Differences in the influence of income on transportation mode choice in Amsterdam and Alkmaar and the environmental impact of travel behavior

Bachelor thesis

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Abstract

Urban transportation patterns are a critical factor in assessing environmental impacts, particularly in the context of CO_2 emissions. This thesis explores the interaction between income levels, transportation choices, and their associated carbon footprints in the cities of Amsterdam and Alkmaar. The primary research question addressed is: *"To what extent does income have an influence on travel behavior in Amsterdam and Alkmaar, and what is the difference in environmental impact of this behavior?"*. To investigate this, a multinomial logistic regression analysis was employed for both cities to determine the effect of income on the likelihood of car usage compared to other transport options. The environmental impact was quantified by calculating the CO_2 emissions associated with different modes of transport, considering the distances traveled and the average emissions per vehicle type for various income groups in each city. The significant findings reveal that in both Amsterdam and Alkmaar an increase in income corresponds to a decreased likelihood of opting for transportation modes other than the car. Furthermore, the environmental impact calculations indicate that while Amsterdam exhibits higher total CO_2 emissions, the emissions per trip per person in Alkmaar are five times greater than these emissions in Amsterdam. The implications of this research highlight the statistical relationship between income and travel behavior. While the study touches on how different cities might influence this relationship in theory, it doesn't statistically examine these urban differences. Additionally, the data utilized reflects travel behavior observations from a single day. Future research should integrate a broader range of relevant variables and extend observations over more extended periods to develop a comprehensive understanding of how travel behavior influences vehicle-related CO_2 emissions.

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1. Introduction

This study investigates the complex relationship between income levels and travel behavior in Amsterdam and Alkmaar. Previous research has demonstrated that income is a significant factor influencing people's travel behavior. Köppchen (2014) states that individuals with higher incomes often have access to various modes of transportation and exhibit different travel patterns compared to those with lower incomes. This thesis builds upon such research by specifically examining the situation in Amsterdam and Alkmaar, two cities in North Holland that offer interesting comparative possibilities.

The central research question is: *"To what extent does income have an influence on travel behavior in Amsterdam and Alkmaar, and what is the difference in environmental impact of this behavior?"*. To address this question, various aspects will be examined, including the modes of transportation used, differences in infrastructure and travel opportunities between the cities, and the frequency of usage per transportation mode and associated environmental effects of different transport options.

From a scientific perspective, the findings of this study contribute to the growing literature on urban mobility patterns and their environmental impacts. By comparing two cities with different characteristics, it offers valuable insights into how income can influence travel behavior and how this can be different in various cities. The societal relevance of this research lies in its potential to inform targeted policy measures aimed at reducing the environmental impact of urban mobility while promoting equal access to transportation. Hell (2017) emphasizes that transport is a significant source of CO_2 emissions and other negative environmental effects. Understanding the interaction between income and travel behavior can therefore contribute to the development of more sustainable and inclusive urban mobility strategies.

The choice of Amsterdam and Alkmaar as comparative subjects is interesting due to their contrasting characteristics. Amsterdam has a higher population density with nearly 5,000 inhabitants per square kilometer (Smits, 2024) compared to Alkmaar, which counts approximately 1,000 inhabitants per square kilometer (CBS, 2024). This difference may be of influence of the availability and efficiency of transport options and could lead to significant differences in environmental impact. Additionally, the average income per resident in Amsterdam is over €36,000, while in Alkmaar it is €30,000 (Allecijfers.nl, 2024). The average income in Amsterdam is thus about 20% higher than in Alkmaar. This disparity may have various implications for travel behavior in these cities. For instance, higher incomes in Amsterdam could lead to increased expenses on transport, such as owning more cars or more frequent use of taxis, resulting in greater negative environmental effects.

Previous research suggests that more compact cities with higher population densities can facilitate more efficient transport (Tillema & Jorritsma, 2016). Consequently, it can be expected that travel behavior in Alkmaar might have a relatively larger negative environmental impact compared to Amsterdam. Furthermore, Amsterdam offers a wider range of transportation options than Alkmaar, leading to the expectation that an increase in income in Amsterdam could more readily result in a change in travel behavior as there are more options available.

This will be investigated through theoretical research into the influence of income on travel behavior and the environmental impact of mobility. Furthermore, a comparative analysis of the urban contexts of Amsterdam and Alkmaar will be conducted to facilitate the interpretation of subsequent findings. By conducting a multinomial regression analysis on the variables of income and mode of transport, results will be obtained regarding the likelihood of choosing a particular mode of transport as income increases. The environmental impact of the cities will be calculated based on usage frequencies, distances traveled, and average CO_2 emissions per mode of transport. Finally, the findings will be interpreted, limitations will be discussed, and suggestions for future research will be made.

2. Theoretical framework

2.1 The relationship between income and travel behavior

In the contemporary urban context, income has an important part in the transportation choices people make. Scientific research demonstrates a clear correlation between income levels and the preference for certain modes of transportation. However, this relationship is not straightforward and can vary depending on the specific urban environment (Geilenkirchen et al., 2010). Households with higher incomes generally show a greater tendency to use the car as their primary mode of transportation. This is associated with various factors, such as higher levels of education, specialized jobs that require longer commutes, and the availability of company cars among higher-income groups (De Maeyer et al., 2021). Additionally, households with higher incomes are more likely to own more cars, making car use a more convenient ant attractive option (De Maeyer et al., 2021). On the other hand, there is a clear link between lower incomes and the reliance on active transportation modes, such as walking and cycling, and public transportation options in urban areas. For example, households with lower incomes typically make a larger proportion of their trips within a 15-minute walking radius of their homes compared to higher-income households (Westling, 2023). This results in more walking trips for basic needs among lower-income groups. This research also shows that low-income households without a car make 23% to 33% more walking trips and 35% to 86% more cycling trips per week than higher-income households. Even low-income households with a car still make 13% more trips on foot and 33% more by bike (Westling, 2023). Additionally, access to public transport is often very limited in smaller cities and rural areas where lower-income populations live, which leaves walking, cycling, or driving as the only options (Ek et al., 2021). The high costs associated with car ownership are a significant barrier for households with lower incomes. Transportation can account for 17% to 22% of overall household costs for the lowest income groups (Scott, 2022). This makes public transport and active transportation economically viable options.

