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Spatial Analysis of COVID-19 Pandemic Impacts on Mobility in Madrid Region

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Abstract: After three years of COVID-19 lockdown and restrictions, mobility seems to have returned to normality. However, the pandemic has left changes in the mobility patterns of the Madrid Region produced by new trends emerging from COVID-19. This paper analyzes these changes, focusing on the impacts on public transport use, the effects of telematic activities and the influence of home relocation. The basis of the analysis is a survey conducted from November to December 2022, with more than 15,000 valid responses. The results show that public transport lost 6% of trips. These trips have different transfer rates depending on their geographic location. In the City Center, the majority transferred to active modes. However, the car attracted most of these trips in the Metropolitan Ring. These changes in mobility patterns are partly a consequence of the increase in telematic activities. Teleworking has increased by more than 20% in the Madrid Region and has caused changes in trips per week and trip purpose. In addition, teleworking has caused 18% of home relocations to peripheral zones of the region. This paper investigates through statistical analysis which sociodemographic and spatial factors explain the differences in mobility impacts throughout the zones of the Madrid Region.

Keywords: COVID-19; post-COVID-19 mobility; urban and metropolitan mobility; modal share; modal shift; public transport; active modes; mobility survey; mobility patterns; binary logit model

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1. Introduction

For years, mobility trends have focused on pursuing sustainable transport, seeking trip reductions and modal shift toward more sustainable modes, such as public transport or active modes. The COVID-19 pandemic was a turning point in these trends due to the induced changes. Some authors identify the COVID-19 crisis as an accelerator of the changes that were to emerge in the long term. However, the pandemic's direct impacts are short-term [1].

The rapid transmission of the virus and the poor reaction time to control the pandemic led to the imposition of various restrictions. The restrictions imposed due to the COVID-19 pandemic ranged from closing jobs and commercial activities to introducing telematic activities as the primary model for work or study [2]. As expected, these restrictions directly impacted mobility patterns [3]. The worldwide imposed restrictions caused the volume of trips to decrease drastically [4]. For example, lockdown reduced trips by up to 39% in Germany [5] and caused a drop of more than 4500 trips in Shenzhen (China) [6]. In the case of Spain, these reductions were more significant, reaching values of around 40–50% fewer trips [7]. These decreases were more notable in public transport, with reductions close to 50% of trips compared to 2019 usage values [8]. Finally, focusing on the Madrid Region, the impacts were more significant than those in the rest of Spain. This was because the restrictions were harsher and more extended in time. The Madrid Region is one of the most densely populated regions in the country. Hence, the total trips were reduced by up to 70% during the lockdown in the Madrid Region [9]. Mobility patterns changed dramatically during the COVID-19 crisis. However, research should focus on something other than these short-term effects. Therefore, it should focus on the overall long-term impact and emerging new trends. Consequently, this paper aims to study the changes in mobility that have persisted after the end of the pandemic. Specifically, this paper analyzes modal shift changes, identifying the variables that influence the population's mobility choices.

This paper begins with a literature review in Section 2, focusing on the new mobility trends that have emerged after the COVID-19 pandemic. Next, Section 3 includes a description of the Madrid Region. Section 4 presents the methodology used in the research, from the preliminary analysis of the Madrid Region to the final analysis of the data collected. Section 5 includes the results of this methodology and their discussion. Finally, Section 6 presents the conclusions of the study.

2. New Mobility Trends after the COVID-19 Pandemic

COVID-19 has led to changes in mobility patterns. Early publications on COVID-19 stated that its impact would focus on four trends: an increase in telematic activities, changes in trip purpose, the fear of infection and the adoption of healthier modes [10]. However, other factors, such as implementing Low Emission Zones (LEZs) and rising fuel prices, have also affected the population's mobility choices. This literature review focuses on the main contributions regarding these trends.

Mobility restrictions led to the increased implementation of telematic activities (teleworking and e-learning). Numerous studies have suggested that telematic activities would gain popularity after the pandemic [11–13]. In European cities, teleworking increased from 37% to 49% due to the pandemic [14]. This type of activity does not necessarily result in a decrease in the number of trips. Telematic activities result in more trips of shorter duration and by car [15]. Moreover, regarding the impact of telematic activities, representative surveys will be necessary to feed strategic behavioral models [16].

The increase in telematic activities, particularly teleworking, means that the purpose of the most frequent trips is changing. Although the number of trips to work is decreasing, recreational trips are replacing these trips, such as shopping or other social or leisure events. This increase in non-working trips may influence a more local scale, as these trips are shorter in duration and distance than working trips [17]. Teleworking has led to a trend toward home relocation. A study in Ireland found that those who saw their non-working time improved by the flexibility of teleworking considered home relocation. Moreover, this behavior happens more among those living in city centers than those living in the outskirts [18]. According to a study conducted in Scotland, the number of people contemplating home relocation increased from 33% to 40%, stating the fear of infection and the possibility of working from home as reasons [19]. The fear of infection has been one of the main reasons for the change in mobility patterns. This reason has made public transport the most affected mode in the pandemic, as its use decreased to avoid crowds [20,21], reduce contact with other people and prevent infection [22]. However, users who were captive to public transport, generally those with less income, had to put aside the fear of infection because they had no other mobility option [23–26]. Ironically, this loss of ridership meant a reduction in the risk of infection on public transport [27]. The authorities increased the frequency of services and implemented vehicle sanitation measures to avoid this loss of passengers [28]. They subsidized fares to make public transport more attractive and to compensate for the increase in fuel prices [29].

The modal shift from public transport led to an overall increase in car use. In South Korea, the demand for car travel in 2020 was higher than that in 2019 on weekdays [30]. A study of car use in different European cities showed how frequently public transport users before the pandemic shifted their primary transport mode to cars [31]. Although the transfer of passengers from public transport has been mainly to cars, people have opted for active modes and micro-mobility alternatives such as walking, cycling or scooters [32,33]. Therefore, COVID-19 provided an opportunity to promote active modes [34]. This opportunity opens the door to developing more environmentally friendly mobility [35] if policies or strategies are in place to support this development [36,37].

Consequently, this paper proposes the following three objectives: first, to study the impact of the COVID-19 pandemic on public transport use; second, to analyze the effects of telematic activities on mobility; and finally, to explore the factors influencing people to undergo home relocation. Therefore, this paper comprehensively analyzes sociodemographic characteristics, mobility patterns and population habits.

