasing car use and modal shift to public transport (Dingil & Esztergàr-Kiss, 2022). The results found between the place of residence and public transport use have been demonstrated in several studies. The population density in the inner suburbs and accessibility to public transportation infrastructure increase public transportation use (Ewing & Cervero, 2010; Buehler, 2011).

The results of NL models showed that bicycle choice is associated with individual and socio-demographic variables such as:

- Age (18 to 34 years)
- High education level
- Low level of car ownership
- High number of people per household

Several studies have shown how age is a factor that influences the choice to bike (Buehler, 2012; Chen *et al.*, 2017; Cole-Hunter *et al.*, 2015; Goodman & Aldred, 2018; Ma & Dill, 2015; Parkin, 2004; Piatkowski & Marshall, 2015). These studies have shown that cycling levels decrease for travel with age. Work by Friehe and Mechtel (2014) and Hude (2022) shows that people with higher levels of education have greater incentives to bike than people with lower levels of education. They explain that people with higher education levels might experience greater gains and lower threats from cycling than people with lower levels of education.

5.2. Incentives impacts on the usage

The comparison of different incentives for the **medium-distance** framework showed that the best incentive for carpooling and public transport among younger people, low-income households, and educated people is a combination of economic incentives such as the carbon tax (250 euro) and non-economic incentives such as nudges. These results are consistent with those of Hilton *et al.* (2014), Bulteau *et al.* (2021), and Raux *et al.* (2021), who show that the combination of an economic and non-economic incentive can encourage a modal shift to other modes than the application of the economic or non-economic incentive in isolation.

For the **short distance** framework, the best incentive to encourage carpooling among 18-24-year-olds is non-economic incentives such as nudges or social norms. Economic incentives such as the FMD are effective for the highest education level respondents. For the choice of public transport, the combination of the €250 carbon tax and nudge is effective for respondents aged 18 to 24, respondents with a high level of education (baccalaureate, >bac+5), and households with two or more people. An economic

incentive is more likely to motivate sustainable transport behavior if it is justified by a non-economic incentive known to the target audience, which is a nudge in the form of an injunctive norm in our study. However, the effectiveness of the combination of these two types of incentives may depend on the intensity of the incentive, which should be reasonable (Hilton *et al.*, 2014).

For the choice of bicycle, the best incentive for 18 to 24-year-olds and respondents with a high level of education is a non-economic incentive such as a nudge. This is in line with research demonstrating the benefits of nudges for young people (Vermeir & Verbeke, 2006; Miesler *et al.*, 2017). Young people are more cognizant of environmental issues and actively participate in ecological recovery (Calculli *et al.*, 2021).

6.CONCLUSION

This chapter seeks to identify what incentives are effective in the medium- and short-distance context to encourage alternative modes of transport to car use for commuting trips. Our study uses a questionnaire with a representative sample of 1502 commuters in the Ile-de-France region (Paris metropolitan area) and nested logit econometric models. The results of these models showed that the combination of an economic push incentive, which is the €250 carbon tax, and a non-economic nudge incentive is very effective in medium-distance trips to encourage respondents with high levels of education to carpool. This combination of incentives is also effective in encouraging young adults aged 18 to 24, people with high levels of education, and those living in the inner suburbs to use public transport. For short-distance trips, non-economic incentives such as nudges and social norms effectively encourage young adults aged 18-24 and those living in the inner suburbs to carpool. For public transport, the combination of the economic incentive of the €250 carbon tax and nudges is effective among people with more than five years of education and young adults aged 18 to 24. The nudge effectively encourages cycling among young adults aged 18 to 24 and people with a high level of education. These results show that a combination of economic push and non-economic incentives are needed to encourage young adults to use sustainable modes of transport as an alternative to driving alone. Younger people are sensitive to environmental emergencies and often take actions in this direction. Also, this same combination could perhaps target those who are educated. For active modes such as bicycling, non-economic incentives such as social norms or nudges can be targeted at younger and more educated people by local governments. Our study has allowed us to answer the questions of economic or non-economic incentives or combinations of effective incentives for a modal shift towards sustainable mobility solutions for medium or short distances in Ile-de-France. However, it has limitations that need to be highlighted. First, testing the impact of the €250 carbon tax in isolation would have been an additional contribution. Second, other economic and non-economic combinations could have been tested, such as combining the FMD with

social norms or health impact. The combination of the carbon tax and social standards or health impact could also have been tested. Third, other econometric models could have been tested. Despite these limitations, the results of this study provide policy recommendations that are useful for policymakers who can apply them in a targeted manner according to age, income, and education level.