The literature consistently shows that residents with lower incomes are more likely to choose affordable transportation modes due to financial constraints, lack of access to cars, and proximity to destinations Ek et al., 2021). Higher incomes in urban areas will generally rely more on the car, even if they have access to other transportation options. This is due to factors such as convenience, time pressure, comfort, and the status associated with car use (De Maeyer et al., 2021). It is important to consider that the relationship between income and transportation choice is not solely determined by financial considerations but also by urban planning and policy, as well as the availability and quality of various transportation options. Therefore, it is important for policymakers and urban planners to take this into account to develop sustainable and inclusive mobility solutions that are accessible to all income groups.

2.2 The importance of urban context

Urban context refers to the specific environment and circumstances of cities. This has a certain influence on the travel behavior and transportation choices of urban residents. In compact, highly urbanized areas with mixed land use and good accessibility to public transportation, such as Amsterdam, car usage is generally lower. Residents here more often use walking, cycling, and public transportation options compared to suburban or rural areas (Tillema & Jorritsma, 2016). On the other hand, office parks and other working places in the suburbs near highways lead to more car traffic than urban workplaces that are well accessible by urban transportation. Moreover, the availability and quality of cycling infrastructure, such as bike lanes and bike parking facilities, greatly influences the attractiveness of cycling as a mode of transport. The better these facilities, the more people will choose to cycle (Geilenkirchen et al., 2010). Parking policies and the availability of parking spaces at residences and destinations can similarly stimulate or discourage car use in cities. Limited parking spaces and high parking fees make the car a less attractive mode of transport, while a larger availability of these facilities will encourage its use (De Maeyer et al., 2021). The presence of a good public transportation network with high frequency, fast connections, and good links to other modes of transportation, encourages the use of trains, buses, trams, and subways by urban travelers. Poor facilities will, on the other hand, lead to more car usage (Landelijk Reizigersonderzoek, 2022).

In relatively smaller urban areas, such as Alkmaar, there is often a reversed relationship where low-income households are more dependent on the car. This is due to limitations in access to alternatives, such as a well-connected public transportation network. Lower population density can lead to more dispersed neighborhoods with separated functions, necessitating more car trips (Fukkink & Oostdam, 2022). As urban areas become more densely populated, such as in Amsterdam, it is expected that residents will switch to using bicycles, public transportation, or walking (Geilenkirchen et al., 2010). In addition, Amsterdam has more compact urbanization and mixed-use development (Fukkink & Oostdam, 2022). This results in shorter trips that can be more easily traveled on foot or by bike.

Based on this, it can be stated that a compact urban form, good public transportation accessibility, cycling infrastructure, and less availability and quality of parking facilities lead to reduced car dependency. Suburban development patterns, low densities, and higher incomes are associated with greater car use among urban residents. Contrary to initial expectations, low incomes in urban areas can be more dependent on the car due to a lack of alternatives.

2.3 The environmental impact of mobility

The environmental impact of different modes of transportation varies significantly. Private cars contribute by far the most to air pollution and greenhouse gas emissions in urban areas (Stein, 2021).

Passenger cars, trucks, and buses that run on fossil fuels such as gasoline and diesel are the largest sources of harmful emissions like carbon dioxide, nitrogen oxides, and particulate matter (Faster Capital, 2024). These emissions contribute to environmental problems such as air pollution, smog, and climate change. The more cars on the road, the greater this negative impact will be. Public transportation such as buses and trams that run on diesel also have a significant environmental impact, but less so than private cars per passenger (Stein, 2021). However, electric public transport produces fewer emissions and is a more sustainable option, especially when powered by renewable energy sources. Walking and cycling have a negligible environmental impact and are therefore the most sustainable modes of transportation in cities (Milieucentraal, 2024). Good infrastructure for cyclists and pedestrians will encourage these clean forms of mobility. Investing in walkable neighborhoods and an extensive cycling network can therefore significantly reduce a city's carbon footprint from transportation. The environmental impact also depends on factors such as vehicle occupancy rates and fuel efficiency. Single-occupancy vehicles have much higher per capita emission rates compared to higher occupancy public transport or carpooling. Newer, more fuel-efficient vehicles and the shift towards electric vehicles can help mitigate emissions from private cars. Still, reducing overall car usage remains crucial for sustainable mobility. Moreover, traffic congestion exacerbates emissions by increasing travel time and reducing fuel efficiency of vehicles. Effective traffic management, road pricing, and incentives for modal shift can help reduce congestion and its associated environmental costs.

3. Urban context

Urban context is an important factor in the choice of transport mode of city residents. To get a clear view, and to better understand the travel behavior of residents in Amsterdam and Alkmaar, the most important characteristics of the urban transport infrastructure in Amsterdam and Alkmaar will be researched and compared.