3. Madrid Region: Sociodemographic and Mobility Framework

3.1. Sociodemographic Framework

The Madrid Region is Spain's third most populated region, with more than 6.75 million inhabitants, and one of the most economically powerful, with more than 3.2 million jobs [38,39]. The Madrid Region is split into 179 municipalities. In turn, Madrid City is divided into 21 districts, where almost half of the population of the Madrid Region (49%) lives. The Madrid Public Transport Authority (CRTM) aggregates the Madrid Region's municipalities into four rings, as shown in Table 1 [40]. The sociodemographic dynamics of the Madrid Region correspond to a concentric model. In terms of population, practically the entire population (92%) lives in the City Center, the City Suburbs and the Metropolitan Ring. On the other hand, the Metropolitan Ring and the City Center rise as the most important work centers.

Table 1. Sociodemographic characteristics of Madrid Region rings. Source: [38,39].

Ring	Surface (km^2)	Population (2022)	Workplaces (2022)
City Center (CC)	42	999,486	1,063,834
City Suburbs (CS)	563	2,304,428	873,674
Metropolitan Ring (MR)	2276	2,950,534	1,156,681
Outer Ring (OR)	5150	519,020	114,478
Madrid Region	8031	6,773,468	3,208,667

3.2. Pre-Pandemic Mobility Patterns

Every ten years, the Madrid Region conducts a Household Mobility Survey. This survey aims to study the mobility patterns of the population of the Madrid Region, including all trips made on a working day. For this purpose, this survey collects this information through telephone (CATI) and face-to-face (F2F) interviews. The latest survey (EDM18) was conducted from February to May 2018 [40]. EDM18 collected information from over 13,000 households, which equates to nearly 35,000 individuals. Its results reference mobility patterns in the Madrid Region before the COVID-19 pandemic.

The origin–destination matrix shown in Figure 1 explains the mobility dynamics among the four rings of the Madrid Region. This matrix contains the home-based trips generated in each ring, specifying their destination. According to the EDM18 results, the population of the Madrid Region generated more than seven million home-based trips on a working day before the pandemic. Considering the difference between inbound and outbound trips for each ring, the City Suburbs and the Metropolitan Ring generate almost 250,000 trips (3%). Moreover, the City Center attracts nearly half a million trips (8%), positioning itself as the ring with the highest trip attraction.

MADRID REGION ORIGIN–DESTINATION MATRIX (%)			DESTINATION			
			City Center	City Suburbs	Metropolitan Ring	Outer Ring
home-based trips = 7,380,088			23 (+8)	31 (−3)	41 (−3)	5 (−2)
ORIGIN	City Center	15	11	3	1	0
	City Suburbs	34	8	23	3	0
	Metropolitan Ring	44	4	5	35	0
	Outer Ring	7	0	0	2	5

Figure 1. Pre-pandemic home-based generated trips in Madrid Region (2018). Source: [40].

3.3. Global Impact of the Pandemic on Trip Generation

The Madrid Region was one of the Spanish regions that was most affected by the pandemic due to its large population. The COVID-19 Community Mobility Reports [30] analysis has shown the evolution of trips during the COVID-19 crisis, presented in Figure 2. This study compares the trips made to a reference period, corresponding to the average value for each day of five weeks between 3 January and 6 February 2020.

Trip generation in the Madrid Region follows a seasonal pattern. Trips drastically reduce in the summer months, reaching minimums in August. Moreover, significant declines occur during Easter and Christmas. Furthermore, trips tend to decrease in May due to several holidays inviting people to leave the Madrid Region.

When COVID-19 arrived, the Spanish government imposed a lockdown with rigid mobility restrictions [41]. During this lockdown, trips were reduced by more than 60%. The lockdown lasted until 11 May 2020, when the lockdown was loosened with moderate restrictions. Initially, these moderate restrictions limited people's trips within a radius of 1 km, except for justified causes. At the end of this phase, trips recovered rapidly, reaching almost 90% of pre-COVID-19 trips.

The normal phase continued through the summer of 2020 with no mobility restrictions. After the summer, a spike in COVID-19 infections led to new soft restrictions imposed in October 2020, such as curfews from 11 p.m. to 6 a.m. and perimeter enclosures, in which people could only move within their neighborhood. These perimeter closures were updated weekly and were applied or not depending on the incidence rates of the virus in each neighborhood. This phase lasted almost a year, leaving trip levels at around 80% by the end of 2020. The Christmas decline in 2021 was not due to COVID-19 restrictions. Instead, this significant decline was due to a landmark snowfall that paralyzed the Madrid Region for two weeks. After Christmas, trips increased to over 90% in the first half of 2021.Finally, the Spanish government lifted the mobility restrictions in July 2021. However, the rest of 2021 remained at 90% of pre-pandemic trips, with a maximum in December. Nevertheless, during 2022, trips remained at 90% again. This paper aims to discover why 100% of pre-pandemic trips have yet to recover.