Future research studies will focus on these limitations and endeavors to consider more complex models and more combinations to propose relevant policies to promote the usage of more sustainable mobility solutions. Also, we will be able to look at other territories different from the Ile-de-France.

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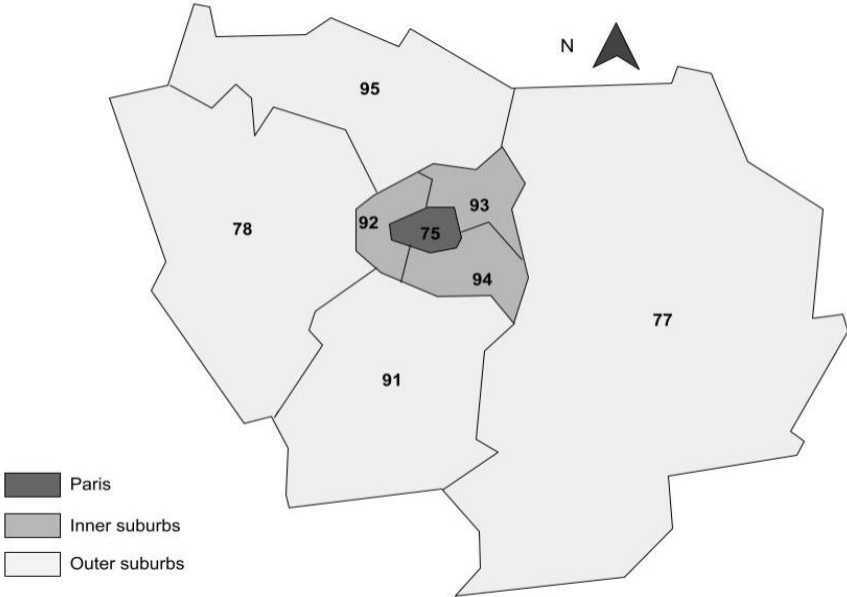
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APPENDIXES

Appendix 1: The administrative organization of the Ile-de-France region



Note: "91": *Département* Code

Appendix 2: Results of Nested logit for medium distance commuting trips (carpooling, 20 km)

Incentives	FMD (M1)		Nudges (M2)		Tax 250 + nudges (M3)	
Variables	OR	P> z	OR	P> z	OR	P> z
Carpooling						
Individual and socio-demographic variables						
Gender						
Female (<i>Ref</i>)	-	-	-	-	-	-
Male	1,116	0,439	1,006	0,966	0,947	0,714
Age						
50 years and older (<i>Ref</i>)	-	-	-	-	-	-
18–24	2,877***	0	3,293***	0	2,983***	0
25–34	2,660***	0	2,199***	0	2,153***	0,001
35–49	1,647	0,008	1,633***	0,01	1,395**	0,087
Income per household €						
2501–4000 (<i>Ref</i>)	-	-	-	-	-	-
500-1000	1,204	0,616	0,878	0,728	1,051	0,897
1001-2500	1,461*	0,07	1,811***	0,006	2,064***	0,001
4001-9000	0,993	0,969	0,955	0,802	1,016	0,933
>9000	0,497**	0,051	0,739	0,424	1,108	0,8
DWA*	0,897	0,767	0,898	0,784	1,093	0,834
Education						
<bac (<i>Ref</i>)	-	-	-	-	-	-
Bac (high school diploma)	1,538	0,104	1,677	0,058	2,160	0,006
bac2-4	1,612**	0,045	1,687**	0,031	1,908***	0,009
>bac+5	1,422	0,18	1,702**	0,046	1,800**	0,031
Number of cars owned by household						
0 (<i>Ref</i>)	-	-	-	-	-	-
1	0,354***	0	0,380***	0	0,296***	0
≥ 2	0,291***	0	0,285***	0	0,215***	0
People per household						
1	-	-	-	-	-	-
2	1,967***	0,004	1,732***	0,02	2,738***	0
3	1,725**	0,027	1,591**	0,064	2,129***	0,003
≥ 4	2,875***	0	2,456***	0	3,676***	0
Contextual variables						
Place of residence						