3.1 Amsterdam

In 2024, the estimated population of the municipality of Amsterdam stands at roughly 930,000 inhabitants, according to Statistics Netherlands (2024). This sizable population puts pressure on the city's transportation infrastructure. Therefore, it is essential that this infrastructure is well-organized to prevent unnecessary traffic congestion and negative environmental impacts. This includes the previously mentioned considerations for parking facilities, availability of high-quality cycling infrastructure, the quality and convenience of the public transportation network, the presence of traffic jams and congestion on the roads.

When it comes to parking facilities, Amsterdam has about fifty parking garages with a total capacity of over 20,000 parking spaces (Q-park, 2024). Additionally, there are various 'Park+Ride' facilities on the outer areas of Amsterdam with a total of nearly 3,000 spaces (Parkeren in Amsterdam, 2023). There is availability of paid parking spaces on the streets in the city center as well. The specific number is difficult to determine, but it can be estimated that there are still thousands of paid street parking spaces in Amsterdam to meet the high parking demand.

A remarkable characteristic feature of Amsterdam is the extensive cycling network. The bike paths together cover a total length of 500 kilometers (Allcharts, 2023). Generally, the bike paths are well-maintained and of good quality. This reflects the city's commitment to promoting sustainable and environmentally friendly modes of transport.

Public transportation plays a major role in the mobility landscape of Amsterdam as well. The city has an extensive network consisting of four metro lines, 16 tram routes, 48 bus lines, and both regional and intercity train stations (Allcharts, 2023). This system is well-integrated and allows for residents and visitors to easily move from one place to another.

Although sustainable mobility is promoted through the extensive cycling infrastructure, the integrated public transportation network and policies, traffic jams remain a significant challenge due to the high volume of car usage within urban boundaries.

3.2 Alkmaar

The municipality of Alkmaar has a population of approximately 110,000 in 2024 (Citypopulation, 2024). Compared to Amsterdam this is a small number. Nevertheless, it remains important for this less populated city to offer good transportation facilities, both for the convenience of its residents and to reduce environmental impact.

As for parking facilities, Alkmaar counts nine parking garages, together providing about 2,900 parking spaces (Gemeente Alkmaar, 2018). Combined with the paid parking spots on the streets, it can be estimated that the total number of parking spaces in Alkmaar is around 3,000 (Gemeente Alkmaar, 2018).

The cycling network in Alkmaar is very extensive. Alkmaar is a cycling city with a strong focus on biking. The city has about 100 kilometers of bike paths (CBS, 2023). This is a result of the municipal program 'Alkmaar Fietst', through which more bike paths were constructed, and existing ones were improved. Besides, bike parking facilities have been expanded, and cycling in general has been promoted (Gemeente Alkmaar, 2021). The cycling infrastructure in Alkmaar is well-maintained and thus contributes to the promotion of sustainable and environmentally friendly transportation.

Public transportation in Alkmaar is less extensive compared to Amsterdam. Alkmaar counts two train stations, where intercity and sprinter trains operate. Furthermore, there are various regional and city bus lines throughout Alkmaar. Currently there are no trams or subways in operation. There used to be a tram line, but it was discontinued in 1929 due to competing bus lines and a lack of profitability because of the low population (Blokker, 2024). There seem to be no plans to establish new tram or subway infrastructures at present. Although this may indicate that the current bus and train services are sufficient for the city, implementing more public transportation options can result in less dependence on the car.

3.3 Comparison

Amsterdam and Alkmaar differ significantly in their urban context. Table 1 gives a clear view on the differences in transportation characteristics. These differences result in diverse challenges and different possible solutions regarding mobility. Variation in population size, infrastructure, and commuter traffic are important factors to consider. Amsterdam has a much larger population than Alkmaar, which puts greater pressure an Amsterdam's infrastructure. As a result, Amsterdam will need to implement more solutions regarding the reduction of congestion and environmental impacts than Alkmaar. Furthermore, the parking pressure in Amsterdam is higher, leading to a greater need for more comprehensive parking policies and spatial planning. Both cities actively promote cycling as a sustainable transport option, which will help reducing traffic congestion and improving air quality. However, Amsterdam will need to make greater efforts to maintain the infrastructure and provide sufficient capacity. Alkmaar has a less extensive public transportation network compared to Amsterdam. This network could either appear to meet the needs of Alkmaar's residents, or could help reducing climate impact by extending, as residents would be less dependent on their car. Both cities face challenges related to commuting, but these congestion problems are on a larger scale in Amsterdam than in Alkmaar.

	Amsterdam	Alkmaar
Parking spaces	25,000	3,000
Bike paths (km)	5,000	100
Train stations	14	2
Other public transportation	Bus, tram, and subway available	Bus available

Table 1. Infrastructure availability in Amsterdam and Alkmaar

These differences between Amsterdam and Alkmaar can largely be attributed to their population size and economic role. Amsterdam is seen as the larger and more economically central city, attracting more commuters, and requiring a more complex and extensive transport network. Although Alkmaar is smaller, it still has the need to provide good transport facilities to make residents less dependent on car usage. As a result of these differences, Amsterdam will need to invest more to manage traffic pressure and minimize environmental impacts. For Alkmaar on the other hand, the focus will mainly be on facilitating good infrastructure connections within the city and expanding its public transportation network. Both cities will benefit from continuous investments in sustainable mobility solutions to promote livability and accommodate future urban growth.