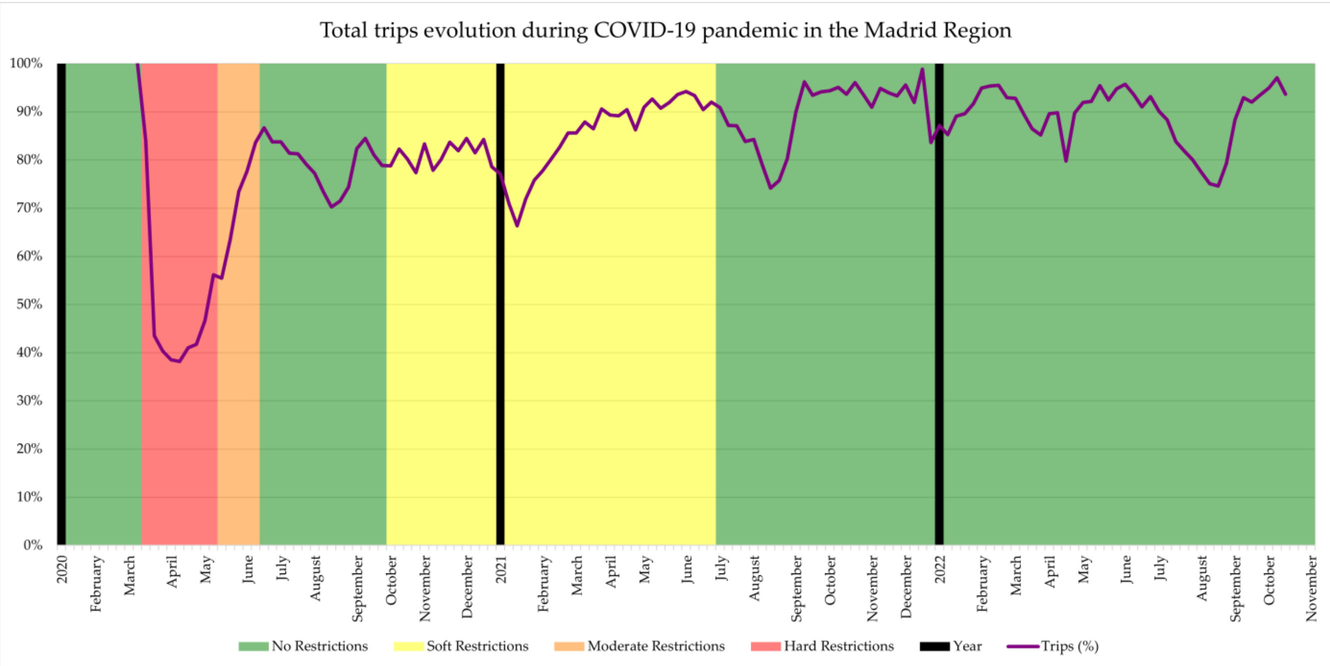

Figure 2. Evolution of trips during the COVID-19 pandemic in the Madrid Region. Source: [42].

4. Survey-Based Methodology

This paper aims to understand these changes in mobility due to the evolution of the population's habits. The best way to capture these changes is to ask people what their habits were before and what they are now. This paper uses the survey-based methodology presented in Figure 3 to achieve this goal.

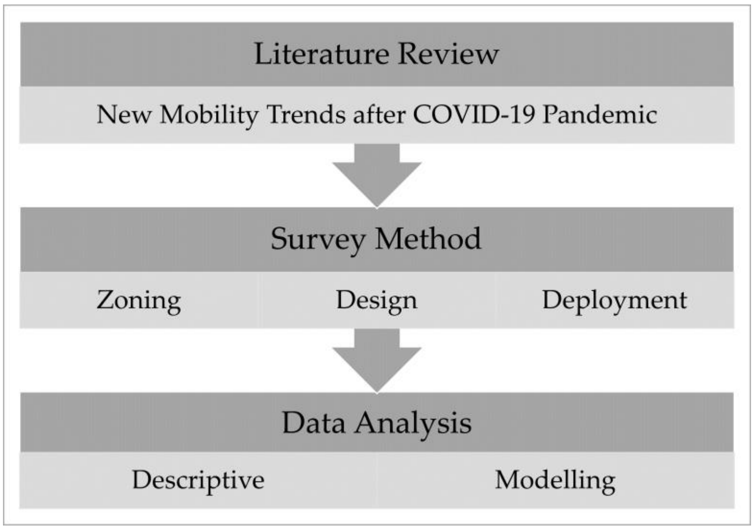

Figure 3. Survey-based methodology overview.

4.1. Survey Zoning

Figure 4 shows the sixteen zones chosen for the survey and their correspondence with the four rings of the Madrid Region. This zoning is based on analyzing sociodemographic characteristics, making them as homogeneous as possible. The use of this zoning helped to capture the differences in mobility patterns in each ring. A minimum target of 425 responses was set for each zone, meeting minimum criteria of twenty-five responses for each age group and 40% representation of each gender. This ensures good representativeness of the sample.

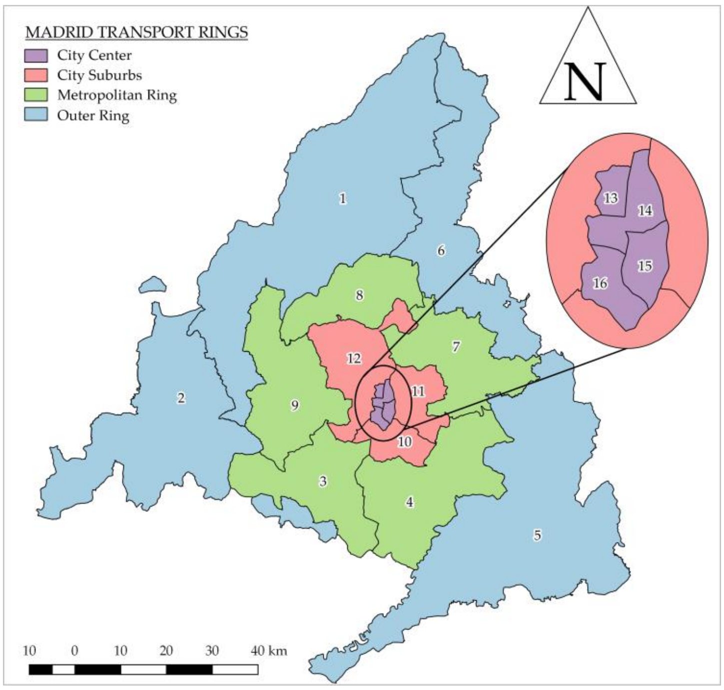

Figure 4. Survey zoning of Madrid Region.

4.2. Survey Design

The Transport Research Centre team designed a multidisciplinary survey to understand the impacts of COVID-19 in the Madrid Region. This survey consisted of seven sections. This paper focuses on three of these seven sections (see Appendix A):

1. Sociodemographic characteristics: data such as gender, age and income. This section also includes questions about home relocation.
2. Changes in mobility patterns: information related to mobility patterns. This section captured changes in mobility patterns, asking about them before and after the pandemic. This provides a picture of the evolution of mobility patterns throughout the pandemic.
3. Performing telematic activities: adoption of activities via telematic means. This section includes using these activities before and after the pandemic.

4.3. Survey Deployment

A company with a lot of expertise in surveys and opinion pools was responsible for the field work. Data collection was performed with a hybrid method combining telephone (CATI) and online (CAWI) interviews. This combination makes it possible to take advantage of the benefits of each technique. First, CAWI interviews yield many responses with minimal investment of time and money [43]. However, these interviews only reach some of the population. Older people, for example, prefer CATI interviews, resulting in biased samples [44]. To avoid this, CATI interviews complemented CAWI interviews, achieving better sample control and ensuring its representativeness. The company selected the CATI sample randomly to ensure the representativeness of the final sample. The company has a panel with thousands of panelists enrolled in the CAWI survey. The selection of this sample was made from their profiles. Panelists were rewarded for their participation in the survey with virtual points that could be exchanged for gifts.

This methodology was applied in a pilot test conducted in October 2022. This test detected errors that were corrected in the final survey and allowed training the surveyor team. Seventy-one responses from the respondents and feedback from surveyors helped improve the survey. Within the design parameters, the average response time was 35 min per survey.

