Spatial and Non-Spatial Covariates of Telecommuting Activities: A Right Truncated Zero-Inflated Poisson Regression Model

Tom Brijs[#], Peter Van der Waerden[‡] and Harry J.P. Timmermans[‡]

[#]Hasselt University
Transportation Research Institute (IMOB)
Agoralaan – Gebouw D
B-3590 Diepenbeek, Belgium
Email: tom.brijs@uhasselt.be

[‡]Eindhoven University of Technology
Urban Planning Group
P.O. Box 513
5600 MB Eindhoven, The Netherlands
Email: p.j.h.j.v.d.waerden@bwk.tue.nl
Email: h.j.p.timmermans@bwk.tue.nl

Bijdrage aan het Colloquium Vervoersplanologisch Speurwerk 2005,
24 en 25 november 2004, Antwerpen

Inhoudsopgave

Samenvatting

Ruimtelijke en niet-ruimtelijke verklarende factoren voor telewerken:
een 'right truncated zero-inflated' Poisson regressie model

Deze paper beschrijft een studie waarbij participatie aan telewerken werd bestudeerd in functie van ruimtelijke en niet-ruimtelijke kenmerken. Op basis van een data set van 2.097 respondenten in Nederland werd een right truncated zero-inflated Poisson regressie model ontwikkeld teneinde de impact van ruimtelijke en niet-ruimtelijke kenmerken te bestuderen op de frequentie van telewerken. Deze kenmerken zijn ondermeer geslacht, leeftijd, rijbewijs, beschikbaarheid wagen, beschikbaarheid openbaar vervoerpas, deelname in de vervoersonkosten, handicap, gezinsstructuur, huishoudinkomen, urbanisatiegraad en reistijd tot het werk. Het voorgestelde model in de paper is innovatief op ten minste twee domeinen. Ten eerste betreft het model een uitbreiding van bestaande modellen in de literatuur, meer specifiek met betrekking tot het bestaan en de interpretatie van een grote hoeveelheid nul-observaties in de data, en met betrekking tot het voorkomen van een maximum waarde voor de afhankelijke variabele: namelijk het maximum aantal dagen per maand dat men kan telewerken. Ten tweede behandelt het model simultaan het al dan niet telewerken (ja/neen) en de frequentie ervan (aantal dagen per maand). Uit de resultaten blijkt dat de meeste van de gebruikte variabelen significant zijn. Naast enkele bevestigende resultaten (bv. met betrekking tot inkomensniveau en beschikbaarheid wagen) vinden we echter ook enkele conflicterende resultaten (bv. met betrekking tot geslacht) cf. de literatuur.

Summary

Spatial and Non-Spatial Covariates of Telecommuting Activities:
A Right Truncated Zero-Inflated Poisson Regression Model

This paper describes a study of participation in telecommuting activities in relation to spatial and non-spatial characteristics. Based on an extensive data set covering 2,097 respondents in the Netherlands, a right truncated zero-inflated Poisson regression model was estimated to study the impact of spatial and non-spatial characteristics on the frequency of telecommuting. The characteristics included in the study involve gender, age, driving license, car availability, availability of public transport pass, availability of travel cost arrangement, handicap, family structure, household income, urban density, and travel time to work. The model proposed in this paper is innovative in at least two respects. Firstly, it adds on some of the existing models in the literature, more specifically with respect to modeling the existence and interpretation of excess zeros in the data and with respect to the right truncated nature of the dependent variable, i.e. number of telecommuting days per month. Secondly, the model treats both the propensity (yes or no) and the frequency/intensity of telecommuting jointly into one model. The results show that most of the variables were significant in explaining the number of days per month a respondent engages in telecommuting activities. Furthermore, although we find evidence in our data that confirms earlier research findings (e.g. with respect to income level, car availability, etc.), we also find some conflicting results (e.g. with respect to gender).

1. Introduction

The emergence, diffusion and rapid improvement of modern communication technologies have in principle enabled employees to work from home, both part-time and full-time. Telecommuting has therefore been advocated as a potentially important policy instrument for reducing traffic volumes (*1, 2, 3*). In fact, it has been argued that between 10 and 25 percent of the workforce could potentially telecommute (*4*). In reality, this percentage is however considerably lower, the actual percentages depending on used definitions (see section 2).