4. Method

4.1 Statistical analysis on the influence of income on car usage

The influence of income level on the choice of transportation mode in Amsterdam and Alkmaar will be investigated using statistical analysis. The data used for this is obtained from the ODiN 2022 dataset. This survey was commissioned by the Dutch Ministry of Infrastructure and Water management and provides comprehensive information about the daily mobility of the Dutch population. It consists of aspects such as the municipality of residence, travel distances, transportation modes used, and more (CBS, 2023). Initially, the dataset undergoes a data cleaning process to ensure that only the variables and respondents relevant to this research are included. Consequently, only the responses from participants residing in the municipalities of Amsterdam and Alkmaar, along with the relevant variables, are retained for analysis. This curated dataset is then imported into STATA for the statistical analysis.

To analyze the influence of income level on the choice of transportation mode, a multinomial logistic regression analysis will be performed. All specific commands used for this analysis can be found in the Appendix. The independent variable is the standardized disposable income. This is the disposable income adjusted for differences in household size and composition. All incomes have been converted to the income of a single-person household. As a result, the welfare levels among different households can be compared on a more consistent basis (CBS, 2023). The dataset categorizes standardized disposable income into deciles, making it an ordinal variable. The primary dependent variable represents the main mode of transport utilized by respondents. This categorical variable differentiates between several main transport modes: car as a passenger, car as a driver, train, bus/tram/subway, bicycle, walking, and other means of transport.

The multinomial logistic regression model analyzes how independent variables influence the probabilities of different outcomes of a multinomial dependent variable relative to a designated base category. This analysis leverages the log odds ratio, which is the natural logarithm of the odds ratio. The odds ratio itself is defined as the ratio of two odds, where the odds are the likelihood of selecting a specific mode of transport compared to the likelihood of not selecting that mode. The log odds ratio provides a measure of how the odds of the dependent variable (the chosen mode of transport) change with a one-unit increment in the independent variable (income level). A positive log odds ratio means that the odds of the dependent variables increase with an increase in the independent variable, and vice versa for a negative log odds ratio. Multinomial logistic regression analysis makes use of a base outcome. The selection of a base outcome in multinomial logistic regression is fundamental for interpreting the results effectively. In this study car usage will be designated as the base outcome. This choice is grounded in the recognition that car transportation is typically associated with heightened CO_2 emissions compared to alternative modes of transport (BDO Belgium, 2022). By setting the car as the base outcome, the coefficients of the other transport modes can be interpreted as the log odds ratio relative to the car, given a unit increase in income. This approach gives a good understanding of how income levels influence the likelihood of opting for different transport modes compared to the car. Following the multinomial logistic regression analysis, the coefficients offer insights into the direction and magnitude of change in transportation mode choice probabilities relative to car usage. This provides a clear picture of the extent to which people with higher incomes are more or less likely to use the car, offering valuable insights for policymaking.

4.2 Environmental impact calculations

This section addresses the environmental impact associated with various modes of transportation, distinguishing between the cities of Amsterdam and Alkmaar, as well as across different income classes. This analysis aims to result in a robust comparison by using a systematic approach using STATA. Initially, the dataset is prepared by selecting key variables: standardized disposable income, primary mode of transportation, and trip distance, which is measured in hectometers. Once the data is imported into STATA, it is filtered to isolate the trips specific to Alkmaar and Amsterdam, allowing for city-specific analyses. Following the filtering, the dataset is cleaned by removing observations with missing values to ensure the integrity and reliability of the results. For this analysis, the income deciles have been reclassified into low, medium, and high-income groups. Then the 'tabulate' command is employed in STATA for each income group to generate frequency tables for trip distance and the main mode of transportation. Multiplying the distances from the output by their corresponding frequencies results in the traveled distance in hectometers, which can be converted to kilometers. After calculating the traveled distances for each transportation mode across all income classes, the results are systematically organized into tables. These tables provide a quantitative representation of how often respondents travel certain distances using specific modes of transport. All specific commands used can be found in the Appendix.

Now that information on the traveled distance per vehicle is obtained, the environmental impact of the respondents' travel behavior can be calculated. For this calculation, CO_2 emissions are considered the primary measure of environmental impact. The analysis assumes that all car trips are conducted using gasoline-powered vehicles, which emit an average of 102 grams of CO_2 per kilometer (BDO Belgium, 2022). In contrast, train trips in the Netherlands, primarily powered by wind energy, produce a significantly lower average of 2 grams of CO_2 per kilometer (Lengkeek, 2023). Buses, trams, and subways form a combined category. The average CO_2 emissions of these vehicles combined are estimated at 75 grams per kilometer (Milieucentraal, 2024). Active transportation modes, such as cycling and walking, are considered entirely CO_2-neutral (Milieucentraal, 2024).

Using these emission factors, the environmental impact of travel behavior for each income class can be calculated. This involves multiplying the distance traveled by each mode of transport by the corresponding emission factor. This results in the total CO_2 emissions for the low, medium, and high-income groups. To enable a fair comparison of emissions across different income classes in Amsterdam and Alkmaar, the emissions data will be normalized to emissions per person per trip within each income class and for the city totals as well. This approach provides a comprehensive overview of the environmental impact associated with travel behaviors in these cities.

5. Results

5.1 The influence of income on car usage

The findings of the multinomial logistic regression analysis for Alkmaar and Amsterdam are presented in Tables 2 and 3, respectively. In this analysis, the transport mode category labeled ‘car’ is designated as the base outcome. Using this as the base outcome allows to directly observe how the probability of choosing another transport mode changes with a one-unit increase in income.