The final survey conducted between November and December 2022 obtained 15,666 valid responses, fulfilling the minimum criteria of representativeness in all zones. The distribution of responses according to ring and gender was extracted. All groups had over 1000 responses, above the 385 responses that ensure the sample's representativeness according to probability sampling. Therefore, it was demonstrated that the data collected are representative for a confidence level of 95% and a margin of error of 5% (Table 2).

Table 2. Representativeness analysis.

Ring	Gender	Population *	Responses	Representative **
City Center (CC)	Male	403,347	1589	✓
	Female	486,072	1920	✓
City Suburbs (CS)	Male	905,240	1956	✓
	Female	1,055,964	2389	✓
Metropolitan Ring (MR)	Male	1,166,263	2516	✓
	Female	1,250,442	2961	✓
Outer Ring (OR)	Male	210,576	1102	✓
	Female	212,057	1233	✓

* $\geq$16 years old; ** Confidence level of 95% and margin of error of 5%.

The sample weighting allowed the provision of population estimations. This weighting adjusted the sample distribution for each zone and type of individual to the actual population distribution according to official sources. The sample weighting process concluded that the 15,666 responses equaled 5,690,634 people.

4.4. Descriptive Analysis

A descriptive analysis of the data collected in the survey reveals the characteristics of the sample. This descriptive analysis covers all survey questions, starting with the sociodemographic factors. Next, this analysis studies the variables related to changes in habits due to the pandemic. This analysis is based on variables designed to capture them in two ways: first, in a scale format (Decrease, Same, Increase), and second, in a binary form (Yes, No). These variables capture changes in habits regarding telematic activities, home relocation, trips per week, car ownership and changes in trip purpose and transport mode. The descriptive analysis shows which mobility trends have persisted in the aftermath of the COVID-19 pandemic and what the main changes in mobility patterns are.

4.5. Modeling COVID-19 Impacts

A binary logit model was applied to identify which factors are determinants of changes in mobility choices. The dependent variable is the modal shift expressed as a binary variable: zero (0) if there is no modal shift and one (1) if there is a modal shift. Numerous research studies on modal shift have used this methodology [45–47]. The model was run with Stata 15.0 software. This software uses the following formulation:

$$P(yj \neq 0|xj) = \frac{exp(x_j\beta)}{1 + exp(x_j\beta)} \quad (1)$$

where x is the value of the independent variable, y is the value of the dependent variable, and β is the coefficient.

Because public transport is the transport mode that was most affected by the COVID-19 pandemic, this modeling analyzes people who used public transport before the pandemic. This paper contains five statistical analyses: one for the entire sample of the Madrid Region and one for each ring. Hence, it is possible to see the differences in these factors in each ring, allowing their comparison.

5. Results and Discussion

The interpretation of results led to the detection of different impacts. The analysis of effects helps to determine whether the new predicted mobility trends are present in the current situation of mobility patterns and population habits in the Madrid Region.

5.1. Descriptive Analysis

The descriptive analysis includes fifteen variables that capture sociodemographic characteristics and the impacts of the pandemic on the population's habits. First, the variables shown in Table 3 characterize the sample from a sociodemographic point of view. As shown, the survey has almost equal representation of men and women. In terms of age, the least represented group is the youngest, which is unsurprising because only those over sixteen years old responded. More than half of the sample has a university degree. Moreover, almost 60% of the sample is employed, with only 7% being students (including those working part-time), 6% being unemployed and 18% being retired. Income ranges have virtually equal representation, ranging from 14 to 23%, except for the smallest range, with only 6%. Finally, only 7% of the sample takes more than 60 min, with the first three trip duration ranges accounting for the majority.

The survey included several questions to analyze changes in activities due to the COVID-19 pandemic. They included mobility patterns, telematic activities and home relocation. Table 4 summarizes those changes. Teleworking has increased by 23%, a relevant change, and 70% of the sample reported no changes in telematic activities. This increase in teleworking has induced changes in the number of trips per week, home location and trip purpose. First, 19% of the sample stated they have decreased their trips per week. Remarkably, 18% reported having moved after the pandemic, with the majority moving to the City Suburbs and the Metropolitan Ring (13%). This behavior is directly related to teleworking: 32% of those who have relocated their home have increased their teleworking habits. Before the pandemic, commuting was at 69%. Of the sample, 19% stated that they changed their primary trip purpose: 13% no longer travel to work, and on the contrary, 6% have switched to commuting. Therefore, traveling to work was reduced by 7%. Finally, 13% of the sample said they have changed their car ownership: 8% have increased it, whereas 5% have decreased it, with a net increase of 3%. This increase is higher in peripheral zones.

Table 3. Sample distribution of general attributes.

Variables	Categories	Distribution (%)
Gender	Male	47
	Female	53
Age	≤25	12
	26–45	37
	46–60	24
	>60	27
Studies	Basic	5
	Secondary (GCSE)	8
	Baccalaureate	17
	Vocational Training	19
	University Degree	51
Occupation	Employee	59
	Self-Employed	7
	Student	4
	Student and Employee	3
	Homemaker	3
	Unemployed	6
	Retiree	18
Monthly Income (€)	≤1000	6
	1000–1500	14
	1500–2000	15
	2000–3000	21
	>3000	23
	No Answer	21
Trip Duration (min.)	≤15	25
	16–30	39
	31–60	29
	>60	7

n = 5,690,634.

Table 4. Changes due to the COVID-19 pandemic.

Variables	Decrease (%)	Same (%)	Increase (%)
Teleworking	7	70	23
E-Learning	11	72	17
Car Ownership	5	87	8
Trips per Week	19	73	8
	No (%)	**Yes (%)**	
Home Relocation	82	18	
Trip Purpose Change	81	19	
Modal Shift	75	25	

n = 5,690,634.

The analysis of modal share changes after COVID-19 is shown in Figure 5. Of the respondents, 25% declared to have changed their transport mode. Public transport was the primary mode affected, with a decrease of 6%. These users have migrated to active modes and cars. The second main change is an increase in active modes (walking and cycling) from a 12 to 16% share. Despite the modal shift, the most used mode in the region is still the car, followed by public transport and active modes.

