Analysis of Automobile Ownership in Hamilton, Canada

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Abstract

Car ownership is a key factor of household travel behaviour determining trip frequency, mode choice and propensity to chain activities during a trip. Also, being a causal factor for trip generation, traffic congestion and air pollution from traffic, it has implications on long-term transport planning. This paper examines the influence of family structure, socio-economic characteristics and the accessibility of place of residence on the number of cars owned by a household. For the purposes of our analyses, we estimate a multinomial logit model using data obtained through a recent Internet survey in the Census Metropolitan Area (CMA) of Hamilton. Several measures of neighbourhood accessibility and types of land use mix are derived for use as independent variables in a multivariate framework with the help of GIS. Results reveal that household life cycle stage, socio-economic factors, mixed-density at the traffic analysis zone level and mixed land-use within walking distance from the place of residence influence the decision of how many vehicles to own. The results can be used for the design of policies that may lead to changes in automobile ownership.

Keywords
car ownership, automobile demand, accessibility, proximity, multinomial logit model, travel demand, land use

1. Introduction

Car ownership is an important determinant of household travel behaviour and it is fundamentally interconnected with residential location and work trip commuting decision making (Scott and Axhausen, 2005). High levels of automobile ownership are associated with urban sprawl, increasing levels of automobile travel and thus, air quality and health problems (Handy et al., 2005). Yet, understanding of how households choose the number of vehicles to own based on where they live is of vital importance to urban planners and decision makers.

In addition to quantifying the relationships between urban transportation and land use (Kanaroglou and Scott, 2002), environmental and health concerns emanating from the transportation sector renewed interested in Integrated Urban Models (IUMs) as tools for assessing emissions of pollutants from traffic (Anderson et al., 1996) as well as the long-term contribution of traffic to air pollution (Potoglou and Kanaroglou, 2005a). Within IUMs, car ownership models play a crucial role determining the number of motorized trips undertaken by a household. However, the role of automobile ownership is often overlooked and is determined using exogenous information rather than being modelled within the system (Miller et al., 1999).

While Canadian cities experience considerably high levels of car ownership and dependence, there is an absence of studies on the factors influencing car ownership levels. Canadian efforts in the broad context of automobile demand were those by Mohammadian and Miller (2003) who studied automobile transactions and vehicle type-choice in the Greater Toronto Area and Ewing and Sarigolu (1998) who investigated the potential demand for alternative fuelled vehicles of suburban households in Montreal, Quebec.

This paper offers insight on how the levels of automobile ownership (i.e., 0, 1, 2 or more cars) are affected by urban form controlling for family structure and the household socio-economic characteristics. For this purpose, we develop a model of vehicle car ownership in which urban form is introduced through a number of indices such as land-use mix, density and a number of proximity measures attributed to a household's place of residence. The analysis is based on the estimation of a multinomial logit model for car ownership levels. Subsequently, the developed model can readily be used within an integrated urban model for Hamilton, that aspires to support endogenous estimation of vehicle ownership at the household level (Buliung et al., 2004).

2. A Household Car Ownership Model for Hamilton Canada

2.1 Study Area and Sources of Data

Analysis in this paper relies on household and car ownership data drawn from the CIBER-CARS survey (Potoglou and Kanaroglou, 2005b), a self-administered Internet-questionnaire conducted by the Centre for Spatial Analysis at McMaster University (CSpA) during April 2005. The sample used contains 774 households comprised of 2,165 individuals and 1,334 vehicles. Figure 1 shows the spatial representation of the collected sample. The collected data were complemented with three other sources of data: the 2001 Transportation Tomorrow Survey, GIS layers from DMTI (DMTI Spatial Inc., 2005), and bus-stop locations provided by the Cities of Hamilton and Burlington.

