Impact of cycle lanes and public bike parking on bicycle commuting: Complementing French census with spatial data for policymaking

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Abstract

Despite its well-documented benefits, cycling accounts for only 5% of home-to-work journeys of less than 5 km in France. Toward sustainable transportation, the French government is embarking on a national target of 12% modal share by 2030. However, the limited knowledge of the quantitative impact of additional bicycle infrastructure on bicycle commuting and heterogeneity in municipalities makes it difficult to achieve an equitable nationwide distribution of bicycle infrastructure. To fill these gaps, this study investigates the impact of additional cycle lanes and public parking spaces on bicycle commuting in mainland France. Census data with 6.7 million observations are enriched with spatial information to build four clustered standard error logit models with municipality correlated random-effects. The results show that a one-unit increase in the rate of cycle lanes increases bicycle commuting by approximately 21% and 15% in the municipality of residence and work, respectively. A one-unit increase in public parking space increases bicycle commuting by 5% and 1% in the municipality of residence and work, respectively. From a policy perspective, there are several conclusions: (1) there is potential for cycling in high-density areas given additional cycle lanes and parking spaces in the municipality of work; (2) medium and low-density areas would require more infrastructure in the municipality of residence; (3) reaching the national target would require jointly increasing the supply of cycle lanes and parking spaces by twofold. If treated as mutually exclusive, the target is achievable by increasing the length of the cycle lane 2.3 times or the parking spaces 17 times. These findings provide a strong policy basis for additional national bicycle infrastructure according to population density and cycling patterns.

Keywords: Bicycle; Commuting; Infrastructure; Lanes; Public parking; Choice model

1 Introduction

Cycling has several environmental, economic and health benefits (Schwarz et al., 2024). Cycling boosts physical activity, reduces greenhouse gas emissions, and is an affordable mode of transport. To encourage bicycle commuting, the *European Declaration on Cycling* (2024) has sought to enhance cycling infrastructure and foster cycling habits at various policy levels. It calls for the expansion of cycling network and connectivity between municipalities as well as providing bicycle parking spaces at home and workplaces. However, in France, cycling still represents only 5% of home-to-work journeys and almost 67% of work-related commutes are made by private car (Havet & Bouzouina, 2025). A national survey unveils significant disparities in the levels of satisfaction with cycling across 1,625 French municipalities of varying size (FUB (2021)). Municipalities with populations ranging from 15,000 to 100,000, which are often dependent on the use of private vehicles, exhibited the least favourable attitudes toward cycling. Conversely, large municipalities, i.e., with populations over 100,000, demonstrated proficiency in fostering cycling at the intercommunal level, while some small municipalities (with populations between 5,000 and 15,000) benefited from facilities funded by tourism. These outcomes have necessitated renewed actions and efforts to promote bicycle as a mode of transport among the French population (Celbiş & Bouzouina, 2025).

The existing literature has shown that a key factor that hinders the development of cycling is the lack of adequate infrastructure, including cycle lanes and designated bicycle parking spaces (Gutiérrez et al., 2020). Unsafe conditions have been identified as a primary disincentive to cycling (Fernandez-Heredia et al., 2014). Amenities that meet the necessary quality standards generate a sense of safety among cyclists, which ultimately encourages ridership (Márquez & Soto, 2021). Also, the provision of enclosed cycle parking facilities in proximity to destinations has been found to encourage ridership, specifically near the workplace (Heinen et al., 2013). Consequently, key strategies in the European Declaration are the allocation of space and adequate infrastructure for cycling.

In this context, the French authorities aim for a cycling modal share of 12% by 2030. To this end, the government has committed to invest two billion euros by 2027 to develop active mobility infrastructure as part of its 2023-2027 cycling and walking plan (European Commission, 2023). The target is to contribute reaching 30,000 additional km of cycle lanes in France by 2027, which would amount to a 60% increase. By 2030, the bike lanes are expected to reach 100,000 km. Undoubtedly, this prospective massive expansion of cycling infrastructure will come at a significant cost and decision makers would want to trade-off the costs to ensure that there is value for money. The expansion of the infrastructure may require reallocating the road space for bicycles, demarcating new cycle lanes, and installing more parking spaces at workplaces and residential neighbourhoods. These make it imperative to quantify the utility that the provision of additional cycle lanes and parking spaces would have on bicycle commuting.

Existing studies were often conducted on a local scale (city, for example) or in specific local contexts (within a campus, for example). Examining the impact of cycling infrastructure on a national scale is still uncommon. Yet, the impact of cycling facilities may vary depending on the spatial context and a large national-scale investigation of these effects will be useful for generalizations. The lack of studies at a national scale is perhaps due to the lack of appropriate cycling data at this large scale. Most national datasets, mainly census data, only cover housing and population information which are socio-demographic in nature and lack spatial data on cycling. The weakness is that, without spatial information, the heterogeneity in population density will be difficult to understand. A recent paper on the impact of cycling infrastructure improvement on cycling usage was also constrained to empirical data collected in Lyon and Paris only, without national-scale impact analysis (Shahriari et al., 2024).

In response to the above research gaps, this study examines the impact of additional cycle lanes and parking spaces on cycling commuting in France. There are three main contributions to the cycling literature and policy. First, this study complements the large-scale national-level census data of 6.7 million observations with spatial information for comprehensive quantitative outcomes to help policymakers. This helps to identify heterogeneity in the effects of cycling infrastructure by building models that compare cycling commuting in dense, medium and low density communities. This segmented analysis is useful for holistic policy and planning, particularly regarding the allocation of resources to different communities. Second, it compares the municipality of work to the municipality of residence, which may have different cycle lane and parking spaces needs. Third, it analyses how additional infrastructure will impact the bicycle modal share which helps to know the infrastructure needed to meet national targets. This is generally useful for backcasting sustainability targets. France is a suitable case study because the built environment and lifestyles are similar to other countries in Europe. Thus, the methodology and policy lessons could be replicated elsewhere.

The remaining parts of this study are arranged as follows. Section 2 presents a review of the literature. It outlines the main findings on the influence of cycling facilities on the decision to cycle in different contexts around the world. Section 3 has a description of the data and methodological choices made to define the modelling process, and Section 4 presents the results. Section 5 discusses the limitations, policy implications, and concludes with recommendations for future research.

2 Literature Review

Extant literature has identified several key determinants of cycling. Individual socio-demographic factors, including age, sex, education, household size, job, income, municipality of residence, type of employment, and car ownership are important determinants of cycling Ospina et al. (2022). Socio-cultural factors such as peer influence, social status, and preferences, impact willingness to cycle Jahanshahi et al. (2025). Built environment and spatial factors such as residential density, topography, population density, and trip distances are determinants of bicycle commuting Çiriş et al. (2024). The trip purpose influences cycling distance and modal choice Harms, Lucas and Bertolini, Luca and te Brömmelstroet, Marco (2014); Mohamed, Firas and Chandrabose, Manoj and Forkan, Abdur Rahim Mohammad and Owen, Neville and Sugiyama, Takemi (2024), The weather patterns may inhibit cycling, especially in extreme conditions Goldmann & Wessel (2021). The perceived quality and safety of infrastructure, such as the bicycle lanes and parking facilities remains a strong determinant of bicycle commuting Rérat & Schmassmann (2024a).

Regardless of this established knowledge, there is a dearth of research covering both cycle lanes and bicycle parking spaces within a national-scale context. Current evidence, as outlined in Table 1, is limited to specific cities and university campuses. It is evident from most past studies that cycle lanes and parking spaces are significant determinants of bicycle commuting, but this would require a national-scale investigation. The growing interest in improving bicycle parking and bicycle lane infrastructure at workplaces and at residential areas calls for large-scale analysis to measure the impacts for appropriate distribution on a national scale. This will help to incorporate smaller cities and rural areas into cycling planning and policy making.