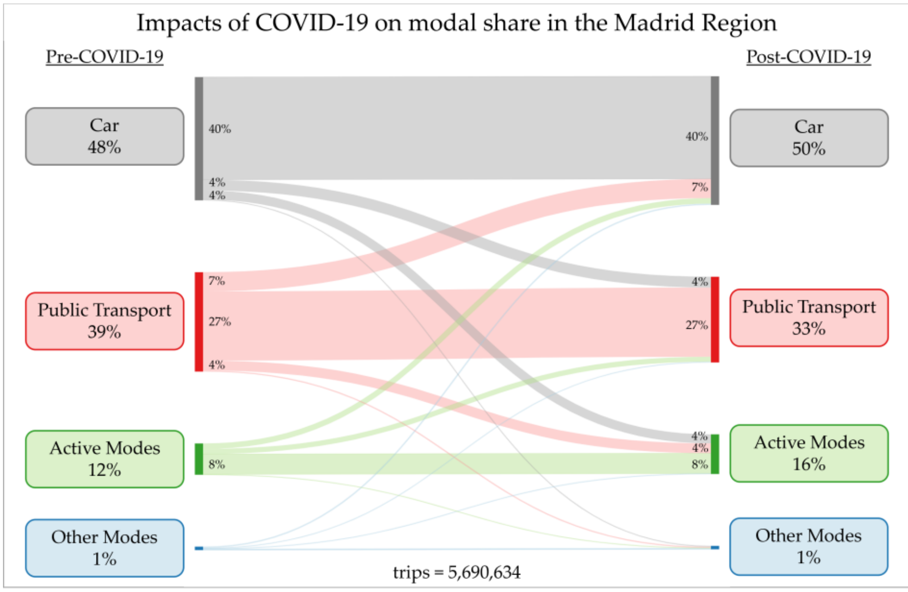

Figure 5. Changes in modal share due to COVID-19 pandemic in Madrid Region.

The impact of the pandemic on modal share has also been different in each ring of the Madrid Region. The modal shift in the central zones are higher than those in the peripheral zones. The analysis of the variations in each transport mode is based on the four matrices, one for each ring of study, presented in Figure 6. As a result of these matrices, it is possible to see how user flows have been in each case.

Before the pandemic, public transport use in the City Center was higher than car use. This may be due to the good supply of public transport and the presence of different LEZs that regulate car access. Madrid has two Special Protection LEZs in the City Center. Only low-emission cars can circulate in these zones. The City Center is also a LEZ, although less restrictive. The most polluting cars cannot access this ring [48]. In addition, car traffic lanes turned into new pedestrian spaces [49]. Reducing the number of cars that enter these LEZs has made the City Center more attractive for pedestrians. This fits with other research results, concluding that people are more likely to be active commuters when fewer cars exist [50]. In addition, the presence of pedestrian [51–53] and cycling [54,55] infrastructure and local commerce with mixed land use [56] further encourages more sustainable transport modes.

As the distance to the City Center increases, car use increases, and public transport use decreases. This is because public transport supply decreases as the distance to the City Center increases. Furthermore, the distance factor makes public transport trips longer. Groth et al. assert [57] that this may also be due to the socioeconomic profile in each city zone. In the center, young and progressive people (who use active modes) settle. In the periphery, people with lower incomes use public transport. Finally, in the outer zones, there are more traditional people who use cars.

Because most of the population has kept the same transport modes, the diagonals present the highest values. In the case of the City Center, those who continue using the car represent 25%, which is less than those who continue to travel via public transport (35%). The car and public transport captives are equivalent in the City Suburbs, with 33% and 35% values, respectively. Finally, car use increases in the peripheral zones, representing half of the population: 48% in the Metropolitan Ring and 56% in the Outer Ring. There is a higher proportion of captives of active modes in the City Center than in the rest of the rings. Specifically, these proportions are twice as high as those in the peripheral rings.

Regarding those who have shifted their transport modes, in the case of the City Center, the highest percentages of users have migrated from public transport to cars and active modes, with the latter being higher. In the rest of the rings, the highest modal shift value was from public transport to the car, with values between 7% and 8%. Although the values are lower, it is surprising that former car users now use public transport or active modes in all rings, with values between 3% and 5%. This may be due to increased fuel prices, which make the car a less attractive transport mode.

The results indicate that public transport has lost more passengers than the other modes. Therefore, the car and active modes are the ones that have received these passengers. Specifically, public transport has lost between 5% and 7%, depending on the zone. The next step in this research is to determine the reason for this trend based on statistical models.

CITY CENTER MODAL SHARE (%) trips = 890,095			POST-COVID-19			
			Car	Public Transport	Active Modes	Other Modes
			34 (+2)	42 (–7)	23 (+5)	1 (=)
PRE-COVID-19	Car	32	25	4	3	0
	Public Transport	49	6	35	7	1
	Active Modes	18	2	3	13	0
	Other Modes	1	1	0	0	0

CITY SUBURBS MODAL SHARE (%) trips = 1,961,005			POST-COVID-19			
			Car	Public Transport	Active Modes	Other Modes
			43 (+2)	42 (–5)	14 (+3)	1 (=)
PRE-COVID-19	Car	41	33	5	3	0
	Public Transport	47	7	35	4	1
	Active Modes	11	2	2	7	0
	Other Modes	1	1	0	0	0

METROPOLITAN RING MODAL SHARE (%) trips = 2,416,201			POST-COVID-19			
			Car	Public Transport	Active Modes	Other Modes
			59 (+3)	26 (–5)	14 (+2)	1 (=)
PRE-COVID-19	Car	56	48	4	4	0
	Public Transport	31	8	20	3	0
	Active Modes	12	3	2	7	0
	Other Modes	1	0	0	0	1

OUTER RING MODAL SHARE (%) trips = 423,333			POST-COVID-19			
			Car	Public Transport	Active Modes	Other Modes
			68 (+3)	16 (–6)	15 (+3)	1 (=)
PRE-COVID-19	Car	65	56	3	5	1
	Public Transport	22	8	12	2	0
	Active Modes	12	3	1	8	0
	Other Modes	1	1	0	0	0

Figure 6. Modal shift flows per ring of Madrid Region.

5.2. Modeling COVID-19 Impacts

Previous analyses have shown that public transport is the mode that has been most adversely affected by the COVID-19 pandemic. For this reason, the modeling and its analysis focus on the users of this transport mode before the COVID-19 pandemic. This part of the analysis characterizes the key factors of those public transport users who changed their usual transport mode after the pandemic.

This analysis applies a binary logit model to the selected sample. The dependent variable of this analysis is the modal shift. The modeling focuses on all former public transport users in the Madrid Region. This helps to understand the key factors influencing the entire population of the Madrid Region. The heterogeneity of the sociodemographic characteristics of the Madrid Region justifies the analysis of the four rings separately. In this way, it is possible to conduct a spatial analysis of the determining factors of each zone.