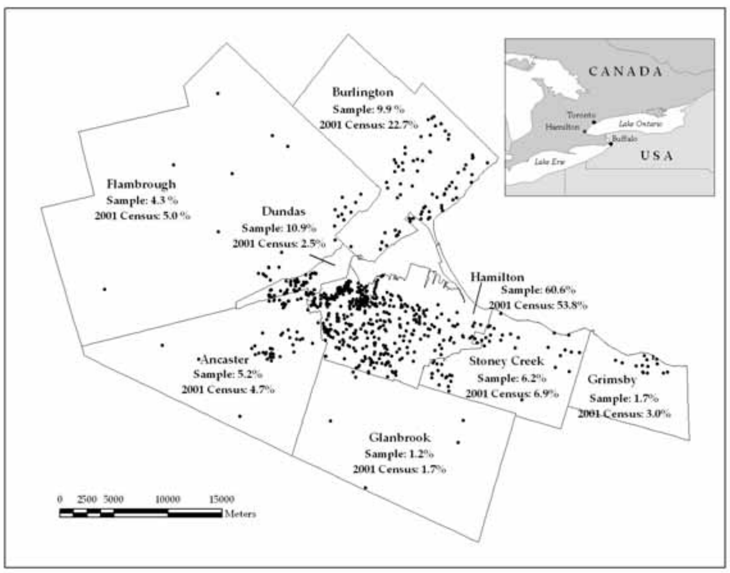

Figure 1. Locations of the obtained sample of households

Known limitations of the collected sample - compared to the 2001 Census is the under-representation of 1-person (16% vs. 27%) households and the over-representation of households with 4+ members (31.1% vs. 26%) (see, Table 1).

Also comparisons between the obtained sample and the 2001 TTS data showed statistically significant difference (χ^2=211.176, *d.f. = 15)* attributed to the under-representation of 1 person-0 vehicles households and the over-representation of 2 person-3-vehicle, 2 person-4 vehicle, 4+person-3 vehicle, and 4+ person-4 vehicle households.

Table 1. Distribution of household size versus number of vehicles (n= 774)

	Number of Vehicles				
Household Size	**0**	**1**	**2**	**3+**	**Total**
1 Person	2.3	12.9	0.8	0.0	16.0
TTS 2001	9.4	14.0	0.9	0.2	24.5
CENSUS 2001	-	-	-	-	27.0
2 Persons	2.2	14.2	13.0	3.9	33.3
TTS 2001	3.2	16.2	12.9	0.8	33.1
CENSUS 2001	-	-	-	-	31.0
3 Persons	0.4	6.2	7.8	4.4	18.7
TTS 2001	1.2	4.8	7.2	3.0	16.2
CENSUS 2001	-	-	-	-	16.0
4+ Persons	0.9	4.9	16.0	9.8	31.1
TTS 2001	0.9	6.1	13.6	5.3	25.9
CENSUS 2001	-	-	-	-	26.0
Total	5.8	38.2	37.6	18.1	100
TTS 2001	14.7	41.1	34.6	9.3	100
CENSUS 2001	-	-	-	-	100
Mean Car Ownership per Capita					0.62
Mean Car Ownership per Household					1.72

For our analyses, we specified four auto ownership level alternatives: zero, one, two and three or more cars. The maximum number of cars owned by a household in the sample was four and its overall share was relatively small (4.3%), hence we assigned those households with four cars in the three cars category. Table 1 summarizes auto ownership shares and the means of car ownership per capita and household in the sample.

2.2 Model Specification: Definition of Explanatory Variables

The explanatory variables tested were categorized into three broad classes: (a) socio-economic and demographic, (b) type of dwelling, land-use patterns and proximity measures at the place of residence, (c) other variables, which did not fall in any of the other two categories.

Socio-economic and demographic variables included total household income and size, family structure, number of licensed drivers, number of full- and part-time workers and life cycle stage of the household. Income was introduced as a set of dummy variables defined by the categories:

low (less than CAN$ 30,000), medium (CAN$ 30,001 - 80,000) and high (CAN$80,000 or more). This structure is capable of capturing non-linear effects in the relationship between household income and car ownership (Chu, 2002). Approximately 40% of the households refused to report their income. Thus, we introduced a fourth category ("income unknown") for inclusion in the model specification. This strategy allowed for estimation of the average effect of unknown income of these households and also, contributed to the estimation of all other coefficients of the model (Ryan and Han, 1999). Specifications involved employment status variables defined by full- and part-time adult workers (i.e., greater than 16 years of age) to portray greater and moderate mobility needs of households, respectively (Kim and Kim, 2004). Other things being equal, households with more full-time working adults would be associated with higher levels of car ownership. However, due to budget constraints, we hypothesized that this is not the case for increases in the number of part time workers.

