

# Space-Time Prism Vertices: Exploring Gender Differences and Multiple-Peak Distributions in Arrival and Departure Times

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This paper investigates gender differences in the origin and terminal vertices of the time-space prism. Using the stochastic frontier method, separate models are constructed for females and males, based on data extracted from activity/travel diaries collected in The Netherlands. As activity patterns become more diverse, multiple peak distributions in arrival or departure times may be observed, to which the stochastic frontier method cannot be applied without violating its assumptions. By disentangling the multiple peak distributions, we demonstrate how this may be circumvented. The results indicate that the factors relating to the male and female prism vertices are not the same and are not in the same order of importance. The results are also discussed in relation to accessibility, further research directions and Dutch policies on gender equality.

*Keywords:* prism vertex; stochastic frontier model; space-time constraints; space-time prism; gender differences; activity patterns

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## 1. Introduction

The space-time prism concept proposed by Hagerstrand (1970) has been integral to further travel behaviour research. The volume of the prism is an indication of accessibility, while its outline embodies the capability, coupling and authority constraints on individual activity and travel patterns. Originally, the space-time prism concept has been used to investigate the impact of constraints, such as work hours and household activities, on activity patterns in a theoretical sense (Burns, 1979). Applications of this concept have typically focussed on investigating to what extent activity patterns of various segments of the population can be accommodated (e.g., Miller, 1982; Jones et al., 1983; Kwan, 1999; Ritsema van Eck et al., 2005). Recently, emphasis has shifted to the vertices of the prism. The origin and terminal vertices mark the earliest start time and latest end time for out-of-home activity and travel. The origin and terminal vertices are also an outcome of the

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perceived temporal thresholds of the individual and the fixity of the activities to be engaged. For example, an individual who usually sets out at 8 A.M. may think that departing earlier at 5 A.M. is not an option. However, the same individual may accommodate a departure at 7.30 A.M. to appear for an important meeting. The observed first departure from home may lie on, or more likely between, the earliest start time and the latest departure time from home. This is because leaving before the latest departure time creates a time buffer, in case of travel delays, and leaving later than the earliest start time may reduce the waiting time for travel or for the next activity to start. Such phenomenon has been investigated in accessibility studies (Ettema & Timmermans, 2007; Hall, 1983; Ashiru et al., 2003).

Studies on activity and travel behaviour have typically used either observed timings or stochastic frontier models to locate the prism vertices. The former approach refers to the use of the observed departure time for the first out-of-home activity and the observed final arrival time at home as the origin and terminal vertices respectively. However, the use of observed timings is potentially erroneous, as the use of these timings assumes full punctuality (Schwanen, 2006). Furthermore, observed timings are not wholly determined by constraints, but an unknown balance of constraints and preferences. The second approach to locate the prism vertices is through the use of stochastic frontier models (Kitamura et al., 2000; Kitamura et al., 2006; Nehra et al., 2004; Pendyala et al., 2002; Yamamoto et al., 2004). Studies have explored different distributions of the disturbance terms within the stochastic frontier model (Yamamoto et al., 2004), carried out analysis on a developing country context (Nehra et al., 2004), and investigated the variability of the prism vertex location for individuals over time (Kitamura et al., 2006). Although this method allows the use of variables to capture the effect of personal and situational circumstances on the individual's prism vertices, there are strict assumptions regarding the distribution of the first departure and final arrival times that must be adhered to. As activity patterns become more diverse, it is less common that the first departure and final arrival times are concentrated at conventional peak periods. Instead, the distribution of departure and arrival times may form multiple, but smaller clusters. Thus there is a need to explore how the stochastic frontier method, which is based on estimating distributions with one peak, can still be applied to distributions with multiple peaks.

This study will present data showing multiple peak periods in arrival times, to which the stochastic frontier method cannot be directly applied without violating its assumptions. These assumptions refer to the position of the earliest departure time being at or after the morning prism vertex and the position of the latest arrival time being at or before the evening prism vertex. We contribute to research by demonstrating how this may be circumvented. A disentangling of the multiple peak periods is achieved through identifying the activities that underlie the differences in arrival times. Consequently the arrival times can be separated according to the activity patterns based on these activities, which are more likely to yield single peak distributions, to which stochastic frontier models can be applied.