Although bicycle lanes have been identified as a determining factor in encouraging people to cycle, bicycle parking has received less attention. Indeed, Heinen & Buehler (2019) observe that the majority of studies treat cycle parking as an ancillary factor, with only a small number focusing exclusively on it. For example, Winters et al. (2011) ranked cycle parking tenth out of 73 variables tested, as an encouraging factor in Vancouver (Canada). Majumdar & Mitra (2013) identified parking as a secondary factor in the case of India. However, the story is different in Europe. For example, the Netherlands and Denmark have since 2015 increased bicycle commuting by providing parking spaces at homes, stations, shopping malls, city centres, and workplaces which have contributed to their progress in bicycle commuting (van Kampen et al., 2021; Schmidt et al., 2024). In Germany, recent studies also reported a higher likelihood of bicycle commuting among university students and employees who have formal and covered bicycle parking racks (Kohlrautz & Kuhnimhof, 2025a, 2024b). This evidence suggests that parking facilities can influence bicycle commuting.

A significant number of studies are conducted at the city level and are confined to specific environments, such as universities, or near the public transit network, rather than the workplace and home (Braun et al., 2016; Heinen & Buehler, 2019; Cannon et al., 2024; Beidenhauser, 2024). For instance, Molin & Maat (2015) categorised cyclists using stations in Delft (Netherlands) based on their propensity to pay for secure parking or to make detours to park for free. In Bogotá (Colombia), Orjuela & Páez (2013) have developed a Geographic Information System (GIS) method for analysing bicycle and bus intermodality through parking. In a more extensive study, Lierop et al. (2012) examined the propensity to pay for secure parking in the city of Montreal (Canada).

In the related literature, various authors have compared different trip-end facilities for cyclists and their effect on the attractiveness of cycling. In particular, parking facilities, showers and lockers have been examined. In the context of the city of Washington (USA), Buehler (2012) has observed a positive correlation among these facilities and cycling to work. The impact is further enhanced when these facilities are present in combination. Hunt & Abraham (2007) conducted a study in Edmonton (Canada), which identified secure parking as a more significant factor than showers for cyclists. Subsequent research into the design of parking facilities has become increasingly specialised. In Sweden, Dickinson & Östlund (2019) emphasise the preferences between a variety of parking types (e.g.,

Table 1: Summary of literature on the effects of cycle lanes and bicycle parking on cycling

Reference	Case study area	Effect	
		Cycle lanes	Bicycle parking
Acosta et al. (2016)	University, Barranquilla, Colombia	+ (s)	
Akar & Clifton (2009)	University, Maryland, USA	+ (q)	
Benedini et al. (2020)	City, Sao Paulo, Brazil	+ (sw)	
Braun et al. (2016)	City, Barcelona, Spain	+ (sw)	- (sw)
Buehler (2012)	City, Washington DC, USA	+ (s)	+ (sw)
Buehler & Pucher (2012)	90 cities, USA	+ (s)	
De Gruyter & Butt (2024)	City, Melbourne, Australia		+ (sh)
El-Assi et al. (2015)	City, Toronto, Canada	+ (s)	
Félix et al. (2019)	City, Lisbon, Portugal	+ (s)	+ (ns)
Fernandez-Heredia et al. (2014)	University, Madrid, Spain		+ (s)
Gutiérrez et al. (2021)	University, Barranquilla, Colombia	+ (s)	+ (s)
Gutiérrez et al. (2020)	City, Santiago, Chile	+ (s)	+ (s)
Hamre & Buehler (2014)	City, Washington DC, USA	+ (s)	+ (s)
Heinen et al. (2013)	4 cities, Netherlands		+ (s)
Hunt & Abraham (2007)	City, Edmonton, Canada	+ (s)	+ (s)
Hwang & Guhathakurta (2023)	3 cities, USA	+ (s)	
Kamargianni (2015)	Secondary and high schools, Greece	+ (s)	+ (s)
Ketikidis et al. (2023)	City, Thessaloniki, Greece	+ (s)	
Márquez et al. (2021)	Public transit network, Bogota, Colombia	+ (s)	
Márquez & Soto (2021)	City, Bogota, Colombia	+ (s)	+ (s)
O'Reilly et al. (2024)	31 countries, Europe	+ (s)	
Orvin & Fatmi (2021)	City, Kelowna, Canada	+ (s)	
Peroni et al. (2021)	City, Porto Alegre, Brazil	+ (s)	+ (s)
Rojas López & Wong (2017)	Singapore	+ (q)	+ (q)
Rosyidah & Kusuma (2022)	Indonesia	+ (s)	+ (s)
Sener et al. (2009)	Texas, USA	+ (s)	+ (ns)
Tin Tin et al. (2010)	City, Taupo, New Zealand	+ (q)	
Verma et al. (2016)	City, Bangalore, India	+ (s)	+ (s)
Wang et al. (2015)	University, Ohio, USA	+ (s)	+ (s)
Weliwitiya et al. (2019)	City, Melbourne, Australia		+ (s)
Winters et al. (2011)	City, Vancouver, Canada	+ (s)	+ (s)
Zhao (2014)	City, Beijing, China	+ (s)	
Xiao et al. (2022)	City, Paris and Lyon, France	+ (s)	
Shahriari et al. (2024)	City, Paris and Lyon, France	+ (s)	

s: significant; sw: significant at work; sh: significant at home; q: qualitative; ns: not significant.

hoops, bollards, communal areas, bicycle cages) by different cyclist profiles (e.g., conventional, electric, cargo). The current parking supply satisfies cyclists looking for speed, but the issue of security against theft remains unresolved. In a broader context, Kohlrautz & Kuhnimhof (2024a) undertook a comprehensive analysis of urban cycle parking facilities, exploring their potential for sustainable development across ten German cities and four additional international locations. Their findings revealed a predominant standardisation in parking facility design, with limited integration of local specificities into the design process.

At the same time, a significant body of research has been dedicated to the design of parking facilities and their spatial distribution. For instance, in the Netherlands, Van der Spek & Scheltema (2015) conducted measurements to assess the saturation of public parking bays and the rise in demand for safer and more secure parking options. Furthermore, the research by Brezina & Pfaffenbichler (2016) and Fuller et al. (2018) highlighted a discrepancy between the parking facilities available in their respective municipalities and the objectives set forth for the modal share of cycling. This research is also relevant to the context of shared bikes, particularly in China, where the substantial expansion of shared bike services is exerting considerable influence on the broader transport system. Lu et al.

(2019) utilised a multi-agent simulation to determine the optimal capacity of shared bike parking facilities in Hong Kong (China). The augmentation of parking spaces in proximity to metro stations has been identified as a potential strategy to alleviate congestion during peak hours, with another proposed solution being the redirection of users to proximate stations. He et al. (2018) have indeed observed the congestion caused by bike-share parking due to the concentration of flows towards certain stations, and by optimising the location of parking facilities, they are able to reduce costs and journey times for users. Guo et al. (2020) have also studied the optimisation of shared bike parking around the Nanjing campus (China). For the same capacity, by optimising the number and location of parking points, journey times were reduced by 6% and construction costs by 27%. In a German study, Kohlrautz & Kuhnimhof (2025b) investigated the parking dynamics on the Aachen campus, analysing factors such as user status (student, employee) and bicycle type (traditional, electric, expensive, etc.) to deduce demand distribution. In a separate study in London (England), Ito et al. (2023) examined the supply and demand dynamics for bicycle parking by comparing the modal share of cycling with the occupancy rate of parking spaces, and taking account of flows between zones.