This modeling includes the variables studied in the descriptive analysis, including sociodemographic characteristics, changes in habits and mobility patterns. This allows a comprehensive analysis of all the factors influencing the decision to shift transport modes. Table 5 collects the main results of the five models in parallel, one for the whole region and one for each ring. The complete results for each model are in Tables A1–A5 in Appendix B. All the models show reliable results and most of the variables are significant in explaining the modal shift from public transport. The large sample size of the survey (15,666 responses) results in significant representation of the population of the Madrid Region.

Table 5. Logit model results for the modal shift from public transport per ring.

Variables	Categories	Region	CC	CS	MR	OR
Sociodemographic						
Age (≤*25*)	26–45		0.264 **	0.398 **		0.713 **
	46–60	−0.377 ***			−0.536 ***	
	>60	−0.502 ***			−0.502 **	
Studies (*Basic*)	Baccalaureate			0.444 *		
	Vocational Training			0.478 *		0.460 *
	University Degree			0.666 **	0.282 **	
Occupation (*Employee*)	Self-Employed				0.473 *	
	Student				−0.504 **	
	Retiree					0.899 **
Monthly Income (€) (≤*1000*)	1000–1500					0.915 **
	1500–2000	0.197 **				0.995 **
	2000–3000	0.169 **				1.151 **
	>3000	0.587 ***	0.386 **	0.441 **	0.580 ***	2.059 ***
	No Answer					0.812 *
Teleworking (*Same*)	Decrease		0.432 *			
	Increase	0.226 **	0.381 **	0.352 **		
E-Learning (*Same*)	Increase				0.276 *	
Home Relocation (*No*)	Yes				−0.280 *	1.128 ***
Mobility						
Car Ownership (*Same*)	Increase	1.176 ***	1.094 ***	1.005 ***	1.127 ***	1.297 ***
Trip Purpose Before (*Non-Working*)	Working					0.887 **
Trip Purpose Now (*Non-Working*)	Working	−0.378 ***	−0.618 ***		−0.430 **	−0.745 *
Trip Purpose Change (*No*)	Yes	0.827 ***	0.637 ***	1.017 ***	0.794 ***	1.214 **
Trips per Week (*Same*)	Decrease	0.876 ***	0.730 ***	1.000 ***	0.908 ***	0.895 **
	Increase	1.581 ***	1.527 ***	1.874 ***	1.205 ***	1.733 ***
Trip Duration (min) (≤*15*)	16–30	−0.438 ***	−0.388 **	−0.419 **	−0.372 **	0.845 **
	31–60	−1.054 ***	−1.146 ***	−1.023 ***	−1.398 ***	
	>60	−1.326 ***	−0.803 **	−1.315 ***	−1.862 ***	−1.429 ***

* $p < 0.100$; ** $p < 0.050$; *** $p < 0.001$.

In three rings (CC, CS, OR), people between 26 and 45 are more likely to use less public transport. In the case of the Metropolitan Ring, those over 45 years old tend to continue using public transport as the most frequent mode. Educational level is not significant in the City Center. However, in the City Suburbs, people with more education are more likely to use less public transport. Occupation is significant in the peripheral rings of the Madrid Region (MR, OR). In these rings, although the self-employed and retirees are more prone to modal shift, students show the opposite behavior. People with higher incomes

(>€3000) throughout the Madrid Region seem to use public transport less. According to other studies, this trend may be because higher-income households have more alternatives to public transport [58]. The results show that gender is not significant: men and women behave similarly.

Teleworking is significant in the central rings, where the presence of jobs that allow this modality is more significant. In the case of the City Center, people who have reduced teleworking are more likely to shift their mode. The coefficients of these variables are like the coefficients of the age group of 26–45 years, which is consistent because this age group constitutes most of the workforce in the Madrid Region. This is consistent with other studies that found that teleworking is highly correlated with age [59].

Home relocation is significant in the peripheral zones. However, although the Metropolitan Ring has not influenced any modal shift, the Outer Ring has led to a more remarkable one. The coefficient of the Outer Ring explains the results obtained from the variables corresponding to income, and all groups are prone to modal shift in this ring. This may indicate that people of all income levels follow home relocation. Furthermore, according to the result for the age variable, most of those who have moved to the Outer Ring are between 26 and 45 years old. These results are aligned with other studies indicating that those that are most prone to home relocation are the youngest [18].

Regarding mobility-related variables, the increase in car ownership is significant for fewer public transport trips in all rings. The weight of car ownership increases with distance to the City Center. This may be because public transport is less competitive than cars in the peripheral zones, especially in the Outer Ring. This result aligns with other studies, which have found a relationship between the increase in car ownership and public transport services supply [60]. On the other hand, the rise in car ownership may be related to income. Therefore, households with higher incomes have increased car ownership.

The results of the three variables related to trip purpose explain a fascinating behavior: people who no longer commute to work have changed the transport mode of their current trips. This means that reducing commuting trips has led to a decrease in public transport use. This result is consistent with the results of the analysis of trips per week, whose results show that people who have varied their total trips are more likely to stop using public transport, with a more significant influence on those who have increased their trips. Finally, public transport trips have a longer duration. The modal choice has shifted to active modes for short trips (≤15 min), becoming the second most used mode (21%). On the other hand, public transport trips that have transferred to the car are now shorter.

6. Conclusions

Mobility has undergone significant changes due to the COVID-19 pandemic. During the pandemic peak, the Spanish government imposed mobility restrictions that led to a decline in trips. However, the pandemic has left some changes in mobility patterns. This paper analyzes these changes and their medium-term impacts.

The survey-based methodology used in this paper provides data on how the pandemic has affected mobility patterns. The literature review states that four concepts influence mobility in the post-COVID-19 era: increased telematic activities, the fear of infection, the adoption of healthier modes and changes in trip purpose. The zoning allows for a spatial analysis, showing how these changes vary in each zone of the Madrid Region. The deep and detailed customized survey provides an overview of these impacts by asking the population about their habits before and after the pandemic. Finally, the large sample size ensures the high representativeness of the survey.