Further, the presence of individuals with a driver's license in a household creates competition for the use of cars among household members, which may affect a household's decision to acquire additional cars. To capture this effect we specified a variable as the ratio of individuals with driver's licence by household size. This variable varies between zero and one, with one indicating equal number of licensed drivers and household members. The expected sign of the associated parameter is positive.

In addition, we introduced a number of household structure dummy variables, which divided our sample into five categories of household type: (a) single (1 if household consists of one member, 0 otherwise), (b) couple, (c) couple with children, (d) single parent (1 if the household consists of 1 adult and one or more children, 0 otherwise) and (e) other. The last category comprised of households with more than one independent (non-related) individuals or extended families. The advantage of using household structure identifiers is the explicit consideration to different contextual situations within the households, which cannot be captured by just the number of household members.

A mentioned earlier, the second class of variables was specific to the type of the dwelling, the land use characteristics and proximity measures at the place of residence. Car ownership is likely to be higher in households that reside in single-family, detached or semi-detached houses because of the availability of free parking in garages and driveways. In contrast, high-rise apartments and multi-family dwellings offer limited parking space - and in most cases - at a certain cost. This parking cost and availability constraints were incorporated into a housing type dummy variable taking the value of one if a household lived in a single-family house and 0 otherwise. In addition, to explore the connection between urban form and car ownership, we developed two density measures: (a) the density index, which was defined as the sum of household and jobs per acre (Prevedouros and Schofer, 1992) and (b) the mixed density index (MDI_i), both at the traffic analysis zone level. The MDI in zone i is defined as (Chu, 2002):

$$MDI_i = \frac{ED_i \cdot (RD_i)}{ED_i + RD_i} \qquad [1]$$

where, ED_i and RD_i are the employment (number of workers per acre) and residential density (number of households per acre) in household's residence zone i. High densities are generally associated with better transit services and access to activity locations while decrease the availability of parking and therefore car ownership costs. In addition, MDI is an indicator of jobs-housing balance, which has been shown to provide shorter commuter distances, decrease traffic congestion and reduce the number of trips (Giuliano and Small, 1993).

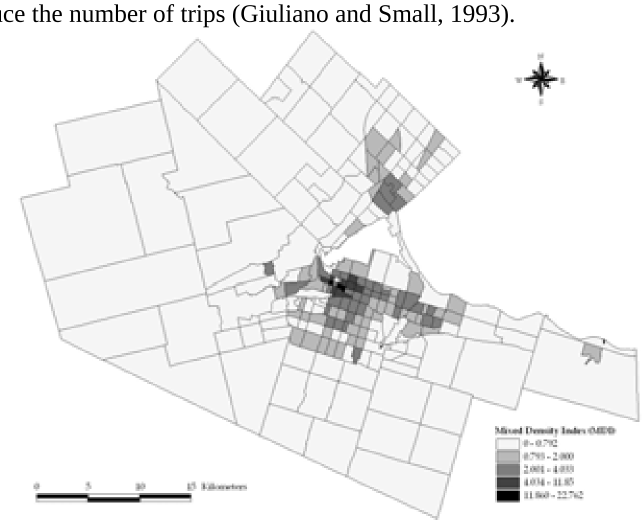

Figure 2. Spatial variation of the Mixed Density Index (MDI) in the CMA of Hamilton

Also, to include diversity characteristics of the residential area, we made use of a modification of the entropy index (EI) used by Cervero and Kockelman (1997) and Chu (2002). The EI_{500} is the value of the entropy index within a walking distance (500 meters) from the location of the household and is calculated as follows:

$$EI_{500} = -\sum_{i=1}^{k} \frac{p_i \cdot \ln(p_i)}{\ln(k)} \qquad [2]$$

where, p_k is the proportion of the developed land in the kth land use type. In this study, we used five (k=5) types of land use including commercial, residential, parks and industrial.

Figure 3 illustrates the calculation of the EI_{500} at the residential location of the household. Values of EI_{500} vary between 0 and 1, with one indicating even distribution among all land use categories (heterogeneity) and zero implying a single type of land-use within the radius of 500 meters (homogeneity) (Cervero and Kockelman, 1997; Chu, 2002). In general, the mix of land use development is expected to reduce car dependency and non-work trips (Cervero and Kockelman, 1997). Also, close to one values of the entropy index within a walking distance from the dwelling location imply ease of access to many activities by walking or biking and therefore the parameter of EI_{500} is expected to be negative.