Over the years, however, the optimism about the impact of telecommuting on reducing trips has tampered for a variety of reasons. First, an increasing number of empirical studies (*5, 6, 7, 8, 9, 10*) have found that the propensity of telecommuting varies considerably. Males were found to be more likely to telecommute than females. Income and education also have a positive relationship with homework in the sense that jobs, demanding a high level of education, are associated with increased frequency of working from home. In addition, there is some evidence that family and household characteristics play a significant role: household size, small children, and feelings of family devotion lead to increased propensity to telecommute. For example, Popuri and Bhat (*11*) studied the influence of individual demographics, work related attributes, Available technology, and household demographics on the adoption and frequency of telecommuting. They developed a joint discrete choice model and found that most included attributes significantly influence the probability of telecommuting. A recent more comprehensive study, conducted by Wernick and Khattah (*12*), showed that working from home was positively associated with respondents who had a greater number of mobile and land-line telephones, access to the internet from both home and work, access to rail, greater commute distances, were male, and had higher levels of education and incomes. Furthermore, working full-time and owning more vehicles were associated with lower propensity to work from home. In a Dutch study, De Graaff and Rietveld (*5*) developed a tobit model, and estimated the effects of selected socio-demographic variables and modem possession on telecommuting. It appeared that the possession of a modem increases total at-home work labor supply by more than 2.5 hours per week and that higher educated and younger individuals work more at home.

Second, even if employees are willing to work from home, the impact on the number of trips and the number of vehicle miles traveled is not necessarily positive. Mixed results have been obtained (*13, 14*), suggesting that telecommuting may have different impact (substitution and complementary) on daily activity-travel schedules. For example, Choo *et al.* (*15*) investigated the impact of telecommuting on short-term transportation (and air quality). They found that the vehicle-miles traveled are substantially reduced for telecommuters on telecommuting days. Illegems *et al.* (*16*) investigated the influence of telecommuting on the congestion levels of the road network in Brussels, Belgium. They found a considerable influence. Hamers *et al* (*17*) found a decrease between 10 and 17 percent in the number of trips made by workers after implementing telecommuting. In contrast to these findings others have found evidence of an increase in the number of trips or distance traveled in the context of telecommuting. For example, Mokhtarian *et al*. (*18*) found a significant increase in the number of commute personal vehicle trips from 1.2 to 1.9 trips per day. This effect was measured in the context of center-based commuting and was mainly caused by trips for lunch at home. On the other hand, the number of non-commute personal vehicle trips decreases. Black (*19*), on the other hand, suggested that telecommuters will travel more because they will be tempted to run kids to school, to drop off and pick up the dry cleaning, to pick up those, and so on. He argued that without commuting to work, many of the trips that are chained in a commuting trip, still have to be made.

Thirdly, job characteristics and corporate attitudes may limit the propensity to telecommute. Factors such as the flexibility in an employee's schedule, the need for face-to-face contact or to work in teams, and the role of the employee in the organization seems critical in this context and suggest that despite a positive attitude and access to technology, not all workers are able or willing to work from home.

In addition to these studies on the factors influencing the propensity of telecommuting and its short-term impact on daily activity-travel schedules, other studies have assessed the longer-term impact of telecommuting. Gareis and Kordey (*20*) provided an overview of research on the likely impacts of telecommuting on traffic and settlement patterns. They found that telecommuting shall not diminish the relative importance of urban agglomerations.

In this study, we focus on selected spatial covariates in addition to socio-demographics. The aim of the study is to contribute to the insights on the relation between characteristics of individuals, households, and build environment (including transportation system), and the frequency of telecommuting. These insights can help both environmental and transportation planners to evaluate their proposals with respect to the effect on telecommuting.

Our study differs in a variety of ways from earlier research (in the Netherlands). First, rather than using a nationwide survey, we use a regional activity-travel diary. Second, most previous work on telecommuting has focused on (explaining) the propensity of telecommuting and not its frequency/intensity. Some interesting exceptions include the work of Popuri and Bhat (*11*) who jointly modeled the adoption choice (yes/no) and frequency of telecommuting in the same model using a set of two correlated equations. Moreover, there is the work of Hole *et al.* (*21*) who modeled the frequency of telecommuting using a Negative Binomial Regression (NBD) model, and the work of Mannering and Mokhtarian (*9*) who adopted a multinomial logit framework to classify telecommuters as being frequent or infrequent. In our paper, we also treat both the propensity and the frequency in the same model. Yet, we believe that there are some remaining methodological issues regarding the model formulation that are not fully addressed in the past (see section on methodology). Hence, our study also differs from previous research in terms of the adopted methodology.