The first objective was to study the impact of COVID-19 on public transport use. According to the results, its demand decreased by 6% in the Madrid Region. A descriptive analysis and a statistical model of the data allowed to characterize this impact. An interesting finding of this research is the increase in active modes (4%). The increase in active modes is more significant in the City Center (5%) than in other zones. The fear of infection, the implementation of LEZs and the promotion of active modes encouraged this behavior. Active modes are also an attractive alternative to public transport in the peripheral zones of the region. Specifically, in the Outer Ring, the increase in cars and active modes was the same (3%). This is because the Metropolitan Ring and the Outer Ring consist of independent urban cores. Although there are extensive trip flows to the capital, a large part of the population lives and works in the same urban center. Car use has increased by 2% in the Madrid Region. The most influential factor in public transport demand is the increase in car ownership. All of the Madrid Region's rings show this trend. Moreover, the population segment that shifted transport modes corresponds to the wealthiest group. This shows a relationship between income and mobility choices: high-income households are more likely to transfer trips from public transport to cars. Gender is not significant for modal shift: men and women have behaved similarly concerning their modal choices.

This research captures trends related to telematic activities: more than 20% claim to telework more than before the pandemic. Increases in teleworking are higher in the central zones: almost 30% of the City Center sample said that they have increased their telematic activities. These new teleworkers have changed their mobility choices, with a 30% modal shift. Teleworking is significant for modal shift in the central zones, leading to a tendency not to use public transport. The flexibility associated with these activities has led to changes in trip purpose and the number of weekly trips: 19% of the sample claim to make fewer weekly trips, and 13% no longer travel to work regularly.

Finally, there has also been a significant change in home location: 18% of the sample said that they have relocated their homes, with 13% of them moving to the peripheral zones. Most of those who have relocated houses are part of the younger population. Home relocation is related to the increase in telematic activities: more than 30% of those who have relocated have increased their teleworking habits. According to the results, home relocation causes a modal shift away from public transport. This may be because there are fewer public transport services in peripheral zones. Therefore, public transport is less attractive than cars for long trips, which causes car ownership to increase.

The results of this paper show the changes that the pandemic has left on mobility in the Madrid Region. The limitations of this research should be considered when interpreting the results obtained. The survey design captures well the changes in the mobility patterns of the population. However, it does not capture the reasons for these changes. This should be improved in future research to enrich the results.

This analysis can serve as a basis for creating strategies or policies to regulate using less sustainable modes. Knowledge of these new trends and their impacts can help when proposing actions to counteract the modal shift resulting from the pandemic. Among these actions, the implementation of LEZs can be highlighted due to restrictions to car access, which encourage the use of public transport and active modes. On the other hand, implementing policies aimed at the development of a 15-min city, such as mixing land use and promoting local commerce, could reduce car use in the city. Such actions will improve the sustainability of mobility in the Madrid Region.

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Appendix A. Questionnaire

Sociodemographic Characteristics

1. Indicate your residence zone:

   ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12 ☐ 13 ☐ 14 ☐ 15 ☐ 16
2. Indicate your gender:

   ☐ Male ☐ Female
3. Indicate your age: ___
4. Indicate your education level:

   ☐ Basic ☐ Secondary ☐ Baccalaureate ☐ Vocational Training ☐ University Degree
5. Indicate your current occupation:

   ☐ Employee ☐ Self-Employed ☐ Student ☐ Student and Employee ☐ Homemaker
   ☐ Unemployed ☐ Retiree
6. Monthly Income:

   ☐ $\leq$1000 € ☐ 1000–1500 € ☐ 1500–2000 € ☐ 2000–3000 € ☐ >3000 €
   ☐ I prefer not to answer.
7. Have you changed your place of residence since the beginning of the pandemic?

   ☐ Yes ☐ No

   Changes in mobility patterns
8. Indicate the number of cars in your household before the pandemic: ___
9. Indicate the number of cars in your household currently: ___
10. Indicate the reason for your main trip before the pandemic:

    ☐ Work or study ☐ Shopping, leisure, etc.
11. Indicate the reason for your main trip currently:

    ☐ Work or study ☐ Shopping, leisure, etc.
12. Indicate the transport mode used on your main trip before the pandemic:

    ☐ Car or moto ☐ Public transport ☐ Walking, bicycle or scooter
    ☐ Car or moto sharing ☐ Bike or scooter sharing ☐ Taxi
13. Indicate the transport mode used on your main trip currently:

    ☐ Car or moto ☐ Public transport ☐ Walking, bicycle, or scooter
    ☐ Car or moto sharing ☐ Bike or scooter sharing ☐ Taxi
14. Indicate the frequency of your main trip before the pandemic:

    ☐ Never ☐ Occasionally ☐ 1–2 times per week ☐ 3–4 times per week
    ☐ More than 4 times per week
15. Indicate the frequency of your main trip currently:

    ☐ Never ☐ Occasionally ☐ 1–2 times per week ☐ 3–4 times per week
    ☐ More than 4 times per week
16. Indicate the duration in minutes of your main trip: ___

    Performing telematic activities
17. Indicate the frequency of teleworking before the pandemic:

    ☐ Never ☐ Occasionally ☐ A few times per month ☐ 1–2 times per week
    ☐ 3–4 times per week ☐ Daily
18. Indicate the frequency of teleworking currently:

    ☐ Never ☐ Occasionally ☐ A few times per month ☐ 1–2 times per week
    ☐ 3–4 times per week ☐ Daily
19. Indicate the frequency of e-learning before the pandemic:

    ☐ Never ☐ Occasionally ☐ A few times per month ☐ 1–2 times per week
    ☐ 3–4 times per week ☐ Daily
20. Indicate the frequency of e-learning currently:

☐ Never ☐ Occasionally ☐ A few times per month ☐ 1–2 times per week
☐ 3–4 times per week ☐ Daily

Appendix B. Logit Model Complete Results

Table A1. Logit model results for the modal shift from public transport in Madrid Region.

Variables	Categories	Coef.	Std. Err.	*p*-Value	95% Conf. Interval	
Sociodemographic						
Age (≤*25*)	46–60	−0.377	0.080	0.000	−0.533	−0.220
	>60	−0.502	0.098	0.000	−0.694	−0.310
Monthly Income (€) (≤*1000*)	1500–2000	0.197	0.094	0.036	0.013	0.380
	2000–3000	0.169	0.085	0.046	0.003	0.335
	>3000	0.587	0.084	0.000	0.422	0.753
Teleworking (*Same*)	Increase	0.226	0.072	0.002	0.085	0.367
Mobility						
Car Ownership (*Same*)	Increase	1.176	0.100	0.000	0.979	1.373
Trip Purpose Now (*Non-Working*)	Working	−0.378	0.086	0.000	−0.546	−0.210
Trip Purpose Change (*No*)	Yes	0.827	0.089	0.000	0.652	1.002
Trips per Week (*Same*)	Decrease	0.876	0.078	0.000	0.723	1.030
	Increase	1.581	0.115	0.000	1.356	1.805
Trip Duration (min) (≤*15*)	16–30	−0.438	0.088	0.000	−0.610	−0.265
	31–60	−1.054	0.091	0.000	−1.233	−0.875
	>60	−1.326	0.131	0.000	−1.582	−1.070

n = 5823; *Pseudo* R^2 = 0.154.