In the context of Alkmaar, the analysis reveals the following insights regarding transport choice dynamics influenced by income. The Pseudo R^2 value of 0.0171 indicates that the income variable accounts for a small part of 1.71% of the variance in transport choice. As for the coefficients stated in Table 2, for transport categories ‘train’ and ‘bus/tram/subway’ the positive coefficients respectively suggest a 2.7% and 23% increase in the likelihood of opting for these modes of transportation over the car when income increases. However, this effect lacks statistical significance. Conversely, category ‘bicycle’ exhibits a significant coefficient of -0.081, indicating an 8.1% decrease in the probability of choosing a bicycle over a car as income increases. Likewise, the probability of opting to walk over driving diminishes significantly by 10.5% with increasing income. For the ‘other’ category, a coefficient of -0.448 points to a 44.8% reduction in the likelihood of choosing this alternative over driving as income rises. Overall, the significant findings underscore that higher income in Alkmaar correlates with decreased tendency for active transport modes and other alternatives compared to choosing the car as income levels increase. While positive coefficients are observed for public transportation modes, these do not achieve statistical significance within this sample.

Transportation mode	Coefficient	P > [z] (95% confidence)
Car	(Base outcome)	(Base outcome)
Train	0.027	0.684
Bus/tram/subway	0.230	0.476
Bicycle	-0.081	0.010
Walking	-0.105	0.001
Other	-0.448	0.000

Table 2. Influence of income on car usage in Alkmaar

As for Amsterdam, the Pseudo R^2 indicates that the model incorporating the income variable explains a minimal fraction of 0.45% of the variation in the dependent variable. Table 3 shows that across all transport categories, the coefficients exhibit negative values that are statistically significant. This indicates that the probability of opting for any transportation mode over the car diminishes as income rises. Among these categories, the ‘bus/tram/subway’ mode demonstrates the most pronounced effect, with a decrease of 11.9%. Conversely, income has the least impact on bicycle usage compared to car preference, showing a decrease of 4.1%.

Transportation mode	Coefficient	P > [z] (95% confidence)
Car	(Base outcome)	(Base outcome)
Train	-0.084	0.000
Bus/tram/subway	-0.119	0.000
Bicycle	-0.041	0.000
Walking	-0.061	0.000
Other	-0.010	0.000

Table 3. Influence of income on car usage in Amsterdam

To summarize, as income increases, respondents from both Amsterdam and Alkmaar exhibit a heightened preference for using cars over alternative, environmentally friendly transport modes.

5.2 Environmental impact of travel behavior

Following the completion of the analyses and necessary calculations, several key observations can be drawn. Table 4 presents the total kilometers traveled using each mode of transport for the three income groups in Alkmaar. From this data, it is evident that the high-income group traveled the greatest total distance on this day, covering 3,526 kilometers, while the low-income group traveled the least, with a total of 1,403 kilometers. When examining the various transportation options, it is clear that the most kilometers were covered by car across all income groups. The low-income group traveled 868 kilometers by car, the high-income group covered the largest distance, with 2,621 kilometers, and the middle-income group is in between these distances, with a total of 1,977 kilometers. In terms of public transport, the middle-income group traveled a greater distance by train compared to the high-income group, while the low-income group did not make any trips by train on this day. It is notable as well that the bus/tram/subway category was scarcely used. Both the low- and middle-income groups did not use these modes at all on the day of data collection, and the high-income group traveled only 8 kilometers with these options. These results suggest that Alkmaar has a limited public transport network, as previously mentioned, which is reflected in the minimal usage of these services. Regarding active transport modes, the low and middle-income groups covered more distance by bicycle compared to the high-income group. The distance traveled by foot lays closely together across the three income groups. However, in the ‘other’ category, the high-income group traveled a greater distance compared to the other two groups.

Transportation mode / Income level	Car	Train	Bus/tram/ subway	Bike	Walking	Other	Total
Low	868	0	0	304	126	105	**1,403**
Medium	1,977	414	0	373	155	66	**2,985**
High	2,621	194	8	199	150	354	**3,526**
Total	**5,466**	**608**	**8**	**876**	**431**	**525**	**7,914**

Table 4. Kilometers traveled per transportation mode in Alkmaar

Table 5 presents the CO_2 emissions associated with the distances traveled in Alkmaar categorized per income group. The table provides details on the number of respondents included, the number of trips taken on this specific day, the average number of trips per respondent, the total CO_2 emissions, and the CO2 emissions per person per trip. From the results presented in Table 5, it can be stated that the three income groups undertake a similar number of trips per person per day. Specifically, the low-income group averages 2.9 trips, while the medium- and high-income groups average 3.5 trips per day each. In terms of total CO_2 emissions, the low-income group contributes the least, with approximately 90 kilograms of CO_2. In contrast, the high-income group produces the highest total emissions, amounting to nearly 270 kilograms. The medium-income group falls in between, with total CO_2 emissions of approximately 200 kilograms. When adjusting for the number of respondents and the number of trips, the values in the column 'CO_2 emissions per person per trip in grams' are derived. From these values, it is evident that the medium-income group has the lowest emissions per person per trip, at 5.55 grams of CO_2. The low- and high-income groups exhibit higher emissions per person per trip, with values of 9.36 grams and 9.33 grams. The bottom row of the table summarizes the data for Alkmaar as a whole. The total CO_2 emissions for all respondents in Alkmaar on this day amount to approximately 560 kilograms. The CO_2 emissions per person per trip for this sample are at 2.66 grams significantly lower than the values for the income groups separately. This difference is due to the medium-income group having the lowest emissions per person per trip and being the most represented group in the sample, thus exerting a greater influence on the overall average.