Central Paris(<i>Ref</i>)	-	-	-	-	-	-
Inner suburbs	1,040	0,852	1,191	0,412	1,157	0,509
Outer suburbs	1,062	0,77	1,200	0,381	1,089	0,689
Public transport						
Individual and socio-demographic variables						
Gender						
Female (<i>Ref</i>)	-	-	-	-	-	-
Male	1,095	0,564	0,956	0,769	0,916	0,566
50 years and older (<i>Ref</i>)	-	-	-	-	-	-
18–24	0,952	0,866	1,837**	0,033	2,393***	0,002
25–34	0,666	0,114	0,601**	0,04	0,841	0,476
35–49	0,932	0,728	0,869	0,483	0,850	0,41
Income per household €						
2501–4000 (<i>Ref</i>)	-	-	-	-	-	-
500-1000	1,191	0,667	1,072	0,855	0,871	0,719
1001-2500	1,428	0,103	1,734***	0,013	1,687**	0,017
4001-9000	1,012	0,954	1,010	0,961	0,988	0,953
>9000	1,065	0,867	1,153	0,713	1,306	0,514
DWA*	1,013	0,975	1,376	0,429	1,863	0,126
Education						
<bac (<i>Ref</i>)	-	-	-	-	-	-
Bac (high school diploma)	2,521***	0,001	2,921***	0	3,596***	0
bac2-4	2,635***	0	2,809***	0	3,361***	0
>bac+5	2,831***	0	3,002***	0	3,546***	0
Number of cars owned by household						
0 (<i>Ref</i>)	-	-	-	-	-	-
1	0,180***	0	0,184***	0	0,180***	0
≥ 2	0,066***	0	0,088***	0	0,080***	0
People per household						
1	-	-	-	-	-	-
2	2,116***	0,002	1,959***	0,005	2,058***	0,002
3	2,039***	0,006	1,815**	0,022	1,451	0,144
≥ 4	2,190***	0,004	2,407***	0,001	2,718***	0
Contextual variables						
Place of residence						
Central Paris(<i>Ref</i>)	-	-	-	-	-	-
Inner suburbs	1,474*	0,079	1,671**	0,019	1,717***	0,013
Outer suburbs	1,049	0,833	1,108	0,647	1,057	0,802
/type						
mob_ind_tau			1		1	

Carpooling tau	-0,1800203	-	-0,3021399	-	-	0,561457	-
Public transport tau	1	-	1	-	1	-	-
Prob > chi2	0,0415	-	0,0197	-	0,0041	-	-

OR = Odds Ratio
DWA = Do not wish to answer
1*p<0.1; **p<0.05; ***p<0.01

reflects that respondents characterized by the variable have a low chance of choosing the mode of transport over the reference

reflects that respondents characterized by the variable have a high chance of choosing the mode of transport over the reference