2. Data

The data used for the analysis were collected in 2000 in the context of the Amadeus research program carried out by a consortium of Dutch universities (*22*). Questionnaires were sent out in the North Wing of the Randstad, The Netherlands. The area encloses the cities of Amsterdam, Utrecht, Amersfoort and Almere. In total, 20000 selection questionnaires were distributed over the selected neighborhoods. Addresses were randomly selected within each neighborhood. Of the distributed questionnaires, 2488 (12.4%) were returned completed. Of these 2488 households 1600 (64.3%) were willing to participate in the main survey. The main questionnaire and diaries were distributed by mail to these 1600 households. Of these main survey questionnaires and diaries, 962 (60.1%) were returned (all the returned diaries contained at least one part of the questionnaire and diary completed by at least on person in the household). The Amadeus research team decided to select an additional 1200 households for a second round survey.

The data of 1581 households covering 2097 respondents are used for the analyses in this study. All these respondents have paid work and were asked to state how many days per month they work at home. Table 1 presents some general statistics of the respondents. It appears that the respondents are equally distributed over the different attribute levels.

TABLE 1 General Statistics of the Respondents

Attribute	*Attribute level*	*Absolute*	*Percentage*
Number of days telecommuting	0	1760	83.9
	1	116	5.5
	2	87	4.1
	3	21	1
	4	56	2.7
	>4	57	2.7
Gender	Female	1021	48.7
	Male	1076	51.3
Age	Younger than 35	503	23.9
	35-45 years	718	34.2
	46-55 years	598	28.5
	Older than 55 years	278	13.2
Family structure	Single household without children	262	12.5
	Single household with children	75	3.6
	Couple without children	730	34.8
	Couple with children	1030	49.1
Car availability	No car available	222	10.6
	Car available without consultation	1134	54.1
	Car available with consultation	741	35.3
Driving license	Yes	2009	95.8
	No	88	4.2
Urban Density	Very high density area (> 2,500 addr/km2)	702	33.4
	High density area (1,500-2,500 addr/km2)	708	33.8
	Low density area (1,000-1,500 addr/km2)	434	20.7
	Very low density area (<1,000 addr/km2)	253	12.1
Public Transport Pass	Yes	801	38.2
	No	1296	61.8
Travel cost arrangement	Yes	1133	54.0
	No	964	46.0
Handicap	Yes	41	2.0
	No	2056	98.0
Travel time to work	1-15 minutes	1032	49.2
	16-30 minutes	616	29.4
	31-45 minutes	279	13.3
	More than 45 minutes	170	8.1
Income level	No income	30	1.4
	Less than or equal to modal	284	13.5
	Between 1 to 2 times modal and 2 modal	859	41
	More than 2 times modal	924	44.1

The definition of telecommuting varies widely in the literature and causes some typical problems, such as for example if and how to include people who own their own company and live in the same building. Douma et al. (23) concluded that there is still a lack of consensus in defining telecommuting. It appears that a variety of behavior is included in the construct of telecommuting such as salaried employees who work at home, paid employment from a telecenter, home-based business, distributed work teams, mobile work forms, geographically dispersed work teams, and after-hours work. Bagley and Mokhtarian (24) defined telecommuting as using technologies to work at home (home-based telecommuting) or at a location close to home (center-based telecommuting), instead of commuting to a conventional work place at conventional time. In addition the Dutch Ministry of Transport, Public Works and Water Management uses the following definition of telecommuting: a telecommuter is an individual who works partly at home (or somewhere other than at work) and who uses ICT for that purpose (5).