In addition to considerations pertaining to public parking, there is an emerging discourse surrounding bicycle parking in domestic settings. Kim & Park (2019) conducted a study on bicycle parking in flats in Gwangju (South Korea), where concerns regarding theft have led to the majority of users opting to store their bikes in the corridors of buildings. In Melbourne (Australia), De Gruyter & Butt (2024) investigated the potential of building standards for bicycle parking in the communal areas of flats. The legal framework stipulates the provision of one bicycle parking space for every five flats, yet the average household ownership of bicycles is four out of five. The analysis indicates that households with access to multiple bicycle parking spaces exhibit a higher propensity for cycling.

Ito et al. (2023) widened the scope of their study by considering the whole of London and its suburbs. Other authors, mentioned in Table 1, have worked on cycling on a larger scale: regional, national and even international. However, only regional studies have dealt with bicycle parking (Sener et al., 2009; Heinen et al., 2013) and a few have measured the effect of cycle lanes on the scale of one or more countries (Buehler, 2012; O'Reilly et al., 2024). This study fills these gaps by supplementing the national scale census data with spatial data to build a choice model that incorporates the provision of cycle lanes and parking spaces in high, medium and low density communities in France.

3 Methodology

3.1 Case Study

This study uses the French context to understand how additional cycle lanes and parking spaces can impact bicycle commuting. Mainland France is located on the west side of Europe and comprises 66 million inhabitants, including 30 million working-age adults. 66.7% of work-related commuting is made by private car, 17.6% by public transit, 6.6% by walking, and 3.5% by cycling (Insee, 2024b). France is an interesting geographical setting for this research due to its cycling history. Several interventions have been made over the past two decades to encourage bicycle commuting in France. This includes the early introduction of bike-sharing systems in major cities (Havet & Bouzouina, 2025), tax-free allowance given to employees who use their own bike to commute (Schreiber, 2017), bike repair subsidies and financial aids to buy electric bikes (Adam et al., 2024). There is also an annual cycling training scheme for 850,000 children (Moinse, 2025). Despite the plethora of policies, the French bicycle modal share is only half the European average. There are also significant disparities between French territories. The most recent 2023-2027 cycling and walking plan calls for an urgent need to understand the relationship between cycling infrastructure and usage.

This study's national-scale approach is motivated by the need to understand heterogeneity in population density and to understand the needs of all municipalities. Figure 1 visualizes bicycle parking spaces, cycle lanes, and the classification of municipalities according to three levels of population density. As seen in Paris, most high-density areas are located in the centre of the metropolis, and the population density dissipates to the fringes and rural areas.

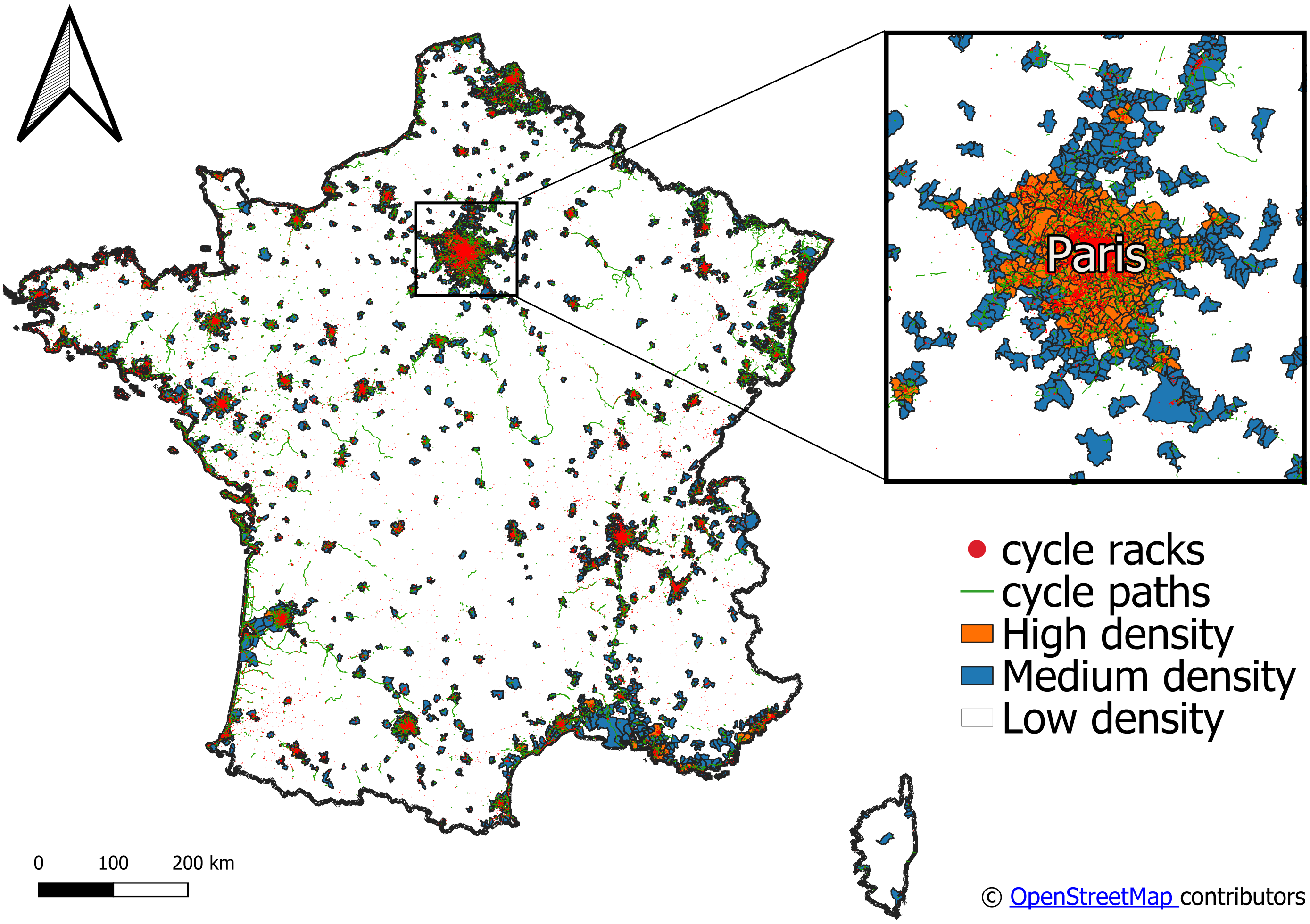


Figure 1: Mainland France according to population density and bicycle facilities

3.2 Data

This study uses a combination of data from the French institute of statistics (INSEE), the Institute of geographic information (IGN), and OpenStreetMap (OSM). These data sources provide comprehensive representative data on the sociodemographic characteristics of the population and spatial information on commuting practices and transport infrastructure. Census data provides numerous socio-economic variables at both individuals and households, including the usual commuting travel mode to work (Insee, 2024b). These data also provide the municipality of residence and work. For privacy reasons, the exact coordinates of these locations are not provided. The IGN (2023) and OSM (2024) data are also reliable sources for information on parking spaces and cycle lanes, which are usually not contained in census data. These spatial datasets were last updated in May 2024, hence, they are current and accurate.