Table A2. Logit model results for the modal shift from public transport in City Center (CC).

Variables	Categories	Coef.	Std. Err.	*p*-Value	95% Conf. Interval	
Sociodemographic						
Age (≤*25*)	26–45	0.264	0.126	0.036	0.018	0.510
Monthly Income (€) (≤*1000*)	>3000	0.386	0.133	0.004	0.125	0.647
Teleworking (*Same*)	Decrease	0.432	0.223	0.053	−0.005	0.869
	Increase	0.381	0.136	0.005	0.115	0.647
Mobility						
Car Ownership (*Same*)	Increase	1.094	0.206	0.000	0.690	1.498
Trip Purpose Now (*Non-Working*)	Working	−0.618	0.147	0.000	−0.906	−0.330
Trip Purpose Change (*No*)	Yes	0.637	0.165	0.000	0.313	0.961
Trips per Week (*Same*)	Decrease	0.730	0.147	0.000	0.442	1.018
	Increase	1.527	0.233	0.000	1.069	1.984
Trip Duration (min) (≤*15*)	16–30	−0.388	0.155	0.012	−0.692	−0.084
	31–60	−1.146	0.181	0.000	−1.502	−0.790
	>60	−0.803	0.336	0.017	−1.461	−0.145

n = 1690; *Pseudo* R^2 = 0.130.

Table A3. Logit model results for the modal shift from public transport in City Suburbs (CS).

Variables	Categories	Coef.	Std. Err.	*p*-Value	95% Conf. Interval	
Sociodemographic						
Age (≤*25*)	26–45	0.398	0.120	0.001	0.163	0.633
Studies (*Basic*)	Baccalaureate	0.444	0.264	0.093	−0.738	0.963
	Vocational Training	0.478	0.259	0.065	−0.290	0.986
	University Degree	0.666	0.237	0.005	0.202	1.131
Monthly Income (€) (≤*1000*)	>3000	0.441	0.150	0.003	0.148	0.735
Teleworking (*Same*)	Increase	0.352	0.131	0.007	0.095	0.609
Mobility						
Car Ownership (*Same*)	Increase	1.005	0.192	0.000	0.629	1.380
Trip Purpose Change (*No*)	Yes	1.017	0.139	0.000	0.743	1.290
Trips per Week (*Same*)	Decrease	1.000	0.140	0.000	0.725	1.275
	Increase	1.874	0.197	0.000	1.488	2.259
Trip Duration (min) (≤*15*)	16–30	−0.419	0.167	0.012	−0.747	−0.092
	31–60	−1.023	0.170	0.000	−1.356	−0.691
	>60	−1.315	0.289	0.000	−1.881	−0.749

n = 1946; *Pseudo* R^2 = 0.170.

Table A4. Logit model results for the modal shift from public transport in Metropolitan Ring (MR).

Variables	Categories	Coef.	Std. Err.	*p*-Value	95% Conf. Interval	
Sociodemographic						
Age (≤*25*)	46–60	−0.536	0.154	0.000	−0.837	−0.234
	>60	−0.502	0.199	0.012	−0.892	−0.111
Studies (*Basic*)	University Degree	0.282	0.123	0.022	0.041	0.524
Occupation (*Employee*)	Self-Employed	0.473	0.261	0.070	−0.038	0.984
	Student	−0.504	0.224	0.025	−0.944	−0.064
Monthly Income (€) (≤*1000*)	>3000	0.580	0.150	0.000	0.286	0.874
E-Learning (*Same*)	Increase	0.276	0.144	0.055	−0.006	0.559
Home Relocation (*No*)	Yes	−0.280	0.146	0.055	−0.567	0.006
Mobility						
Car Ownership (*Same*)	Increase	1.127	0.184	0.000	0.765	1.489
Trip Purpose Now (*Non-Working*)	Working	−0.430	0.167	0.010	−0.758	−0.103
Trip Purpose Change (*No*)	Yes	0.794	0.171	0.000	0.460	1.129
Trips per Week (*Same*)	Decrease	0.908	0.145	0.000	0.623	1.192
	Increase	1.205	0.216	0.000	0.781	1.629
Trip Duration (min) (≤*15*)	16–30	−0.372	0.169	0.028	−0.703	−0.040
	31–60	−1.398	0.166	0.000	−1.724	−1.072
	>60	−1.862	0.213	0.000	−2.279	−1.445

n = 1679; *Pseudo* R^2 = 0.196.

Table A5. Logit model results for the modal shift from public transport in Outer Ring (OR).

Variables	Categories	Coef.	Std. Err.	*p*-Value	95% Conf. Interval	
Sociodemographic						
Age (≤*25*)	26–45	0.713	0.245	0.004	0.233	1.194
Studies (*Basic*)	Vocational Training	0.460	0.263	0.080	−0.055	0.975
Occupation (*Employee*)	Retiree	0.899	0.443	0.043	0.030	1.768
Monthly Income (€) (≤*1000*)	1000–1500	0.915	0.425	0.031	0.082	1.747
	1500–2000	0.995	0.442	0.024	0.129	1.861
	2000–3000	1.151	0.429	0.007	0.310	1.993
	>3000	2.059	0.455	0.000	1.166	2.951
	No Answer	0.812	0.418	0.052	−0.007	1.631
Home Relocation (*No*)	Yes	1.128	0.266	0.000	0.607	1.650
Mobility						
Car Ownership (*Same*)	Increase	1.297	0.298	0.000	0.713	1.881
Trip Purpose Before (*Non-Working*)	Working	0.887	0.415	0.033	0.074	1.701
Trip Purpose Now (*Non-Working*)	Working	−0.745	0.429	0.083	−1.586	0.097
Trip Purpose Change (*No*)	Yes	1.214	0.394	0.002	0.442	1.986
Trips per Week (*Same*)	Decrease	0.895	0.295	0.002	0.317	1.473
	Increase	1.733	0.399	0.000	0.951	2.515
Trip Duration (min) (≤*15*)	16–30	0.845	0.294	0.004	0.268	1.421
	>60	−1.429	0.285	0.000	−1.986	−0.871

n = 508; *Pseudo* R^2 = 0.284.

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