This study is no exception in the sense that the data were collected for a general purpose, and not specifically to collect data for telecommuting. Thus, an operational definition was chosen for this study: telecommuting was defined as working episodes at the home address for a paid job during normal work hours. Yet, it is assumed that the type of questioning prevents that non-telecommuting behavior (e.g. self-employed home-based business) is included in the data. Table 1 lists the selected covariates that may impact the choice of telecommuting. In addition to the usual socio-demographics (gender, age, household composition, and household income), some spatial and transport-related attributes were selected. The latter included car availability, drivers' license, public transport pass, and travel costs arrangements. It is assumed that the easy availability of a car increases an individuals' flexibility and will thus increase the probability of telecommuting (11). Similarly, it is assumed that if individuals have decided to buy a public transport pass, they will be inclined to use it, and therefore, ceteris paribus, their propensity to telecommuting will be lower. Similarly, if individuals have some arrangement that they are reimbursed for their travel costs, we hypothesize that they will be less included to telecommuting. As for the spatial covariates, urban density and travel time to work were selected. We anticipate that the effect on the propensity to telecommuting will increase with increased density. Finally, we expect the probability of telecommuting to increase with increasing travel time. Table 2 illustrates how dummy variables were created from the different independent variables in our model, with the reference category shown in italic. This also implies that the results for every variable discussed later in section 4, will be evaluated relative to the reference category.

TABLE 2 Investigated Attributes with Attribute Levels and Dummy Coding

Attribute	*Attribute level*	*Dummy variable*	*Coding*
Gender	Female	Gender	1
	Male		0
Age	Younger than 35	Age 1	1 0 0
	35-45 years	Age 2	0 1 0
	46-55 years	Age 3	0 0 1
	Older than 55 years		0 0 0
Family structure	Single household without children	Family structure 1	1 0 0
	Single household with children	Family structure 2	0 1 0
	Couple without children	Family structure 3	0 0 1
	Couple with children		0 0 0
Car availability	No car available	Car availability 1	1 0
	Car available without consultation	Car availability 2	0 1
	Car available with consultation		0 0
Driving license	Yes	Driving license	1
	No		0
Urban Density	Very high density area	Urban density 1	1 0 0
	High density area	Urban density 2	0 1 0
	Low density area	Urban density 3	0 0 1
	Very low density area		0 0 0
Public Transport Pass	Yes	Public transport pass	1
	No		0
Travel cost arrangement	Yes	Travel cost arrangement	1
	No		0
Handicap	Yes	Handicap	1
	No		0
Travel time to work	1-15 minutes	Travel time to work 1	1 0 0
	16-30 minutes	Travel time to work 2	0 1 0
	31-45 minutes	Travel time to work 3	0 0 1
	More than 45 minutes		0 0 0
Income level	No income	Income level 1	1 0 0
	Less than or equal to modal	Income level 2	0 1 0
	Between 1 to 2 times modal and 2 modal	Income level 3	0 0 1
	More than 2 times modal		0 0 0

3. Methodology

In this paper, we define the frequency of telecommuting as the number of days a person is telecommuting per month (similar to Popuri and Bhat (*11*) who used the number of days per week) and treat it as a random variable *Y*. Then, at the individual level, *Y* is assumed to be Poisson distributed with rate parameter λ. Furthermore, we specify that people differ in their mean rate λ by linking each individual's λ_i to a set of observable characteristics, i.e., socio-demographics, spatial and transport related attributes. This leads to the well-known Poisson regression model:

$$\begin{aligned} y_i &\sim Poisson(\lambda_i) \\ \log(\lambda_i) &= \beta x_i \end{aligned} \tag{1}$$

Where β is a vector of regression coefficients and x_i a vector of covariates.

However, there are two aspects about this standard Poisson regression model that are too restrictive for this application. First, the data set contains a large number of zeros for the response variable. Furthermore, when respondents are asked about the number of days they are telecommuting, a zero answer can arise from two underlying responses. If the individual is not allowed to telecommute, they would always answer zero. If they are, however, the zero may be just the number of days they are telecommuting. In this case, fitting a simple Poisson regression model to these data would inflate the theoretical probability of zero in the Poisson model. Zero-inflated regression models are therefore characterized by a dual-state process, where the observed count can either be located in a perfect state or in an imperfect state with a mean λ. This type of model is therefore suitable for data generated from two fundamentally different states: one state being a normal count-process and the other being a zero-count state. The count of zeros observed across the entire population of respondents under this dual state process results in "excess" zeros not explained by a Poisson process. Formally, let $P(y;\lambda)$ denote the probability function of the simple Poisson distribution with parameter λ evaluated at point *y*, then the zero-inflated Poisson (ZIP) model with inflation proportion *p* takes the form:

$$ZIP(y;\lambda,p) = \begin{cases} (1-p)P(y;\lambda) + p & y = 0 \\ (1-p)P(y;\lambda) & y = 1,2,\ldots \end{cases} \tag{2}$$

The reader is referred to Lambert (*25*) and Li *et al*. (*26*) for additional information about the pdf and the characteristics of likelihood function of zero-inflated models.