Table 2 has the descriptive statistics of the independent variables used to explain bicycle commuting. A Variance Inflation Factor (VIF) test was computed to address multicollinearity. The maximum value is observed between household size and having children (VIF ≈ 4), but is still under the usual criteria of 5. Bicycle lanes at home and at work areas have a VIF of 2.5, and every other variable has a VIF <2. The variables are described in the first two columns. The other three columns show some important insights into the French population based on the census. "All trips share" is the proportion of trips made in the sub-group irrespective of the modal choice. For example, 49.1% of trips recorded are made by females. “Bike trips share” is the proportion of trips made by bike. For example, 40% of bike trips are made by females. “Bike share” is the bike modal share of all trips in the sub-group. It is the proportion of trips made by bike. For example, 2.8% of trips made by females are by bike.

The first part has sociodemographic variables. Sex is included to ensure gender-inclusive cycling which has always been of concern to policymakers (Moinse, 2025). Age is also an important variable that helps to understand heterogeneity in the population. The educational status determines the type of employment and sometimes the wages received and attitudes which influences travel choices. Education is classified according to the high school diploma. High education means at least 3 years of college, medium is utmost 2 years of college, low refers to middle school and below, and technical corresponds to professional paths after middle school (including professional baccalaureate). Household characteristics can exert an influence on individual mode choice and are also included. Similarly, the type of employment can also influence the mode choice. Part-time jobs are less than 35 hours a week in France and can have atypical starting and ending hours. Car ownership is also included for it has long been a strong determinant of cycling commuting.

Table 2: Description of variables. *Ref* means reference category in the model.

Socio-demographic variables	**Category**	**All trips share**	**Bike trips share**	**Bike share**
Sex (biological gender as)	Female	49.1%	40.0%	2.8%
	Male (ref.)	50.9%	60.0%	4.1%
Age class	15–24 (ref.)	9.5%	9.0%	3.3%
	25–34	23.4%	28.2%	4.2%
	35–44	24.8%	25.5%	3.6%
	45–54	25.1%	22.7%	3.1%
	55–64	15.6%	13.5%	3.0%
	65+	1.6%	1.1%	2.4%
Education	PhD	1.3%	3.8%	10.5%
	High	30.5%	51.4%	5.8%
	Medium	25.1%	18.8%	2.6%
	Low	3.6%	2.6%	2.5%
	Technical	30.9%	17.8%	2.0%
	No degree (ref.)	8.6%	5.6%	2.3%
Household size	1 person (ref.)	19.9%	24.2%	4.2%
	2 people	28.1%	29.9%	3.7%
	3+ people	52.0%	45.9%	3.0%
Household with child	No child (ref.)	44.1%	52.3%	4.1%
	Yes child	55.9%	47.7%	2.9%
Job	Full-time (ref.)	84.1%	83.6%	3.4%
	Part-time	15.9%	16.4%	3.6%
Car ownership	0 (ref.)	12.0%	24.6%	7.1%
	1 car	39.2%	49.2%	4.4%
	2 cars	38.7%	22.1%	2.0%
	3+ cars	10.1%	4.1%	1.4%

Spatial variable	**Min–Max**	**All trips average**	**Bike trips average**
Distance	0–80 km	9.8 km	4 km
Cycle lanes ratio* (Home)	0–16	1.8	2.6
Cycle lanes ratio* (Work)	0–16	1.8	2.5
Parking spaces** /100 inh. (Home)	0–260	0.95	1.75
Parking spaces** /100 inh. (Work)	0–260	1.19	1.82

*Length of cycle lanes proportional to the size of the area; **Public bicycle parking spaces.

The spatial variables include travel distance between home and work, the ratio of cycle lanes, and parking spaces, divided between the municipality of residence and work. The beeline distance between municipalities is determined using the coordinates of the town halls. Several authors have already used the beeline distance (He et al., 2018; Heinen et al., 2013; Kohlrautz & Kuhnimhof, 2024a). Compared to the network distance, the beeline is unaffected by the absence or existence of a cycling or network infrastructure between the two municipalities. These infrastructure-related variables are described using the ratio of cycle lanes. The distance associated with intra-zone trips is defined as the radius of the built area of the municipality ($\sqrt{Area/\pi}$). We used the beeline distance because we did not have the exact address of origin and destination of commuters to measure the exact trip distance. For internal municipality trips, the level of precision of the data is not sufficient to calculate precise distances of trips. In calculating the trip distance between two different municipalities, the cyclists choose the shortest path that is similar to the beeline distance. Cycling infrastructure (cycle lanes and parking racks) is provided by OSM. Cycle lanes are designated bicycle routes. Parking racks are defined as a set of public spaces available for bikes. Parking space corresponds to a place to park one single bike. It is derived from the location of parking racks and their assigned capacity. For 10% of the data, the capacity was missing. Therefore, missing values were replaced by the average capacity of the parking racks of the municipality, or the national average capacity if the municipality does not have this information. Parking spaces refer to the number of bike parking spaces per 100 inhabitants. For each municipality, the density of cycling lanes is computed. This density is defined as the ratio between the total length of cycling lanes of the municipality divided by its radius. This ratio could have been defined as the share of the cycling infrastructure relatively to the road network, but it was not relevant for low density municipalities. These rural municipalities are often built around few major roads. When crossed by touristic bicycle lanes, these municipalities show a high share of cycling infrastructure even if these are mostly designed for leisure trips not commuting.

Population density is an important factor in the choice of cycling (Nehme et al., 2016). However, its values at residential and work areas are significatively correlated one with another, and may also interact with facility levels like bicycle lanes and public bicycle parking (VIF ≈ 3), which makes its inclusion in a mode choice model challenging and the estimate of its parameters likely biased. In this work, we choose to categorise the municipalities into three levels according to their population density, based on Dijkstra et al. (2021). This classification makes it easier to measure heterogeneity in the population regarding cycling. There are two steps in the classification. Three density levels are used: high density (average 7500 inhab/sq.km), medium density (700 inhab/sq.km) and low density (100 inhab/sq.km) density. The full definition of this classification can be found in (Insee, 2024a)

3.3 Choice model and simulation

The following assumptions were used for the statistical modeling and to ensure the robustness of the results, particularly concerning the effect of cycling infrastructure.

- Assumption 1 is non-independence of observations (hierarchical structure):
  Individuals nested within geographic areas share common infrastructure characteristics, violating independence assumptions in standard logit models. Thus, the present study uses a multi-level modeling approach (i.e., clustered standard error logit model with municipality correlated random-effects) to account for this hierarchical data structure, treating geographic areas as random effects.

- Assumption 2 is baseline cycling propensities are strongly linked to the population density of municipalities:
  The models are segmented into three distinct population density classifications, which directly correspond to the variation in baseline cycling propensities across France Institut national de la statistique et des études économiques (INSEE) (2024); Service de l'Observation et des Statistiques (SOeS) (2021). High density areas exhibit high baseline cycling propensities (between 5% to 15%) due to shorter trip distances, severe car congestion, and historically greater investment in cycling infrastructure (e.g., Paris, Lyon, Marseille city centers). Medium density areas feature

moderate baseline cycling propensities (between 2% to 5%), where longer distances are a factor but growing infrastructure and congestion propel cycling. Low density or rural areas exhibit the lowest baseline cycling propensities (less than 1%) due to long distances and reliance on the car, as well as sparse, discontinuous cycling infrastructure. Therefore, infrastructure impacts are estimated for each density segment inherently accounting for the different baseline probabilities, as the propensity itself is highly correlated with the density structure. This density-based classification is not only a methodological choice but directly mirrors the approach taken by the French government and regional planning authorities in the design and funding of cycling policy (e.g., the Plan Vélo). French public policy and funding decisions are often segmented into urban areas, peri-urban/suburban areas, and rural areas. By reporting the impact of infrastructure coefficients for our high, medium, and low density groups, we are providing policy-relevant estimates that align precisely with these established policy segmentation categories, allowing decision-makers to directly apply our findings to their respective geographical and administrative zones.