Income level	Number of respondents	Number of trips	Average trips per respondent	CO_2 emissions in grams	CO_2 emissions per person per trip in grams
Low	57	166	2.90	88,536	9.36
Medium	102	358	3.50	202,482	5.55
High	91	316	3.50	268,330	9.33
Total Alkmaar	**250**	**840**	**3.36**	**559,348**	**2.66**

Table 5. CO_2 emissions corresponding travel behavior for Alkmaar's respondents

Table 6 displays the distances traveled by different modes of transportation for the low-, medium-, and high-income groups in Amsterdam. The results indicate that the car being the transportation mode with the largest total distance covered compared to other options applies to Amsterdam as well. Specifically, the low-income group traveled the least distance by car, totaling 5,477 kilometers, whereas the medium-income group traveled the most, covering 29,462 kilometers by car. Regarding public transportation in Amsterdam, which offers a greater variety of options, the distances traveled by train are nearly equivalent across all income groups, each covering approximately three kilometers. The low-income group has the highest usage of bus/tram/subway services, traveling approximately 500 kilometers more than both the medium- and high-income groups. In terms of bicycle usage, the low- and medium-income groups have traveled similar distances, with 1,592 kilometers and 1,390 kilometers. Notably, the high-income group traveled a significantly greater distance by bicycle, totaling over 3,000 kilometers. This value is nearly double the distance of the other income groups. For the categories 'walking' and 'other', there are no large differences in the distances traveled among the income groups.

Transportation mode / Income level	Car	Train	Bus/tram/ subway	Bike	Walking	Other	Total
Low	5,477	3,242	1,380	1,592	771	387	**12,852**
Medium	29,462	2,112	809	1,390	850	421	**35,046**
High	16,249	3,621	828	3,030	974	529	**25,233**
Total	**51,189**	**8,976**	**3,018**	**6,013**	**2,596**	**1,338**	**73,132**

Table 6. Kilometers traveled per transportation mode in Amsterdam

For the distances traveled by respondents from Amsterdam, the corresponding CO_2 emissions of their travel behavior are presented in Table 7. It can be inferred that respondents from Amsterdam undertook an average of approximately four trips per day. This figure is slightly higher than the average number of trips in Alkmaar, which stands at around 3.5 trips per day. Regarding total CO_2 emissions, the middle-income group has a significantly larger environmental impact, exceeding 3,000 kilograms. The high-income group follows, with emissions around 1,700 kilograms. The low-income group has the lowest total CO_2 emissions, amounting to 668 kilograms. The last column indicates that the middle-income group has the highest CO_2 emissions per person per trip, at 3.19 grams of CO_2. Both the low- and high-income groups exhibit very low CO_2 emissions per person per trip, each being less than one gram. Compared to the figures for Alkmaar, these values for Amsterdam are considerably lower across all income groups. When examining the total row, it is evident that the emissions per person per trip are only half a gram, which is remarkably low compared to the other values.

Income level	Number of respondents	Number of trips	Average trips per respondent	CO2 emissions in grams	CO2 emissions per person per trip in grams
Low	448	1,711	3.80	668,638	0.87
Medium	514	1,916	3.70	3,071,448	3.19
High	671	2,692	4.00	1,726,740	0.96
Total Amsterdam	**1,633**	**6,319**	**8.87**	**5,466,826**	**0.53**

Table 7. CO2 emissions corresponding travel behavior for Amsterdam's respondents

6. General discussion

This study aimed to determine the extent to which income level influences the choice of transportation modes among respondents from Amsterdam and Alkmaar, and to identify the difference of this influence between these two cities. Additionally, the study examined the variations in environmental impact resulting from these travel behaviors. The significant results indicate a positive relationship between income and car usage in both Amsterdam and Alkmaar. As income increases, the likelihood of choosing the car as the preferred mode of transport increases as well. Although the travel behavior of respondents from Amsterdam results in the highest total CO_2 emissions, the emissions per person per trip are significantly lower than the figures corresponding to Alkmaar's respondents.

6.1 Summary and conclusion

The results of this thesis contribute to a better understanding of the relationship between income and transportation mode choice, alongside the associated environmental impacts of these choices. A distinction is made between Amsterdam and Alkmaar, as they differ significantly in urban context despite their close proximity, potentially resulting in variations in travel behavior.

Previous research has indicated that higher-income households tend to prefer using cars as their primary mode of transport (De Maeyer et al., 2021), whereas it is expected for lower-income households to predominantly rely on active modes of transport for their daily trips (Westling, 2023). These previous findings are supported by the results obtained. The significant outcomes from the multinomial logistic regression of income on transportation mode choice for respondents from Alkmaar reveal negative coefficients for the transportation categories 'bicycle', 'walking', and 'other'. This indicates that as income increases by one unit, the likelihood of choosing these transportation modes over the car decreases. Conversely, higher income increases the likelihood of car usage. Similar trends are observed among respondents from Amsterdam. As income rises, the probability of opting for the train, bus/tram/subway, bicycle, walking or other transportation modes significantly decreases.

In absolute terms, it can be noted that across low-, medium-, and high-income groups in both Amsterdam and Alkmaar, the greatest distances are covered by car. Specifically, while in Alkmaar the high-income group has traveled the greatest distances by car, in Amsterdam the medium-income group accounts for this. The presence and quality of transport infrastructure in cities plays a part in this. For instance, Alkmaar has limited public transportation options (Blokker, 2024). The results from Table 4 concerning distances traveled by public transport indicate minimal usage of these options. The lack of adequate facilities for public transport and active modes of transportation may result residents of sparsely populated cities such as Alkmaar, where destinations are more spread out, to favor more environmentally polluting transport options such as the car (Fukkink & Oostdam, 2022).