The second problem arises from the fact that the data for the response variable is truncated at the right at the value of $y = 31$. Indeed, there are a theoretical maximum number of days per month someone is telecommuting. However, since the standard Poisson regression model for the response variable is defined on the range zero to infinity, the standard Poisson model would allocate a (small) probability to values $y > 31$, which for these data makes no sense and thus would be theoretically incorrect. The model therefore needs to be truncated to the right so that it cannot produce a probability for values $y > 31$. Building on the zero-inflated Poisson model, and adding right truncation to it, we obtain the right truncated zero-inflated Poisson model (RT-ZIP) with probability function:

$$RT - ZIP(y;\lambda,p,M) = \frac{ZIP(y;\lambda,p)}{\sum_{k=0}^{M} ZIP(k;\lambda,p)} \tag{3}$$

Where M is an upper bound that cannot be exceeded (in our case M = 31) and the λ's are again defined via a log-link function and associated with a vector of covariates. Note that the right truncated ZIP model coincides with the simple ZIP model when $M = \infty$. In practice, if M is large and $P(Y > M)$ is very small, the right truncated ZIP model will almost provide the same fit as the simple ZIP model, which for this application is also the case. In fact, both the simple ZIP regression model and the right truncated ZIP regression model were fitted on the data and did not show any differences in the results, i.e. almost identical likelihood and regression coefficient estimates. Both models were implemented in the statistical software language 'R' and an expectation-maximization (EM) type of algorithm was used to maximize the likelihood of the models. Hereafter, we will discuss the results of the right truncated ZIP regression model, as we believe that it is theoretically the most correct model. Note, furthermore, that from a more practical perspective, the model enables to study both the propensity (i.e. inflation proportion p) and the determinants of intensity of telecommuting simultaneously.

In this respect, our model formulation is, however, clearly different from other models previously introduced in the literature. For example, Popuri and Bhat (11) also introduced a model to study the propensity and intensity of telecommuting behavior jointly in one model. However, in contrast to our model formulation, they do not model the observed choice and frequency explicitly; they rather use a set of latent underlying continuous variables that mimic the observed discrete ones. In this respect, our model is more natural since it directly models the variables of interest. Furthermore, the treatment of a 'zero' observation for the frequency variable (number of telecommuting days per week/month) can be problematic since the meaning is rather ambiguous: is the person not allowed to telecommute or is the person allowed to telecommute but did not do it during the period of the survey? The same ambiguity of a 'zero' observation holds for the work of Hole et al. (21) who modeled the frequency of telecommuting using the Negative Binomial Regression (NBD) model. Therefore, since telecommuting frequency is characterized by a dual-state process, a zero-inflated model structure like the one proposed in this paper is clearly preferred. Finally, the definition of the frequency/intensity variable as proposed in (*11* and *21*), i.e. the number of telecommuting days per week/month, is typically bounded to the right by a maximum number (see above) and as far as we know, this aspect has not been treated in any practical telecommuting model before. Therefore, we proposed in this paper a theoretically more correct model with right truncation to overcome this problem, i.e. the right truncated zero-inflated Poisson regression model.

4. Results

The results of the truncated zero-inflated Poisson regression model are presented in Table 3, where the significant variables are indicated in boldface. The likelihood of the model equals 1808.122 and was achieved after 19 iterations. It turns out that the probability to belong to the category of people that never telecommute equals 0.823. In other words, this is the expected proportion of respondents in the data that never telecommute.

The interpretation of the covariates in our model is straightforward and can be expressed in terms of the effect of a unit change in the covariate on the relative change (in percent) of the mean of the Poisson distribution (see column 3 in table 3). More specifically, let λ_1 and λ_2 be respectively the old and new mean of the Poisson distribution. Then, it can be easily derived that $\lambda_2 = exp(\beta)\ \lambda_1$. In other words, $exp(\beta)$ measures the percentage change in the mean of the Poisson distribution due to a unit change in the covariate. Moreover, since all covariates are dummy variables and are expressed relative to the covariate's reference category, a covariate's effect measures the percentage change in the expected number of telecommuting days relative to the variable's reference category.