Appendix 3: Results of Nested logit for short distances

Nested logit (carpooling driver + carpooling passenger)										
Incentives	FMD(M4)		Health impact (M5)		Nudges (M6)		Social norms (M7)		Tax 250 + nudges (M8)	
Variables	OR	P> z	OR	P> z	OR	P> z	OR	P> z	OR	P> z
Carpooling										
Individual and socio-demographic variables										
Gender										
Female (<i>Ref</i>)	-	-	-	-	-	-	-	-	-	-
Male	0,798	0,157	0,981	0,905	0,942	0,717	0,988	0,939	0,961	0,811
Age										
50 years and older (<i>Ref</i>)	-	-	-	-	-	-	-	-	-	-
18–24	2,171***	0,007	1,742*	0,075	2,516***	0,004	2,507***	0,002	2,388***	0,008
25–34	2,173***	0,002	1,706**	0,034	2,074***	0,004	1,820***	0,017	1,559*	0,082
35–49	1,335	0,176	1,394	0,126	1,397	0,121	1,315	0,202	1,333	0,194
Income per household €										
2501–4000 (<i>Ref</i>)	-	-	-	-	-	-	-	-	-	-
500-1000	1,203	0,647	1,284	0,554	1,028	0,948	1,166	0,708	1,245	0,607
1001-2500	2,112***	0,001	1,916***	0,007	1,883***	0,01	2,011***	0,003	2,312***	0,001
4001-9000	1,078	0,713	0,998	0,991	0,865	0,488	1,260	0,26	0,930	0,731
>9000	0,966	0,941	1,966	0,15	0,844	0,709	1,850	0,192	1,286	0,605
DWA*	1,283	0,553	1,366	0,453	1,739	0,188	1,322	0,505	1,179	0,714
Education										
<bac (<i>Ref</i>)	-	-	-	-	-	-	-	-	-	-
Bac (high school diploma)	1,399	0,263	1,303	0,391	1,639	0,108	1,628	0,109	1,322	0,372
bac2-4	1,886**	0,018	1,442	0,177	2,077***	0,007	1,715**	0,046	1,160	0,586

>bac+5	1,833**	0,04	1,319	0,356	1,738*	0,062	1,579	0,122	1,210	0,523
Number of cars owned by household										
0 (Ref)	-	-	-	-	-	-	-	-	-	-
1	0,334***	0	0,525***	0,02	0,384***	0,001	0,483***	0,008	0,487***	0,014
≥ 2	0,209***	0	0,343***	0,001	0,273***	0	0,308***	0	0,377***	0,004
People per household										
1	-	-	-	-	-	-	-	-	-	-
2	2,153***	0,004	1,552	0,105	1,466	0,16	1,635*	0,065	2,149***	0,006
3	1,668**	0,069	1,188	0,554	1,110	0,718	1,144	0,633	1,760**	0,055
≥ 4	3,299***	0	2,178***	0,007	2,234***	0,006	2,310***	0,003	3,740***	0
Contextual variables										
Place of residence										
Central Paris(Ref)	-	-	-	-	-	-	-	-	-	-
Inner suburbs	1,571*	0,06	1,299	0,275	1,773**	0,022	1,515*	0,086	1,364	0,215
Outer suburbs	1,493*	0,086	1,261	0,322	1,661**	0,037	1,514*	0,078	1,356	0,212
Public transport										
Individual and socio-demographic variables										
Gender										
Female (Ref)	-	-	-	-	-	-	-	-	-	-
Male	1,150	0,388	1,049	0,77	1,059	0,729	1,133	0,44	0,936	0,688
Age										
50 years and older (Ref)	-	-	-	-	-	-	-	-	-	-
18–24	1,012	0,968	1,340	0,34	1,738*	0,083	1,659*	0,092	1,837*	0,057
25–34	0,805	0,408	0,602**	0,051	0,837	0,497	0,707	0,173	0,651*	0,09
35–49	0,748	0,167	0,734	0,146	0,812	0,33	0,648**	0,04	0,801	0,292
Income per household €										
2501–4000 (Ref)	-	-	-	-	-	-	-	-	-	-
500-1000	1,118	0,785	0,932	0,868	1,017	0,969	0,944	0,887	0,688	0,382
1001-2500	2,117***	0,001	1,740**	0,016	2,004***	0,003	1,794***	0,009	2,008***	0,003
4001-9000	1,178	0,451	0,837	0,418	1,068	0,766	1,040	0,855	0,898	0,618
>9000	2,379*	0,045	2,124	0,105	1,626	0,256	2,327*	0,065	1,898	0,163
DWA*	1,388	0,462	1,177	0,709	1,228	0,665	1,149	0,75	1,561	0,306
Education										
<bac (Ref)	-	-	-	-	-	-	-	-	-	-
Bac (high school diploma)	2,993***	0	3,304***	0	4,151***	0	3,023***	0	4,210***	0
bac2-4	3,508***	0	3,092***	0	4,080***	0	3,340***	0	3,944***	0
>bac+5	3,158***	0	3,395***	0	3,594***	0	2,819***	0	3,733***	0
Number of cars owned by household										
0 (Ref)	-	-	-	-	-	-	-	-	-	-
1	0,164***	0	0,240***	0	0,195***	0	0,238***	0	0,197***	0
≥ 2	0,069***	0	0,091***	0	0,069***	0	0,079***	0	0,076***	0