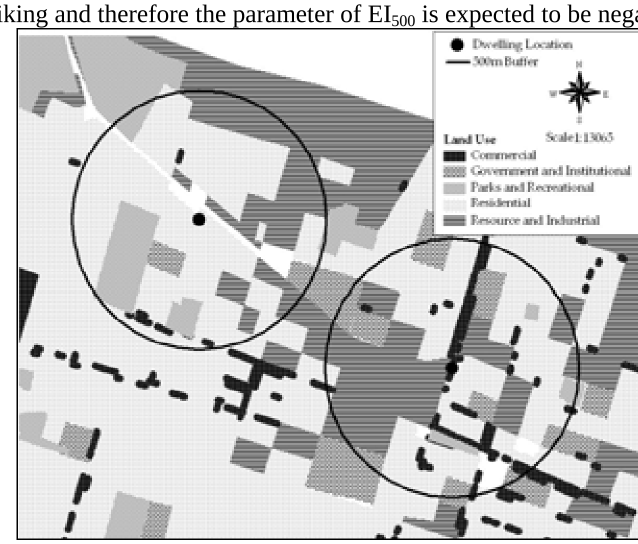

Figure 3. Land use characteristics incorporated in EI_{500} index

The last set of variables included the distance intervals to work, as reported by the respondents for each employed member of the household. The actual variable tested in the model's specification was the number of employees in the household working within the following distances from their home: (a) (number of employees working) less than 1 km - meaning that work was within walking distance (b) 1 to 6 kilometres, implying access to work by bike, transit or walk and (c) number of employees working at seven kilometres or more, highlighting a need for car(s) to travel to work.

3. Results and Discussion

3.1 MNL Estimation Results

As previously noted, we considered four alternatives of household car ownership: (a) zero, (b) one, (c) two and, (d) three or more. The model estimated was a MNL with a linear-in-parameters systematic utility. All estimations were performed using LIMDEP/NLOGIT Ver. 3.0 (Greene, 2002). Table 2 reports the final estimated model parameters. All parameters have the anticipated sign, as discussed in Section 3.2. Overall, our model performs well as indicated by the relatively high values of rho-square (ρ^2) and adjusted rho-square (adj-ρ^2), which are measures of goodness-of-fit evaluated by the following:

$$\rho^2 = 1 - \left[\frac{L(\beta)}{L(C)}\right] \qquad [3]$$

$$adj-\rho^2 = 1 - \left[\frac{L(\beta) - M}{L(C)}\right] \qquad [4]$$

where, L(β) and L(C) are the values of the log-likelihood function at its maximum and when only alternative specific constants (ASC) are included in the model, respectively. M is the number of parameters estimated in the model excluding the alternative specific constants. Also, the likelihood-ratio-test was used to test the null hypothesis that all the parameters other than the alternative specific constants are zero. With a chi-square value of 546.366 (*d.f. = 25)* the null hypothesis is rejected.

In our model, we specified three *alternative specific constants* for the one, two and three or more cars alternative options and all appeared to be statistically significant. In general, alternative specific constants capture unobserved information. Their negative signs emphasize on the negative effects of the unobserved information in the choice of one, two and three or more cars. Specifically, in models of car ownership, alternative specific constants incorporate the costs associated with the ownership of vehicle(s), namely, maintenance and operation fees as well as the cost for purchasing or leasing the vehicle(s) (Ryan and Han, 1999).