Thus, the results confirm expectations that higher income results in more car use, and that Alkmaar has a greater negative environmental impact compared to Amsterdam. Although Amsterdam clearly exhibits the highest total CO_2 emissions due to travel behavior, adjusting for the number of respondents and trips reveals that the average emissions per person per trip in Alkmaar are approximately five times higher than the emissions in Amsterdam. This outcome may be attributed to Amsterdam's extensive cycling and public transportation networks, along with the city's combined functions of destinations due to its large population (Fukkink & Oostdam, 2022). These characteristics reduce the relative distance between destinations and facilitate the use of active or public transport mode, resulting in a lower environmental footprint.

6.2 Theoretical and societal impact

The findings of this thesis have the potential to make substantial contributions to both scientific knowledge and societal applications in various ways. From a scientific perspective, this study provides profound insights into the relationship between income and transportation mode choice. The research confirms previous findings that higher incomes correlate with a strong preference for car usage (De Maeyer et al., 2021), while lower incomes are more inclined towards active transport (Westling, 2023). By comparing Amsterdam and Alkmaar, this study offers valuable insights into how differences in urban context can further influence the relationship between income and transportation choice. This comparison contributes to a more nuanced understanding of the role urban environment plays in transport decisions. Another scientific contribution of this research lies in the quantification of environmental effects. By calculating CO_2 emissions per person per trip for different income groups, the study provides a concrete framework for understanding the environmental impact of transportation choices. This quantification can contribute to the development of accurate models and predictions in future research on sustainable transport.

From a societal perspective, the results of this study offer valuable insights for policymakers. The findings can serve as a foundation for developing targeted strategies to promote sustainable transport, considering income disparities. This is particularly relevant in light of the increasing focus on sustainability and social equity in urban planning. Moreover, the research can contribute to greater societal awareness of the environmental impact of various transportation choices. By clarifying the relationship between income, transportation mode choice, and CO_2 emissions, the study may encourage behavioral changes among individuals and communities. By focusing on the relationship between income and transportation choice, this thesis contributes to the societal debate on the accessibility of sustainable transport for different income groups. This may lead to a reconsideration of existing transport policy measures to promote social equity.

6.3 Strengths, limitations, and future research

The comparative analysis between Amsterdam and Alkmaar conducted in this thesis presents a unique research perspective. To the best of our knowledge, no prior studies have examined if and how the influence of income on travel behavior differs between these cities and the subsequent environmental impact of these travel patterns.

A limitation of this study lies in the low Pseudo R^2 values obtained from the multinomial logistic regression analysis, which explain only a small portion of the variance in the model. This research primarily focuses on the influence of income on transportation mode choice, hence the decision to include only these variables in the analysis. However, it is evident that multiple factors can influence the selecting process of a transportation mode. For instance, education levels and commuting patterns (De Maeyer et al., 2021), car ownership and parking availability (De Maeyer et al., 2021), quality of cycling infrastructure (Geilenkirchen et al., 2010), and the connectivity of public transport networks (Landelijk Reizigersonderzoek, 2022). In this study, multiple of these factors are used solely to provide a clearer picture of the urban differences between Amsterdam and Alkmaar, and to gain an initial impression of how these urban characteristics might relate to the obtained results regarding the influence of income on travel behavior. Incorporating more of these variables into the statistical analysis would likely result in a higher Pseudo R^2 value, explaining more of the variation in the model and thereby providing a more comprehensive understanding of the factors influencing transportation mode choices.

Furthermore, the statistical analyses and calculations are based on information from the ODiN 2022 dataset. As this dataset contains information concerning the number of trips on a single day (CBS, 2023), it may result in potential bias and distortion of results. The travel behavior recorded for respondents on this particular day may differ from their behavior when observed over a longer period. Additionally, the income variable used for the analyses is originally divided into deciles. This can cause the same deciles in Amsterdam and Alkmaar to differ when considering absolute values, potentially leading to different results compared to when working with absolute values.

Moreover, for the CO_2 calculations, average values were used for the transportation categories ‘car’ and ‘bus/tram/subway’. Although electric or hybrid cars produce lower emissions, the calculations assumed that all car trips were made in gasoline-powered vehicles. Since gasoline-powered cars emit more CO_2 in comparison to (partially) electric cars, this assumption may lead to distortion in the results as well. Similarly, for the emission calculations of the bus/tram/subway category, an average emission value for these three public transport modes was used. The study did not account for how frequently each mode (bus, tram, or subway) was used separately. This, combined with the average emission value, again results in an outcome that is an approximation.

Future research should consider incorporating a broader range of relevant variables in the analyses to obtain a more comprehensive understanding of the factors influencing travel behavior. In addition, utilizing data collected over an extended time period would help to mitigate potential bias and allow for more robust conclusions to be drawn from the results. Furthermore, differentiating between various types of cars (gasoline, diesel, electric, or hybrid) and distinguishing between different modes of public transportation would contribute to a more nuanced and accurate assessment. This approach would not only enhance the precision of the environmental impact calculations, but also provide a more detailed insight into the relationship between socioeconomic factors, transportation choices, and their associated environmental consequences.