People per household										
1	-	-	-	-	-	-	-	-	-	-
2	1,883***	0,011	1,571*	0,07	1,696*	0,038	1,944***	0,007	2,045***	0,004
3	1,327	0,293	1,317	0,308	1,088	0,761	1,245	0,412	1,510	0,126
≥ 4	1,469	0,177	1,171	0,585	1,415	0,235	1,865***	0,027	2,098***	0,01
Contextual variables										
Place of residence										
Central Paris(Ref)	-	-	-	-	-	-	-	-	-	-
Inner suburbs	1,590**	0,042	1,626**	0,033	1,438	0,117	1,469*	0,086	1,390	0,147
Outer suburbs	1,145	0,56	1,222	0,393	1,024	0,919	0,990	0,965	1,049	0,835
Cycling										
Individual and socio-demographic variables										
Gender										
Female (Ref)	-	-	-	-	-	-	-	-	-	-
Male	0,948	0,753	1,105	0,536	0,974	0,874	1,184	0,316	1,088	0,615
Age										
50 years and older (Ref)	-	-	-	-	-	-	-	-	-	-
18–24	2,488***	0,002	4,449***	0	5,014***	0	3,253***	0	4,710***	0
25–34	2,362***	0,001	1,969***	0,008	2,082***	0,006	1,881***	0,019	1,808***	0,025
35–49	1,165	0,515	1,403	0,128	1,339	0,204	1,382	0,162	1,391	0,153
Income per household €										
2501–4000 (Ref)	-	-	-	-	-	-	-	-	-	-
500-1000	0,827	0,653	0,885	0,763	0,873	0,752	0,819	0,634	1,117	0,786
1001-2500	1,129	0,623	1,326	0,227	1,343	0,232	1,253	0,351	1,578	0,065
4001-9000	1,172	0,467	1,263	0,261	1,196	0,409	1,264	0,285	1,387	0,134
>9000	1,787	0,188	1,736	0,238	1,197	0,681	2,023	0,143	1,925	0,171
DWA*	1,114	0,81	0,692	0,423	0,921	0,865	0,955	0,92	0,965	0,94
Education										
<bac (Ref)	-	-	-	-	-	-	-	-	-	-
Bac (high school diploma)	1,755*	0,063	1,738*	0,06	2,410***	0,004	1,867**	0,039	1,753**	0,069
bac2-4	1,734*	0,041	1,473	0,13	1,992***	0,01	1,526	0,111	1,344	0,265
>bac+5	1,349	0,317	1,390	0,246	1,707*	0,069	1,194	0,546	1,014	0,964
Number of cars owned by household										
0 (Ref)	-	-	-	-	-	-	-	-	-	-
1	0,256***	0	0,275***	0	0,262***	0	0,320***	0	0,278***	0
≥ 2	0,199***	0	0,231***	0	0,209***	0	0,297***	0	0,248***	0
People per household										
1	-	-	-	-	-	-	-	-	-	-
2	1,033	0,907	0,903	0,697	0,863	0,592	0,706	0,204	1,072	0,797
3	1,049	0,868	0,806	0,44	0,896	0,702	0,663	0,151	0,850	0,575
≥ 4	1,655*	0,086	1,295	0,356	1,327	0,338	1,092	0,764	1,699*	0,071


Central Paris(Ref)	-	-	-	-	-	-	-	-	-	-
Inner suburbs	1,298	0,276	1,285	0,277	1,192	0,463	1,226	0,395	1,175	0,502
Outer suburbs	1,016	0,946	1,378	0,159	1,043	0,858	1,040	0,868	1,119	0,637
Type										
Tau solo driving	1	-	1	-	1	-	1	-	1	-
Tau carpooling	-	-	-	-	-	-	-	-	-	-
	1,010815		0,8064969		0,9205203		1,222942		1,054665	
Tau Public transport	1	-	1	-	1	-	1	-	1	-
Tau Cycling	1	-	1	-	1	-	1	-	1	-
Prob > chi2	0,0014	-	0,0062	-	0,0029	-	0,0003	-	0,0014	-