- Assumption 3 is linear effects of infrastructure on bicycle commuting:
  We make a strong assumption of linear effects of infrastructure based on previous studies in Paris and Lyon that found that increasing bicycle infrastructure significantly increased cycling volumes Xiao et al. (2022); Shahriari et al. (2024). Measuring the impacts of new cycle lane infrastructure (between 2014 and 2017) on cycling in Paris and Lyon, researchers found that the intervention increased cycling counts/day Xiao et al. (2022). This assumption was again confirmed using a generalised spatial difference-in-differences (GS-DiD) fixed effect spatial lag model to analyze data collected from bicycle counters in the same cities Shahriari et al. (2024). Notably, the interaction of network effects and threshold phenomena associated with transportation infrastructure can affect this assumption in some cities. However, the present study is building on previous literature to understand how additional infrastructure will impact bicycle commuting. Thus, the insights as presented from the two largest cities in France formed a solid foundation for the assumption of linear effects.

A discrete choice model is used for the choice between cycling and other modes of transport to work. The binomial Logit model is specifically used to model the probability P of choosing the bike ($y = 1$). The utility function of this model is specified in Equation 1, with $X = \{x_i\}$ being the set of variables of Table 2. In total, 4 models were estimated (Table 3): a national model and 3 models corresponding to the three density levels. The β_i parameters are estimated using the maximum likelihood. The models show acceptable goodness-of-fit as indicated by a significant chi-square and a McFadden pseudo R2 between 9.5% and 12.5%.

$$U = \sum_i \beta_i x_i + \epsilon \tag{1}$$

With ϵ following a type-I generalized extreme value distribution, i.e. Gumbel.

In discrete choice modelling, the effect of the variables can be interpreted using different measures, such as the average marginal effect, elasticity or semi-elasticity, and odd-ratios. In this paper, we use the semi-elasticity (Eq. 2) which gives the percentage change in P in terms of a change (not percentage-wise) in x_i. The use of semi-elasticity is more intuitive in interpreting the influence of a variable (especially categorical variables) when P exhibits low values, as is the case of bike commuting in France.

$$f(x) = \begin{cases} \frac{P(y=1|X,x_i=1)-P(y=1|X,x_i=0)}{P(y=1|X,x_i=0)}, & \text{for categorical variables.} \\ \frac{\partial P(y=1|x)}{P\partial x_i} = \frac{\beta_i}{1+\exp(\beta X)}, & \text{for continuous variables.} \end{cases} \tag{2}$$

Meanwhile, ignoring the hierarchical nature of the data may overestimate the coefficients' standard deviation and inflate their statistical significance. To address this issue, two specifications are added to make the model estimates as robust as possible. The first specification makes use of the Clustered Standard Error Logit model that accounts for the fact that observations are nested within municipalities and may have errors that are correlated within these groups. Standard errors are clustered at

the municipality level (residence and work) to account for arbitrary within-municipality correlation. Observations from different municipalities are still assumed independent. This correction adjusts inference for the effective number of independent, without affecting coefficient estimates.
However, the clustered standard error logit only addresses the issue of variance, not the bias in coefficients. This bias can stem from the omission of variables that are difficult to collect, such as bike or car municipality culture. Conventionally, the bias from these omitted variables can be addressed by including a municipality fixed effect that will account for all municipality omitted variables and hence reduce the bias. The limitation here is that, by including these effects, it is no longer possible to estimate the effect of cycling infrastructure (cycling and parking). These variables will be perfectly correlated with the municipality fixed effect. Consequently, the second specification relies on municipality (correlated) random effects to address this limitation.
Standard random effects logit models rely on the assumption that unobserved (error terms in the model) municipal heterogeneity is uncorrelated with observed covariates. Given that cycling infrastructure is likely targeted to municipalities with stronger pro-cycling preferences, we relax this assumption by estimating a correlated random-effects (Mundlak) specification. This model accounts for both within effects (how individual characteristics influence bike use) and between municipality effects (how cycling infrastructure influences cycling between municipalities) including the specific effect of cycling infrastructure. The new specification is:

$$U_{ihw} = \alpha + \beta_i X_{ihw} + \gamma_h c Z_{hc} + \gamma_h p Z_{hp} + \gamma_w c Z_{wc} + \gamma_w p Z_{wp} + \mu_h + \mu_w + \epsilon_{ihw} \tag{3}$$
$$\mu_h = \bar{X}_h + \vartheta_h \tag{4}$$

Where U_{ihw} is the utility of individual i living in municipality h and working in municipality w to use the bike for commuting. X_{ihw} are a set of individual dependent variables (age, gender, working status, etc.). Z_{hc} and Z_{wc} is the cycling infrastructure at home and work, respectively. Z_{hp} and Z_{wp} is the parking infrastructure at home and work, respectively. μ_h and μ_w are random error of home and work municipalities. ϵ_{ihw} is an model random error (The Mundlak specification).

Next, the investments needed to achieve the national target were simulated. The results of the model were exploited to simulate how much bicycle lanes or bicycle spaces should be built to reach several targets of bicycle share in commuting trips. This consists of recalculating the probability to bike for every individual, but with the beta coefficient of bicycle lanes or public parking bicycle spaces being multiplied by an increasing factor, until the average probability to cycle to work reach the target. This methodology aimed to highlight the impact of bicycle lanes and public parking bicycle spaces. It does not suggest that developing these two infrastructures is a sufficient strategy on its own to increase bicycle share in commuting trips.

4 Results

The influence of the variables on cycling to work is presented and commented on. The results are then interpreted in relation to the 12% bike share French target for 2030. Table 3 shows the effects, i.e., β_i, of independent variables on bicycle commuting holding other variables constant. While a 12.5% McFadden pseudo R^2 fit might seem lower compared to traditional R^2 values, it is important to note that in discrete choice modeling, pseudo R^2 values tend to be much lower. Our model explains a significant portion of the variation in choices beyond a baseline model, indicating it captures key factors influencing bicycle commuting.

4.1 Spatial factors

The core of this research is the spatial dimension, which explains the impact that additional infrastructure and parking spaces would have on bicycle commuting. The spatial variables have homogeneous impacts for all density levels. Apart from distance, all other spatial variables have a positive effect