Table 2. Multinomial logit estimated parameters of household car ownership

	No. of Vehicles			
Variable	0	1	2	3+
Alternative Specific Constant	--	-2.022 (-3.819)	-2.748 (-4.209)	-4.082 (-5.078)
Type of Dwelling: Single Family House	--	2.302 (5.665)	3.131 (6.565)	3.269 (6.172)
No. of Full-Time Workers (16 - 64 years of age)	--	--	0.387 (2.117)	1.442 (6.612)
No. of Persons Employed Part-Time	--	-0.699 (-3.613)	-0.859 (-4.444)	--
No. of Individuals with Driver 's Licence / Household Size	--	1.664 (2.920)	1.625 (2.501)	2.383 (3.264)
Household Type: Single	--	2.030 (5.464)	--	--
Household Type: Couple	--	1.360 (4.038)	1.485 (5.096)	--
Household Type: Couple with Children	--	1.208 (3.481)	1.681 (6.043)	--
Household Type: Single Parent	--	1.616 (4.168)	--	--
Household Income: Medium (CAN$30,000 - CAN$80,000)	--	0.560 (2.835)	--	--
Household Income: High (CAN$ 80,000 or more)	--	--	0.352 (1.788)	--
Mixed Density Index (MDI) at the traffic analysis zone of dwelling	--	--	-0.192 (-2.127)	-0.285 (-2.025)
Land Use Entropy Index (EI) within walking distance (500 m) from dwelling	--	--	-0.980 (-1.901)	-0.980 (-1.901)
No. of Bus Stops within walking distance (500 m) from dwelling	--	--	--	-0.023 (-1.957)
No. of Individuals working at distance 7 km or more from dwelling	--	1.053 (3.089)	1.574 (4.432)	1.174 (3.246)
Number of observations				774
Likelihood ratio index = - 2 (L(c) - L(β)), (*d.f.*)				546.366, (25)
Log-likelihood Function: No Coefficients (L(0))				-1072.992
Constants Only (L(C))				-936.536
Model (L(β))				-663.353
Rho-Squared (ρ^2)				0.291
Adjusted Rho-Squared (Adj-ρ^2)				0.283

Note: t-statistic in parentheses

An alternative way to introduce ownership costs in our model would be to assign an arbitrarily fixed annual ownership cost per vehicle; however, this would not represent a real-world situation, because vehicle costs vary significantly with vehicle's age, class, type of engine as well as its mileage before purchase. In our case, we preferred not to include a car ownership costs variable and leave this to be captured by the alternative specific constants. As shown in Table 2, all else being equal, the values of ASC seem to increase the disutility with the number of cars. This trend in the ASC agrees with the assertion of Ryan and Han (1999). We feel that letting the model to determine endogenously the associated costs of ownership and maintenance costs of the vehicle(s), after controlling for other factors, is a better way of incorporating such vehicle ownership costs in the model.

Estimated parameters in the MNL represent the effect of variables on the observed utility of each car ownership level relative to zero-cars alternative. The *single-family house* attribute separates our sample into households living in a single-family house and those who live in any other kind of dwelling (e.g., apartment, condo, trailer). Alternative specific coefficients of this variable imply that its effect into households' utility is higher as levels of car ownership increase. In addition, the size of the parameters in all three alternatives indicates its high importance in the decision of a household to own vehicles (Bhat and Pulugurta, 1998).

Also, we found that *working adults* and the *number of persons with driving license*- the latter controlled by the household size - are positive and statistically significant. Both attributes represent the household's daily commitments and increased mobility needs, respectively (Kim and Kim, 2004; Scott and Axhausen, 2005). Higher number of workers increases the probability of a household owning two or more cars, whereas increased *number of drivers* has a positive effect in the probability of owning one or more cars. In contrast, households with *part-time workers* are less likely to own one or two cars, because of their potential budget constraints. While the number of part-time workers would not reflect the typical profile of a family-type household (e.g., couple with children) and has never been introduced before in studies of car ownership, we believe that it captures a group of individuals who work part-time (e.g., teaching assistants) and pursue full-time graduate studies. In absolute values, the effect of license ownership is greater than that of full- and part- time workers indicating that the number of individuals with driving license variable is one of the primary determinants of car ownership in the household.

Household type variables correspond to the trend of automobile ownership across several life-cycle stages. We used as reference class the household structure "Other", which includes households with two or more independent persons (e.g., housemates) or extended families. Each household type variable was specified in the utility functions based on its relevance. For example, single-person households are not generally expected to own two or more vehicles, thus we introduced this variable only in the one-car alternative. The same applies to "couple", "couple with children" and "single parents with child(ren)" household types, which are not expected to own more than two and one vehicles, respectively. The parameters of household type variables are statistically significant and positive signs reflect their positive effect in household's utility to own one or more cars.

Household income is one of the most important variables in determining car ownership it provides a household with the financial means that allow to own and maintain a vehicle (Roorda et al., 2000). As mentioned earlier, our sample was divided into four segments of "low", "medium', "high" and "income-unknown" income. The latter was necessary to be defined because of the high number of individuals (approximately 40%) who refused to provide such information. Alternative specifications showed that the unknown-income class had no effect in the utility function of any of the car ownership levels. Medium income had a positive effect on households' decision to own one vehicle. In addition, high-income was marginally significant (10% level) and had a positive effect only to households' decision to own two vehicles. The reason for this may be the relative small variability of the income variable in the way the sample was collected and the fact that high-income households may spend money for more expensive than greater number of automobiles (Prevedouros and Schofer, 1992). Also, we tried a number of interaction terms associated with income, but no significant results appeared for any of the car ownership categories.