OR = Odds Ratio

DWA = Do not wish to answer

1*p<0.1; **p<0.05; ***p<0.01

 reflects that respondents characterized by the variable have a low chance of choosing the mode of transport over the reference

 reflects that respondents characterized by the variable have a high chance of choosing the mode of transport over the reference

CONCLUSION AND RECOMMENDATIONS

Road transport brings real benefits to a country's economy. The development of road transport allows for accessibility to roads, flexibility concerning transport needs, the economy of scale, job creation, and contribution to international trade. The total expenditure on transport amounted to 438.2 billion euros, i.e. 18.1% of GDP in 2019 in France. 34% of employees were employed in passenger transport, 29% in freight transport in 2019 in France (Données et études statistiques, 2021)⁴. However, it generates negative externalities (congestion, noise, air pollution, road accidents) that negatively impact the environment and society. The introduction of sustainability in the transport field requires a balance between the economic benefits of transport, the preservation of the environment for future generations, and social welfare. Thus, sustainable mobility implies actions or measures that favor modal shifts from solo driving to more sustainable modes of transport such as cycling, walking, public transport, and sustainable mobility behaviors (carpooling). This is the direction in which my PhD thesis goes. It studies how to reduce the externalities of road transport of people by promoting sustainable modes of transport and travel behaviors. Despite numerous modal shift policies implemented since the 1980s and 1990s in developed countries, the modal share of the private car remains very high outside the most densely populated urban areas. Thus, my thesis answers this research question: How can we promote a modal shift from the private car to more sustainable mobility solutions for commuting trips?

Today, there is a panoply of regulations or standards and tools from the authorities that allow this objective to be achieved. The literature also contributes by proposing various instruments from several specific fields. My thesis focuses on economic and non-economic instruments. It is approached by combining expertise in economics, social psychology, and econometrics and is presented in three parts.

The first part of the thesis reviews the literature on incentives for a modal shift from solo driving toward sustainable mobility solutions. We start with a bibliographic analysis, showing that economic incentives can be classified into two instruments: price regulation (fuel taxes, road pricing through urban tolls, parking fees, mileage allowances for bicycles, bonus-malus systems) and quantity regulation (tradable emission permits). These instruments contribute to modal shift but have limitations (rebound effects, social acceptability problems, difficulty in implementing measures).

⁴ Données et études statistiques, 2021. « Chiffres clés du transport - Édition 2021 », https://www.statistiques.developpement-durable.gouv.fr/sites/default/files/2021-05/datalab_89_chiffres_cles_transport_2021_infographie_mai2021.pdf

Also, some instruments are more effective than others in specific contexts. The literature reveals that direct policy instruments related to private car use (fuel taxes) are more effective in dense urban areas than indirect policy instruments (parking management policies, cordon tools). These various limitations of economic incentives suggest that psychological factors should be considered in public policies to encourage sustainable mobility solutions. Non-economic incentives have shown that transport mode choices are guided by psychological factors (attitudes, subjective norms, perceived behavioral control, habits) and persuasive technologies. It has been shown that, as with economic incentives, non-economic incentives also have limitations (boomerang effect, effectiveness of instruments dependent on cultural context, policies applied, and economic environment).

Next, a comparative analysis between economic and non-economic incentives is made through a bibliometric analysis. We show that the independent application of different types of incentives (economic and non-economic) has its limits. Combining economic and non-economic incentives is suggested to optimize the modal shift towards sustainable mobility solutions. Also, it is shown that there are very few studies that address the combination of incentives (economic and non-economic). A variety of mobility user profiles are assumed to respond to different incentives or combinations of incentives to change their behavior. Different incentives or combinations of incentives are tested on these different profiles.