To finish with, the goal of this research was to study the differences of the influence of income on travel behavior in Amsterdam and Alkmaar and its associated environmental impact. The aim was to answer the following research question: *"To what extent does income have an influence on travel behavior in Amsterdam and Alkmaar, and what is the difference in environmental impact of this behavior?"*. The significant coefficients obtained from the multinomial logistic regression concluded that for both Amsterdam and Alkmaar residents are more likely to choose the car when income increases. The coefficients, and with that the likelihood of choosing another transportation mode over the car, do not differ significantly between Amsterdam and Alkmaar, apart from one remarkable value. For Alkmaar, the likelihood of opting for the category 'other' over car usage decreases with a striking 44.8% when income rises with one unit. As for the environmental impact it can be stated that although Amsterdam has the highest total emissions, the travel behavior of residents of Alkmaar is the most polluting, with 2.66 grams of CO2 emissions per person per trip.

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Appendix

STATA Do-file

```
import excel "/Users/samvanleeuwen/Documents/Scriptie/OD_Respondents_index.xls",
sheet("OD_Respondents_index") firstrow

*** Multinomial logistic regression for Alkmaar trips ***
keep if WoGem ==361
tabulate KHvm HHGestInkG
* Remove missing variables from transportation mode variable
gen vervmissing = regexm(KHvm, "#NULL")
drop if vervmissing ==1
drop vervmissing
* Convert KHvm to numeric
label define KHvm 1 "auto" 2 "auto" 3 "trein" 4 "bus/tram/metro" 5 "fiets" 6 "wandelen" 7 "overig"
encode KHvm, gen(vvnum)
label values vvnum vervoer
* Combine categories 'car as passenger' and 'car as driver' to one
recode vvnum (1=1) (2=1) (3=2) (4=3) (5=4) (6=5) (7=6)
* Multinomial logistic regression wit car (1) as baseoutcome
mlogit vvnum HHGestInkG, baseoutcome(1)
* Save regression and convert to word
estimates store mlogitAMS
estout mlogitAMS, replace
estout mlogitAMS using mlogitAMS.txt, replace

clear all
import excel "/Users/samvanleeuwen/Documents/Scriptie/OD_Respondents_index.xls",
sheet("OD_Respondents_index") firstrow

*** Multinomial logistic regression for Amsterdam trips ***
keep if WoGem ==363
tabulate KHvm HHGestInkG
* Remove missing variables from transportation mode variable
gen vervmissing = regexm(KHvm, "#NULL")
drop if vervmissing ==1
drop vervmissing
```

```
* Convert KHvm to numeric
label define KHvm 1 "auto" 2 "auto" 3 "trein" 4 "bus/tram/metro" 5 "fiets" 6 "wandelen" 7 "overig"
encode KHvm, gen(vvnum)
label values vvnum vervoer
* Combine categories 'car as passenger' and 'car as driver' to one
recode vvnum (1=1) (2=1) (3=2) (4=3) (5=4) (6=5) (7=6)
* Multinomial logistic regression wit car (1) as baseoutcome
mlogit vvnum HHGestInkG, baseoutcome(1)
* Save regression and convert to word
estimates store mlogitAMS
estout mlogitAMS, replace
estout mlogitAMS using mlogitAMS.txt, replace

*** Frequency tables per income class for Alkmaar trips ***
import excel "/Users/samvanleeuwen/Documents/Scriptie/OD_Respondents_index.xls",
sheet("OD_Respondents_index") firstrow

* Divide income in three groups
generate income_group = .
replace income_group = 1 if inrange(HHGestInkG, 1, 3)
replace income_group = 2 if inrange(HHGestInkG, 4, 7)
replace income_group = 3 if inrange(HHGestInkG, 8, 10)
label define income_groups 1 "Low" 2 "Medium" 3 "High"
label values income_group income_groups
tabulate income_group
* Remove missing values from KHvm and AfstR
gen vervmissing = regexm(KHvm, "#NULL")
drop if vervmissing ==1
drop vervmissing
gen AfstRmissing = regexm(AfstR, "#NULL")
drop if AfstRmissing ==1
drop AfstRmissing
* Select Alkmaar and income group.
keep if WoGem == 361
keep if income_group == 1
* Frequency table of distance x transport category for income group 1
tabulate AfstR KHvm
```

```
* Number of unique values = number of respondents
distinct Person_index
* Clear all, run previous commands again and change income group to 2 'medium'
* Do this again for income group 3 'high'

*** Frequency tables per income class for Amsterdam trips ***
import excel "/Users/samvanleeuwen/Documents/Scriptie/OD_Respondents_index.xls",
sheet("OD_Respondents_index") firstrow

* Divide income in three groups
generate income_group = .
replace income_group = 1 if inrange(HHGestInkG, 1, 3)
replace income_group = 2 if inrange(HHGestInkG, 4, 7)
replace income_group = 3 if inrange(HHGestInkG, 8, 10)
label define income_groups 1 "Low" 2 "Medium" 3 "High"
label values income_group income_groups
tabulate income_group
* Remove missing values from KHvm and AfstR
gen vervmissing = regexm(KHvm, "#NULL")
drop if vervmissing ==1
drop vervmissing
gen AfstRmissing = regexm(AfstR, "#NULL")
drop if AfstRmissing ==1
drop AfstRmissing
* Select Amsterdam and income group.
keep if WoGem == 363
keep if income_group == 1
* Frequency table of distance x transport category for income group 1
tabulate AfstR KHvm
* Number of unique values = number of respondents
distinct Person_index
* Clear all, run previous commands again and change income group to 2 'medium'
* Do this again for income group 3 'high'
```