Table 3: Parameter estimates and goodness of fit of the Logit models

Variable	Total (Z-value) n=6.7M	High Density n=3.2M	Medium Density n=1.7M	Low Density n=1.8M
Intercept	-0.72 (2.45)	-9.08 (-8.15)	-2.74 (-3.10)	0.87 (1.89)
Sex (ref. Male)				
Female	-0.55 (-119.41)	-0.51 (-95.49)	-0.69 (-63.28)	-0.60 (-34.17)
Age (ref. 15–24)				
25–34	0.16 (18.52)	0.34 (33.50)	-0.21 (-11.03)	-0.64 (-20.02)
35–44	0.24 (26.57)	0.45 (42.55)	-0.17 (-9.10)	-0.66 (-21.68)
45–54	0.25 (27.47)	0.41 (37.87)	-0.02 (-1.13)	-0.46 (-16.32)
55–64	0.20 (20.50)	0.32 (27.32)	-0.00 (0.05)	-0.48 (-15.63)
65+	-0.48 (-21.73)	-0.28 (-10.79)	-0.81 (-15.92)	-1.28 (-18.38)
Education (ref. No degree)				
Technical education	0.15 (14.72)	0.32 (22.27)	0.01 (0.75)	-0.20 (-7.50)
Low education	0.30 (18.44)	0.33 (14.57)	0.21 (7.16)	0.15 (3.71)
Medium education	0.35 (33.21)	0.65 (46.39)	0.11 (5.32)	-0.23 (-7.68)
High education	0.95 (95.27)	1.25 (93.84)	0.61 (31.23)	0.10 (3.09)
PhD	1.31 (85.65)	1.57 (87.02)	0.99 (22.14)	0.68 (7.79)
Household size (ref. 1 person)				
2 people	0.39 (60.74)	0.37 (50.01)	0.44 (27.57)	0.35 (12.76)
3+ people	0.72 (68.31)	0.73 (60.00)	0.75 (29.36)	0.50 (11.82)
Household with child (ref. No child)				
Yes child	-0.35 (-38.06)	-0.36 (-33.00)	-0.37 (-17.58)	-0.24 (-7.14)
Job (ref. Full time)				
Part-time job	0.10 (15.80)	0.07 (8.95)	0.18 (12.91)	0.31 (14.60)
Car ownership (ref. 0)				
1 car	-0.25 (-40.70)	-0.12 (-18.20)	-1.02 (-63.69)	-1.16 (-35.71)
2 cars	-0.78 (-96.29)	-0.61 (-65.52)	-1.50 (-81.73)	-1.58 (-45.73)
3+ cars	-0.87 (-68.24)	-0.67 (-39.20)	-1.65 (-65.48)	-1.75 (-43.45)
Share in the municipality of residence				
'Female'	1.73 (10.27)	2.02 (2.20)	0.30 (0.56)	1.12 (5.49)
'Age_25-34'	-4.02 (-17.61)	0.26 (0.21)	-5.24 (-7.31)	-2.24 (-8.10)
'Age_35-44'	-4.07 (-19.09)	3.12 (2.77)	-3.42 (-5.09)	-2.20 (-8.40)
'Age_45-54'	-3.87 (-17.77)	2.56 (2.30)	-4.72 (-7.15)	-2.29 (-8.47)
'Age_55-64'	-4.10 (-18.32)	1.94 (1.64)	-3.16 (-4.58)	-2.64 (-9.43)
'Age_65+'	-7.35 (-16.20)	-7.14 (-2.91)	-5.37 (-3.68)	-4.56 (-8.44)
'Household with child'	1.22 (6.04)	0.39 (0.31)	0.79 (1.15)	0.24 (1.00)
'Part-time job'	0.02 (0.12)	4.53 (6.37)	0.49 (1.22)	0.07 (0.43)
'Technical education'	-1.41 (-7.52)	1.72 (1.89)	1.62 (2.77)	-0.51 (-2.21)
'Low education'	-2.01 (-6.06)	2.36 (0.93)	-1.89 (-1.62)	-1.27 (-3.23)
'Medium education'	-1.16 (-6.01)	0.28 (0.31)	0.99 (1.75)	-0.33 (-1.40)
'High education'	-0.25 (-1.46)	2.43 (3.57)	2.28 (4.52)	0.29 (1.27)
'PhD'	0.15 (0.24)	2.91 (2.07)	5.21 (3.50)	0.002 (0.00)
'Household size_2 people'	-1.29 (-6.70)	1.00 (1.02)	0.50 (0.84)	-0.52 (-2.15)
'Household size_3+ people'	-2.34 (-9.29)	1.07 (-0.83)	0.26 (0.33)	0.65 (0.43)
'Car ownership_1 car'	-0.46 (-2.33)	-0.32 (-1.10)	2.58 (3.09)	-1.80 (-4.44)
'Car ownership_2 cars'	-0.69 (-4.03)	-1.26 (-4.19)	1.50 (2.10)	-1.63 (-4.12)
'Car ownership_3+ cars'	-1.99 (-10.18)	-1.77 (-2.10)	0.26 (0.33)	-2.35 (-5.80)
Spatial				
Distance (log)	-0.41 (-203.68)	-0.30 (-93.80)	-0.48 (-98.85)	-0.36 (-82.10)
Cycle lanes (Home)	0.22 (19.98)	0.03 (3.37)	0.15 (8.53)	0.66 (18.45)
Cycle lanes (Work)	0.16 (20.86)	0.23 (19.00)	0.12 (10.45)	0.01 (0.64)
Parking spaces /100 inh. (H)	0.05 (11.02)	0.03 (3.66)	0.04 (4.67)	0.03 (4.53)
Parking spaces /100 inh. (W)	0.01 (4.69)	0.03 (4.11)	0.02 (4.52)	0.01 (2.65)
McFadden R^2	12.5%	10.2%	9.5%	10.0%

Non-significant variables at 90% are in gray.

Table 4: Semi-elasticities of cycle lanes and parking spaces (in %)

Variable	Total	High Density	Medium Density	Low Density
Cycle lanes (Home)	20.95	2.99	14.98	65.37
Cycle lanes (Work)	15.42	21.73	11.49	0.91
Parking spaces /100 inh. (H)	4.67	3.28	4.21	2.85
Parking spaces /100 inh. (W)	1.06	3.29	1.54	0.90

All effects are significant at 99.9% except the ones in gray.

on bicycle commuting. This suggests that increasing their ratio will lead to increase in bicycle commuting. Table 4 shows the semi-elasticity of cycle lanes and parking spaces. An increase in the rate of cycle lanes, whether in the municipality of work or residence, has a positive impact on bicycle commuting for all density levels. A one-unit increase in the rate of cycle lanes in the municipality of residence or work increases the probability of bicycle commuting by approximately 21% and 15%, respectively. Observably, high density areas show the most promising increase in cycling commuting to the workplace if additional cycle lanes are provided (approximately 22%). The opposite is seen in medium and low density areas where the focus should be put more on the municipality of residence. The effect of cycle lanes around the working location is more than 10 times that around the home location in high-density cities. In low density areas, a one-unit increase in the rate of cycling lanes at the municipality of residences increases the probability of cycling commuting by approximately 65%, but it is non-significant in the municipality of work. Therefore, in high-density areas, cycle lanes look more promising in the municipalities of work, whereas in medium- and low-density areas, cycling commute seems to be more sensitive to the cycling infrastructure of the municipality of residence. Two possible reasons may explain this result. First, 90% of the inhabitants of a high density municipality work in either the same municipality or another high density municipality, which means they have relatively shorter home-work trips to make. Second, high density municipalities have better cycle lanes infrastructure than other areas.

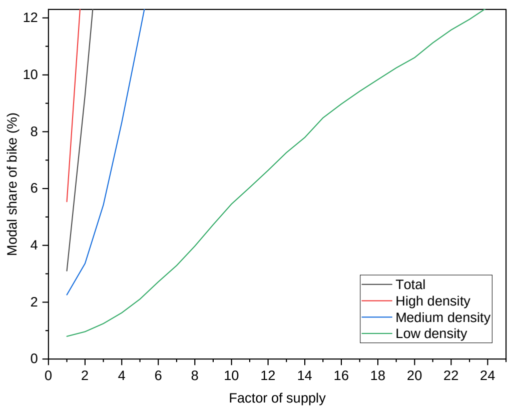
Parking provision also shows potential to promote bicycle commuting in France. Across the whole sample, adding one extra parking space per 100 inhabitants increases the probability of cycling commuting by approximately 5% at the home location and 1% at the work location. In high-density cities, extra parking spaces will yield almost the same outcome whether in the municipality of residence or work. In medium and low density areas, parking spaces have a higher effect in the municipality of residence.