In the second part of the thesis, we analyzed the combination of economic (*Forfait Mobilité Durable*=FMD) and non-economic (nudges, trusting others to carpool) incentives to encourage carpooling to work or school in the Ile-de-France *Région* (Paris metropolitan area). A questionnaire was conducted on a sample of 1502 respondents, including 509 car drivers living and working in Ile-de-France. Using Multinomial logit models and Binomial logit models, we analyzed: (1) the effect of non-economic incentives, such as nudges and trust in others during carpooling, (2) the effect of the combination of nudges and employer subsidies for sustainable mobility on the intention to carpool as a driver or passenger for the commute home-to-work (or to school) trips. We show that nudges are most effective among younger and more educated individuals and encourage such mobility users to carpool more. Young people's awareness of environmental issues might be a valuable tool in encouraging them to carpool to work. Applying nudges in isolation appears to be more effective in encouraging carpooling for commuting than the combination of nudges and employer subsidies. We also show that the intention to carpool with a stranger is higher for men than for women.

Chapter 3 measures the intention to choose more sustainable modes of transport over solo driving, in the context of medium and short distances for home-to-work (or study) trips in the Île-de-France region, under the impact of incentives or combinations of incentives. We use the same database as in Chapter 2 (1502 respondents). We measure

the intention to choose between solo driving, carpooling, and public transport for medium distances. For short distances, we measure the intention to make the same choices as for medium distances, with the difference that we add the electric bicycle. Discrete choice models, including nested logit models, are used for choice estimation. We examine separately (1) the impact of non-economic incentives such as nudging on medium-distance commuting. We also study the effect on the health of different modes of transportation and the social norm for short-distance travel. Similarly, we examine separately (2) the impact of an economic incentive (250 euro/ton carbon tax and FMD) alone and (3) the combination of the selected economic and non-economic incentives. For medium distance commuting trips, we show that the combination of the 250 Euro carbon tax and nudge is very effective in shifting the modal shift from solo driving to carpooling and public transport among young adults, low-income households, and people with a high level of education. For short distance commuting trips, we reveal that nudge is effective for the choice of carpooling and electric bicycles among young adults and for the choice of public transport among people with a high level of education. The results show that: (1) overall, combinations of economic and non-economic incentives are more effective than the same incentives applied in isolation. (2) However, there are mobility situations (distance) and mobility user profiles for which isolated applications of incentives are more effective. (3) This research highlights certain mobility situations and user characteristics.

Based on these results, we can propose some policy recommendations. In terms of user profiles, young people should be the focus of mobility management strategies that use "nudges" to encourage them to choose carpooling and e-bikes as viable options for driving alone for commuting. Nudges can also be used to encourage people with higher levels of education. Employers should set up carpooling services for commuting to work to encourage their employees, especially women, to carpool. If women travel with colleagues, they are more likely to carpool.

For distance categories, authorities can combine an economic "push" incentive with a non-economic incentive, such as "nudges," to encourage sustainable modes for medium-distance commuting. For short-distance commuting, non-economic incentives could be a real asset in encouraging electric bicycles and public transport use. These recommendations are for commuting (or study) only.

Despite the results provided by this thesis, it has some limitations. First, it would have been interesting to test the effect of the FMD in isolation on solo drivers in the second part. Then, the impact of the €250 carbon tax could also have been tested in isolation in Part 3. Second, other economic and non-economic combinations could have been tested, such as the combination of the FMD with social norms or the health impact. The combination of the carbon tax with social standards or health impact could also have been tested.

Despite the results provided by this thesis, it has some limitations. First, it would have been interesting to test the effect of the FMD in isolation on solo drivers in Part 2. Second, the impact of the €250 carbon tax could also have been tested in isolation in Part 3. Other economic and non-economic combinations could have been tested, such as the combination of the FMD with social standards or the impact on health. The impact of combining the carbon tax with social standards or the impact on health was not tested as well. Third, the effect of the incentives on a different type of territory and other travel motives (leisure, shopping) could be analyzed. Fourth, one could have tested other more complex discrete choice econometric models such as mixed logit or latent class models.

Future studies will address these limitations and investigate more complicated models and combinations to suggest strategies to support sustainable mobility alternatives.