TABLE 3 Results of the Truncated Zero-Inflated Poisson Regression Model

Variable	*Coefficient*	*Effect*	*Std.error*	*p-value*
Intercept	0.612	-	0.336	**6.84e-02**
Driving license	1.469	+435%	0.314	**2.88e-06**
Income level 1	-2.231	-89%	0.581	**1.239e-04**
Income level 2	-0.455	-37%	0.119	**1.393e-04**
Income level 3	-0.039	-4%	0.052	4.416-01
Urban density 1	0.394	+48%	0.080	**9.534e-07**
Urban density 2	0.214	+24%	0.087	**1.413e-02**
Urban density 3	0.241	+27%	0.091	**8.163e-03**
Gender	0.340	+40%	0.049	**7.885e-12**
Age 1	-0.924	-60%	0.078	**0.000**
Age 2	-0.780	-54%	0.065	**0.000**
Age 3	-0.746	-53%	0.067	**0.000**
Handicap	0.536	+71%	0.158	**6.999e-04**
Car availability 1	0.154	+17%	0.081	**5.877e-02**
Car availability 2	-0.012	-1,2%	0.057	8.301e-01
Family structure 1	-0.130	-12%	0.096	1.754e-01
Family structure 2	-0.097	-9%	0.129	4.520e-01
Family structure 3	-0.131	-12%	0.052	**1.108e-02**
Public transport pass	-0.162	-15%	0.052	**1.867e-03**
Travel cost arrangement	-0.315	-27%	0.047	**1.180e-11**
Travel time to work 1	-0.149	-14%	0.067	**2.602e-02**
Travel time to work 2	-0.575	-44%	0.077	**8.926e-14**
Travel time to work 3	-0.211	-19%	0.076	**5.159e-03**

The variable ‘driving license’ is highly significant and points out that people who possess a driving license on average engage in telecommuting much more (435%) than people who do not have a driving license (the latter being the reference category).

With respect to household income, the results show that as income increases, also the frequency of telecommuting increases. In fact, compared to the reference category (households with an income above 2 times the modal income), the frequency of telecommuting for households without an income (income level 1) is 89% lower. For households with an income less or equal than the modal income (income level 2), the number of telecommuting days is 37% lower compared to the reference category. Once the income level is between one and two times the modal income (income level 3), the number of telecommuting days does not differ significantly from the reference category. It is therefore clear that lower income households tend to engage less in telecommuting than higher income households.

With respect to the variable urban density, the results show that as the urban density increases, also the amount of telecommuting increases. For example, compared to the reference category (very low urban density area), respondents who live in a very high urban density area (urban density level 1) engage in telecommuting activities 48% more. For respondents who live in a high urban density area (urban density level 2) or in a low urban density area (urban density level 3), the frequency of telecommuting is still respectively 24% and 27% higher compared to the reference category. These results show that as the urban density increases, also the amount of telecommuting tends to increase.

Gender differences also play a very significant role in the amount of telecommuting. The results from our model show that compared to men, women engage in telecommuting on average 40% more, and this variable is also highly significant. With respect to the age of the respondents, this study shows that as age increases, also the number of days someone is telecommuting increases, and the results are highly statistically significant. In fact, compared to the reference category (age>55), respondents aged below 35 (age level 1) engage in telecommuting 60% less. Similar, but slightly less pronounced results hold for the other age categories. More specifically, compared to the reference category, the number of days someone engages in telecommuting is 54% and 53% lower respectively for respondents aged between 35 and 45 (age level 2) and between 45 and 55 (age level 3). Also the fact whether someone is disabled plays a significant role in the number of days one engages in telecommuting. Our results show that disabled persons engage in telecommuting 71% more than the other respondents.

The availability of a car also turns out to play a significant role in the number of days someone is telecommuting. In fact, respondents who do not possess a car tend to engage in telecommuting activities 17% more than respondents who have a car at their disposal after consultation with the other family members. For those respondents who have a car at their disposal without consultation with other family members, the number of telecommuting days does not differ significantly from the reference category. Consequently, these results tend to show that it is not the fact whether one has to consult other family members or not to use the car that plays an important role in the amount of telecommuting, but it is the actual possession or absence of a car in the family that determines the frequency of telecommuting.