4.2 Sociodemographic factors

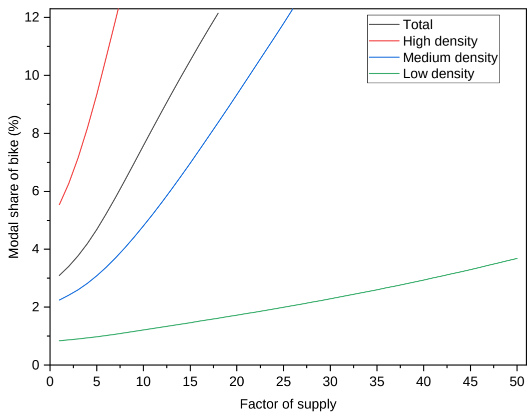
Socio-demographics were used as control variables to model the impacts of the spatial and public parking outcomes in the models. Consistent with general knowledge of cycling, females are less likely to cycle to work than men. The effect of age on bike commuting is non-linear and depends on density. Older people in high density areas have a higher likelihood of bicycle commuting than those under 25 years, but the opposite is found in medium and low density areas. The more people are educated, the higher their likelihood of bicycle commuting. Commuters from larger households have higher likelihood of bicycle commuting regardless of the density, but this becomes less likely when they have children. Often, taking care of children imposes constraints on daily activity plans and requires a means of transport accommodating two or more individuals. Households of two or at least three people have more chances to commute by bicycle than single-person households. A group travel behaviour and peer influence can promote cycling. As expected, car owners have lesser likelihood of bicycle commuting. The more cars a household has, the less likely its working members will use the bike to commute. This effect is non-linear and it is more prevalent in medium and low density areas than in highly dense areas.

4.3 Simulation of bicycle infrastructure investment needs

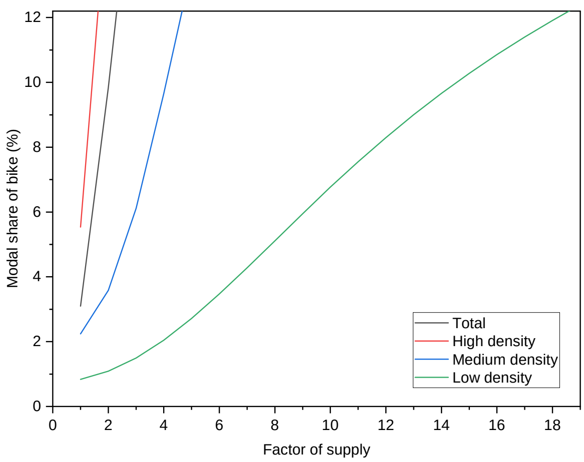
Based on the overall model, Figure 2 shows the simulated change in the modal share of cycling as a function of cycle lanes, the number of public cycle parking facilities, and both. The French National Strategy for low Carbon emissions aims to increase the modal share of cycling from 3% to 12% by 2030, and to 15% by 2050 (SNBC, 2020). The simulation results suggest that the 12% modal share target will require increasing the length of cycle lanes 2.3 times, or increasing the number of parking spaces 17 times. However, this effect is not uniform depending on the density of the municipalities. In high density areas, adding approximately twofold the length of cycle lanes can help to reach a 12% modal share, whereas medium density areas would require fivefold, and twenty-threefold in low density areas. In high density areas, the number of parking spaces should be increased approximately sixfold, whereas approximately twenty-fivefold is needed in medium density areas. However, in low density areas, a modal share of 12% is difficult to reach with the parking lever only. When additional cycle lanes and parking spaces are provided simultaneously as shown in Figure 2c, this would require increasing the infrastructure by twofold. Thus, expanding both cycle lanes and parking spaces simultaneously rather than focusing on one of them.



(a) Cycle lanes



(b) Parking spaces



(c) Cycle lanes and parking spaces

Figure 2: Simulation scenarios of bike commuting modal share

5 Discussion and Conclusion

This study examined the impact of additional cycle lanes and parking spaces on bicycle commuting in mainland France, using national census data combined with spatial information. It provides new quantitative evidence of how bicycle infrastructure can impact bicycle commuting in municipalities of different population densities. Existing studies have shown that enhancing bicycle infrastructure can increase bicycle commuting (Van Veghel & Scott, 2024; Karpinski, 2021; Shahriari et al., 2024; Xiao et al., 2022), but they were unable to measure the combined effect of cycle lanes and parking spaces as well as cater for heterogeneity in population density in the municipality of work and residence. This study has addressed these gaps and further simulated the impacts of additional infrastructure on bicycle modal share. Methodologically, the combination of census data and spatial information provides important data for choice modelling because of the mix of socio-economic factors and the infrastructure. The classification of cycle parking spaces per 100 inhabitants also makes it easier for policymakers to grasp the results. These quantitative outcomes have several policy implications. Before discussing the policy implications, some basic assumptions and limitations are noteworthy.

5.1 Assumptions and limitations

Three assumptions underline this study. First, the municipalities within the same density class can exhibit significant differences regarding mobility and cycling. 66% of French workers live and work in different municipalities. These violate the basic assumption of independence in standard logit models. The heterogeneities are accounted for by the clustered standard error logit models with municipality correlated random-effects. Second, the baseline cycling propensities in France are strongly linked to the population density of municipalities. The French policymaking and resource allocation for cycling is according to the population density of municipalities (i.e., low, medium, and high-density), which mirrors cycling propensity among individuals. Accordingly, this study simulated semi-elasticities by population density. This is noteworthy since it may differ from baseline conditions in other countries' cycling and policy contexts. Third, the simulation assumed a linear effect of bicycle infrastructure on bicycle commuting. Whereas this assumption is not always true, it is supported by two research works from Paris and Lyon Xiao et al. (2022); Shahriari et al. (2024). Thus, infrastructure can have a linear effect on cycling volumes in some city contexts.

The absence of some variables from the census data can impact the estimated effect sizes of cycle lanes and public bike parking spaces on bicycle commuting. Income level is a key socio-economic variable missing in the model. Whereas education level, job type, and car ownership could act as proxies, they cannot always explain income. This missing variable could have explained whether bicycle commuting is prevalent among the high-income, middle-income or higher-income groups. Also, having trip chains to/from work, such as for shopping and picking children from school, can also inform a commuter's mode of transport, but this information is not indicated in the census. We controlled for the distance to/from work, but there was no information on the distance of the commuter's residence to the nearest public transport station. Environmental factors such as topography and weather conditions were also unaccounted for in the model. These could have impacted the outcomes for the spatial variables. Attitudinal factors such as the perceived safety of cycling and cycling culture could have also impacted the outcome variable. It is also noteworthy that private bicycle parking was not considered in this research.

5.2 Policy implications

The findings suggest that additional cycle lanes and parking spaces will significantly increase bicycle commuting and modal share. As much as additional infrastructure would be beneficial, appropriate distribution is essential for maximizing their benefits. Studies from Vancouver (Canada) and five Brazilian cities have shown that building the infrastructure in an inequitable manner or targeting a specific population did not increase cycling modal share as expected (Firth et al., 2021; Fortes et al., 2024). Our study has found that high density areas would need additional infrastructure in the municipality of work, which is consistent with findings from London (Ito et al., 2023). Meanwhile, medium and low density areas need infrastructure in the municipality of residence. The research of Delclòs-Alió & den Hoed (2024) from Spain is a rare example of small to medium-sized urban areas worth comparing to France. In their study, they found that although bicycle commuting was just 1% of trips, 73% of respondents were willing to cycle if they could have infrastructure near their residences. A qualitative study from Colorado (USA) also supports the call for cycling infrastructure in rural residential areas (McAndrews et al., 2018). Already, the French policy imposes a minimal number of cycle racks to be provided in residential complexes, offices, and public service buildings (Béchu et al., 2022). Based on our findings, policymakers should vary the parking space requirements according to the municipality of residence and work. Thus, in the French context, buildings in the municipality of work in high density areas could have a higher requirement for parking spaces than residential buildings. The opposite may apply to medium and low density areas. Other countries may adopt a similar policy initiative according to their bicycle commuting context.