As noted in section 2.2, another class of variables was defined on the basis of density and diversity at the place of residence. Our estimates were in agreement with previous research (Chu, 2002) and showed that both the mixed density index (MDI) and to a lesser extend the entropy index (EI) affect negatively household car ownership. In the case of MDI, as the jobs and households mix increases within a traffic analysis zone, the probability of a household to own two or more vehicle decreases. The monotonic increase - in absolute values - of the MDI coefficient from two- to three-or-more cars option reflects the greater negative impact of MDI in the decision of the household to own three-or-more cars. It is worth mentioning that our estimations tested also the impact of the variable *density*, defined by the ratio of jobs and households per acre. In the latter case, we found that its explanatory power was weaker compared to MDI and also, density was highly correlated with several variables of proximity to (i.e., minimum and average distance to retail locations) and number of opportunities (e.g., number of shopping locations). Generally, in subsequent estimations, MDI overshadowed all other variables of proximity and number of opportunities as well as dummy variables specific to municipal units (see, Figure 1). Regarding diversity, the EI was defined within walking distance (500m) from the household's location to capture the availability of activities in close proximity of the residence. Our assumption was based on the fact that diversity of activities within walking distance of the dwelling would reduce the need for additional vehicles dedicated for non-work / recreational activities.

The *number of bus stops within walking distance* from the place of residence was used as a proxy for defining access and level of service of alternative modes of transportation, such as local public transit. Our hypothesis was that availability of alternative-to-car modes of transportation might reduce the need for additional vehicles. As the number of bus stops increases at the place of residence, it is apparent that better transit service is available to several directions. As expected, increased number of bus stops has a negative, however marginal, effect on the probability of a household to own three or more vehicles. It is evident that transit availability might reduce excess of household car ownership, but it less likely to eliminate it completely. This is important for Hamilton, where city planners are in the process of designing policies that will reduce automobile dependency. We suggest that such strategies should not only focus on improved transit service, mixed and diverse land uses but also on investigating the balance of distances between place of residence and place of work.

While model estimates reveal that ownership of one car is considered more of a necessity rather than a luxury, as demonstrated by the performance of the socio-economic and demographic variables, car ownership is also influenced by the distance between home and work. The *distance-to-work* variable in our model was defined as the number of persons in the household who worked at distance more than 7 km from their home. Thus, increase in the number of workers who work at distances more than 7 km - and therefore, driving is the only convenient and reliable way - has a positive effect in the probability of a household to own one or more vehicles.

4. Conclusions

Environmental concerns and the need for comprehensive planning strategies for sustainable urban transportation systems require refined components of transportation and land-use. One of the most critical is household car ownership because it is a key determinant of household travel behaviour and major contributor to air pollution. While disaggregate models of car ownership have a history of more than twenty years, advances in GIS technology and availability of data have allowed researchers to enhance these models with fine-grained spatial data resulting in better exploration of the relationship between urban form and car ownership after controlling for socio-economic and demographic characteristics.

The objective of this paper has been to conduct an analysis of car ownership levels in the Census Metropolitan Area of Hamilton. We approached this task by studying car ownership at the household level using recently collected data through an Internet survey as well as urban form measures and transit proximity. Estimation of a MNL model allowed us to determine the effects of the aforementioned variables to household decisions to own zero, one, two or three-or-more cars. In general, results of our models agree with existing literature and provide a showcase for the Canadian urban context. In addition, we found that a more disaggregate determination of the entropy index and transit proximity/availability -defined within walking distance from the place of residence - impact on high car ownership levels. Based on the results of the analysis, car ownership is a necessity, especially for a number of household members who work at distances greater than 7 km from the place of residence and thus, future sustainable plans in the area should focus on defining good connections between place of residence and place of work. After the city's shift from a steel-industry-town profile to one focusing on services, education and health sciences, traffic emissions remain a major contributor to poor air quality. Future research will investigate the demand for alternative fuelled vehicles in the area and their potential to reduce vehicle emissions in the long-term.

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