Results for the variable 'family structure' are somewhat indecisive. Only the results for the variable 'couple without children' are significant with respect to the reference category (couple with children). It turns out that, compared to couples with children, couples without children engage 12% less in telecommuting activities. For the other variables, no significant effects could be found. When looking at some of the financial considerations related to home-work travel, it turns out that compared to respondents who do not own a public transport pass, the possession of a public transport pass reduces the number of days one is telecommuting with 15%. Similarly, when the respondent benefits from a travel cost arrangement, he tends to engage significantly less in telecommuting activities. Indeed, respondents who have a travel cost arrangement on average engage in telecommuting 27% less then those who do not have a travel cost arrangement. Finally, travel time from home to work also turns out to play a significant role in the frequency of telecommuting activities. The results from our study indicate that compared to the reference category (travel time above 45 minutes) respondents who spend less time traveling to work engage on average less in telecommuting activities. The effect is most pronounced for travel times between 16 and 30 minutes (44% less telecommuting) and less pronounced but still important for travel times below 15 minutes (14% less telecommuting) and between 30 and 45 minutes (19% less telecommuting).

5. Conclusions

This paper reported the results of an analysis of the participation and intensity of telecommuting as a function of socio-demographic and spatial characteristics in the North Wing of the Randstad, The Netherlands. A right truncated zero-inflated Poisson regression model (RT-ZIP) was used for this analysis. The use of this model specification is, to the best of our knowledge, never proposed before in the literature of telecommuting and it overcomes two important problems (zero inflation and right truncation) that are inherent to the data. Furthermore, this application illustrates the usefulness of this model in that participation and intensity can be estimated simultaneously by the same model.

In terms of substantive research findings, the results of the present study to some extent confirm earlier results, found elsewhere, but also suggest some differences. Consistent with findings in earlier work, we found that higher income employees show a higher tendency to be involved in telecommuting. Also, the estimated effects for car availability have been reported earlier. However, unlike the dominant findings in earlier research, we found that women telecommute more. One reason may be that the majority of the women in the Netherlands work part-time. They might be more inclined to work at home on those days that they only work a few hours to start with. Future analyses should be conducted to elaborate this research finding.

The results of the present in light of those of similar, previous studies can be used to assess the differential impact of policies targeted at telecommuting. Analytical results like these provide better insight into the phenomenon. For true impact predictions, telecommuting should be studied and modeled as part of an integral model system. Unfortunately, not much research along these lines has been conducted yet. In part, this may be due to the fact that scholars who have focused on quantitative or qualitative analytical studies often do not master (or at least do not show any evidence of it) modeling skills. In part, with very few exceptions, modelers have mot yet delivered their promise of examining substitution and other, more complex, patterns between traditional out-of-home activities and ICT-driven activities at home, including telecommuting. The results of this study suggest that any realistic modeling effort should incorporate to what extent companies allow their employees to telecommute, and the willingness to participate in such schemes, conditional on task allocation, family roles, nature of the job, environmental and activity schedule characteristics. Socio-demographics may be nothing but variables that tend to have some strong covariance with some of these motivations, organizational and institutional drivers, and hence are only of indirect relevance.