Our simulations suggest that reaching the national target of 12% bicycle modal share would require increasing the supply of cycle lanes and parking spaces by twofold. The policy lesson is that the development of both infrastructure should go in tandem. Admittedly, cycle lanes are more expensive, complicated, and funded by the government, hence, researchers often focus on it (Shahriari et al., 2024; Rérat & Schmassmann, 2024b). Thus, it is possible to give more budgetary allocation to cycle-lane infrastructure but parking spaces should also be given attention. Given that the joint effect of cycle lanes and parking spaces on bicycle modal share remains understudied, there is an opportunity for other countries to draw lessons from our findings in France.

This research also raises the question of reverse causality between bicycle infrastructure and bicycle commuting: does infrastructure provision drive cycling demand, or do cycling paths develop in response to existing demand? The phenomenon of reverse causality in cycling infrastructure research has led to the development of sophisticated econometric methods using longitudinal panel data and quasi-experimental designs like Difference-in-Differences (DiD) and Instrumental Variables. The consensus from studies employing these advanced methods is that while reverse causality is a genuine concern, high-quality, protected cycling infrastructure demonstrably leads to substantial, rapid, and sustained increases in cycling demand Xiao et al. (2022); Shahriari et al. (2024); Garber, Michael D. and Flanders, W. Dana and Watkins, Kari E. and Lobelo, Felipe and Kramer, Michael R. and McCullough, Lauren E. (2022); Kraus, Sebastian and Koch, Nicolas (2021). It is up to the policymaker to understand the local context. In developed cycling environments like The Netherland, Denmark, and Germany, the resource allocation will be based on the cycling demand because the cycling culture is already advanced and infrastructure only comes in as a support mechanism Lanzendorf & Busch-Geertsema (2014); Gössling (2013). However, in French society and other countries where the bike modal share is steadily low, the perception of the environment and the cycling infrastructure still has a stronger effect Xiao et al. (2022); Shahriari et al. (2024). The underlying implication is to make room for both policy actions according to municipalities. Also, infrastructure is not the sole driver of cycling but there should be other supportive policies that constrain car usage and make cycling rewarding.

In addition to infrastructure concerns, the fact that only one-third of the French population works within their municipality of residence has implications for planning. Some studies from Norway and Italy have established a strong relationship between residential location, workplace, and cycling choice (Piras et al., 2023; Pritchard & Frøyen, 2019). Given that the working population is highly mobile, motorised transport remains necessary for most commuters. Presumably, such commuters can use the bicycle to connect to public transport terminals. Consistent with (Kosmidis & Müller-Eie, 2024), we recommend the bicycle-public transport synergy. Recent studies in Lyon emphasize that this policy approach is promising as most students complement public transport with cycling for short journeys of less than 10 km and more so when shared bikes are available (Celbiş & Bouzouina, 2025; Havet & Bouzouina, 2025, 2024)

Similar to previous research, distance to the workplace has a significant impact on bicycle commuting (Siiba et al., 2025). We found a 3.3% decrease in bicycle commuting as the distance increases by 10%. It implies that urban and transport policies are needed to reduce the home-work distance. We recommend policies such as relocation of workers, development zoning, and intermodality of cycling and public transport. These would require a multi-sector collaboration of stakeholders. It is in light of this, that the 15-minute city concept (Moreno et al., 2021) becomes quintessential in French cities so that commuters do not have to travel long distances. For those who cannot live within the 15/30 minute to their workplace, they could be encouraged to use electric bicycles, which are more convenient than traditional bicycles for long distances.

The socio-demographic barriers to bicycle commuting, mainly sex, age, and car ownership, cannot be overlooked even in this pursuit for additional infrastructure. Previous studies have associated male-dominated cycling with the risk-averse attitude of women (Fortes et al., 2024; Alimo et al., 2023). However, Higuera-Mendieta et al. (2021) suggest that trip-end cycle lanes can attract more women to bicycle commuting. It is important to continue providing incentives for cycling commuters, especially for women in medium and low density areas. The results are also consistent with a previous study in Paris which found that the working class in high density areas tend to cycle to work more than those in medium and low density areas because they have better cycling infrastructure (Wysling & Purves, 2022). Most of the working class in medium and low density areas work outside the municipality of residence and may tend to use motorized transport due to the long distance (Combes et al., 2012). It is refreshing that those aged between 25 and 64 have interest in bicycle commuting since they form 89% of the working class. Higher education is found to correspond to higher probability of cycling in France, consistent with working-age residents in Germany and the Netherlands (Hudde, 2022; van Wijk et al., 2017). Highly educated individuals are more likely to work in city-centres and to afford accommodation nearby (Combes et al., 2012), which makes commuting by bike convenient. They may also have higher environmental awareness than the less educated. These results suggest that educational campaigns should target people with low levels of education. Regarding car ownership, it is seen as one of the major disincentives for medium and low density inhabitants. Notably, part-time workers have a higher (12%) probability of commuting by bike than full-time workers. This might be due to several reasons, including (i) the need for individual travel modes (such as a bike or a car) of part-time workers that can have a typical working hours and (ii) the lower revenues of these workers which might reduce their access to the car. A study across 19 European cities found that residential proximity to the city centre has the greatest predictive importance for car ownership (Berrill et al., 2024). The policy approach adopted in some countries is e-bike incentives under the premise that it has the potential benefit of displacing travel by private automobile (Bigazzi & Berjisian, 2021). This policy approach could be encouraged in countries having car ownership barriers to cycling.

Furthermore, one of the key components of this research is the comparison of cycling commuting in the municipality of work with the municipality of residence. Most spatial-based transport studies mainly divide communities into population density e.g., high, medium/intermediate, and low without probing further to differentiate behaviours at where residents live from where they work (Mattson, 2020; Palm et al., 2014; Ingvardson & Nielsen, 2018). The closest attempt was made in Denmark (Nielsen & Skov-Petersen, 2018), where bikeability was assessed at workplaces and residential areas but this was only constrained to urban areas over 9,000 inhabitants. Interestingly, our findings and theirs have shown clear differences in cycling behaviours depending on these two categories. Thus, among the same population, cycling behaviours differ in the municipality of residence and work. Clearly, travel behaviour researchers and practitioners must consider these two categories in future research to ensure appropriate distribution of infrastructure and targeted policies. This policy insight goes beyond active transport studies to all travel behaviour and community-based policy research, particularly on a national scale as ours.

The results indicate that achieving the French target for bike mode share will be difficult, although it is less challenging in some places than in others. The investment per capita in medium and low density municipalities will be higher. Consequently, it is unlikely that proportionate actions will be taken to reach the 12% target in all communities. Instead, decision makers might be inclined to focus the effort and money where it is less challenging to increase this mode share, namely in high density areas. This effort can fuel the spatial disparities between areas and communities. In pursuit of efficient bicycle policy interventions, spatial equity challenges may emerge between densely populated regions and other areas. This calls for a need to consider equity issues when translating the national cycling target into local policies.

Future research may address some of the limitations of this study. Variables on attitudes or preferences towards cycling could be incorporated into the models. Admittedly, censuses do not provide this data; supplementary data sources may be required. In addition, private bike parking could be incorporated to encapsulate all parking options available to commuters. In addition, it would also be possible to examine how residential bike parking influences bicycle ownership and trip chains.

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