References

1. Choo, S., Mokhtarian, P., and Salomon, I. (2005) Does telecommuting reduce vehicle miles traveled? An aggregate time series analysis for the U.S.. Submitted to: *The Energy Journal*.
2. Koenig, B., Henderson, D., and Mokhtarian, P. (1996) The travel and emissions impacts of telecommuting for the state of California Telecommuting Pilot Project. *Transportation Research C* **4(1)**, 13-32.
3. Accart, J.P. (1998) Networks and new ways of working: human aspects. *INSPEL* **32**, 40-45.
4. Hotopp, U. (2002) Teleworking in the UK. *Labour Market Trends*, 311-318.
5. De Graaf, T. and Rietveld, P. (2004) ICT and substitution between out-of-home and at-home work. *Environment and Planning* **A 36**, 879-896.
6. Drucker, J. and Khattak A. (2000) Propensity to work from home: Modeling results from the 1995 Nationwide Personal Transportation Survey. *Transportation Research Record* **1706**, 108-117.
7. Belanger, F. (1999) Worker's propensity to telecommute: An empirical study. *Information & Managemen*t **35(3)**, 139-153.
8. Teo, T., Lim, V. and Wai S. (1998) An empirical study of attitudes towards teleworking among information technology (it) personnel. *International Journal of Information Management* **18**, 329-343.
9. Mannering, J. and Mokhtarian P. (1995) Modeling the choice of telecommuting frequency in California: an exploratory analysis. *Technological Forecasting and Social Change* **49(1)**, 49-73.
10. Handy, S. and Mokhtarian P. (1996) Forecasting telecommuting: an exploration of methodologies and research needs. *Transportation* **23**, 163-190.
11. Popuri, Y.D. & Bhat, C.R. (2003) On modeling the choice and frequency of home-based telecommuting. Proceedings CD-ROM of the 82nd Annual Meeting of the Transportation Research Board, Washington DC.
12. Wernick, S.J. and Kattah A.J. (2005) Working from home in us metropolitan areas: the role of new technologies. Proceedings CD-ROM of the 84th Annual Meeting of the Transportation Research Board, Washington D.C.
13. Mokhtarian, P.L. (2000) Telecommunications and travel. Proceedings CD-ROM of the 79th Annual Meeting of the Transportation Research Board, Washington, D.C.
14. Glogger, A.F., Zängler T.W. and Karg G. (2004) Changing travel characteristics and activity travel patterns of households through telecommuting?. To appear.
15. Choo S., Mokhtarian P.L. and Salomon I. (2003) Does Telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S.. Proceedings CD-ROM of the 82nd Annual Meeting of the Transportation Research Board, Washington D.C.
16. Illegems, V., Verbeke, A. and Jegers, R. (2001) The potential of teleworking as an urban traffic demand management tool: the case of Brussels, the Belgian Capital. Proceedings of the 9th World Conference on Transport Research, Seoul, Korea.
17. Hamers, R., Kroes, E. and Van Oostroom, H. (1992) Teleworking in the Netherlands: an evaluation of changes in travel behaviour – further results. *Transportation Research Record* **1357**, 82-89.
18. Mokhtarian, P. and Varma, K. (1998) The trade-off between trips and distance traveled in analyzing the emissions impacts of center-based telecommuting. *Transportation Research D* **3(6)**, 419-428.

19. Black, W. (2001) An unpopular essay on transportation. *Journal of Transportation Geography* **9**, 1-11.
20. Gareis, K. and Kordey, N. (1999) Telework – An overview of likely impacts on traffic and settlement patterns. *Netcom* **13**, 265-286.
21. Hole, A., Jensen-Butler, C., Madsen, B. and Møller, L. (2004) Teleworking and transport: a study of the determinants of the propensity to telework and its intensity. Discussion paper series, Department of Economics, University of St. Andrews, Scotland.
22. Timmermans, H., Arentze, T., Dijst, M., Dugundji, E., Joh, C.H., Kapoen, L., Krijgsman, S., Maat, K. and Veldhuisen, J. (2002) Amadeus: A framework for developing a dynamic multi-agent, multi-period, activity-based micro-simulation model of travel demand. Proceedings CD-ROM of the 81st Annual Meeting of the Transportation Research Board, Washington D.C.
23. Douma, F., Wells, K. Horan, T.A. and Krizek, K.J. (2004) ICT and travel in the twin cities metropolitan area: enacted patterns between internet use and working and shopping Trips. Proceedings CD-ROM of the 83rd Annual Meeting of the Transportation Research Board, Washington D.C.
24. Bagley M.N., and Mokhtarian P.L. (1997) Analyzing the preference for non-exclusive forms of telecommuting: modeling and policy implications. *Transportation* **24(3)**, 203-226.
25. Lambert, D., (1992) Zero-inflated Poisson regression, with an application to defects in manufacturing. *Technometrics* **34(1)**, 1–14.
26. Li, C.-C., Lu, J.-C., Park, J., Kim, K., Brinkley, P.A. and Peterson, J.P. (1999) Multivariate zero-inflated Poisson models and their applications. *Technometrics* **41(1)**, 29–38.