In addition, this study will present separate models for males and females to investigate gender differences in the origin and terminal prism vertices. The models will be based on a Dutch dataset, which will offer an alternative perspective from earlier research on data from India, Japan and the United States. The Netherlands is a country in transition from a male breadwinner model to a more individual model where gender equality is increasingly important (Knijn, 2003). Although some policies of the Dutch government have sought to narrow the gender gap (Tweede Kamer, 1992), the traditional division of tasks still persists (Portegijs et al., 2008; Portegijs and Keuzenkamp, 2008). The Dutch labour force is unique because of the high levels of participation in part-time work, as many women work part-time, while men typically work full time (Fouwels, 2009). This contributes to the

persistent gender differences in income (Van den Brakel and Bos, 2009), and the significant numbers of Dutch women who are not economically independent (Portegijs et al., 2006). As activity participation has important economic and social consequences, it is important to investigate to what extent the space-time prism that encompasses and constrains these activities is different for men and women (Kwan, 1999). A closer investigation of prism vertex locations could identify gender biased constraints and facilitate the formulation of gender sensitive policies aimed at improving the temporal availability of activities.

The remainder of this paper is organised as follows. The next section provides a background to the burgeoning diversity of activity patterns, gender differences in activity and travel behaviour and the developments in modelling prism vertices. The stochastic frontier model is elaborated in the third section, followed by a description of the data. The fifth section presents the results and analysis of the different models. The paper ends with a conclusion and suggestions for further research.

## 2. Literature Review

### 2.1 *Activity Patterns*

One significant trend in activity and travel behaviour is the increase in female participation in the workforce. This has implications for the timing of activities for women and their spouses. As work activities are added to the list of household and childcare tasks that are for the most part performed by women, the adoption of complicated activity patterns with trip chains and a readjustment of final arrival time at home and first departure time from home may be required to cope with all the activities. Furthermore, studies have documented that in households of highly educated working women, their spouses tend to shoulder more household responsibilities than husbands in other types of household (van der Vinne, 1997; van Velzen, 1997; Willemsen, 1997). This implies that changes in the activities of women could have an impact on the activities of their spouses, which further implies possible temporal re-arrangements on the spouses' part.

One explanation for diverse activity patterns is the steady rise in car use. In The Netherlands, the period from 1995 to 2002 saw an increase of more than 500 000 car commuters, and by 2002, car commuters accounted for more than 60% of all commuters (StatLine, 2004). Unlike commuters in public transport, car users do not have to follow time tables and have more flexibility in choosing their own start and end times. In addition to being a transportation device, the car can also be used to hold items such as groceries, exercise attire and equipment, which may reduce the hassle of carry these items around and facilitate the chaining of different activities. As more people choose the car as their preferred mode, heterogeneity in activity timings and activity patterns may become pronounced, and larger differences in prism vertices may emerge.

Factors such as the use of information and communication technologies for work and work timing flexibility may also have an impact on space-time prisms. In The Netherlands, a Working Hours Act in 1996 introduced flexible limits on working hours. Work could be performed outside of conventional working hours and on weekends (Van den Broek and Breedveld, 2004). The use of information and communication technologies for work or the availability of work timing flexibility provides individuals with the opportunity to rearrange their schedules to better suit their needs. Both strategies can be used to avoid peak commute and congestions periods, or to exercise their preference for activity timings and in turn prism vertex locations.

The growing myriad of activity patterns are also supported by the extension of the opening hours of shops and facilities that allow larger time windows, where one could engage in more activities, and have more flexibility in arranging these activities. One could undertake a multiple purpose trip chain, or engage in some activities, return home, and come out again for other activities. The new shopping hours act in The Netherlands extended shopping hours in the evening and on Sundays is one example, where significant number of shoppers was noted at these times (Van den Broek and Breedveld, 2004).

In addition to individual and temporal changes in activity and travel behaviour, spatial changes such as mixed and multiple land use developments also enable a larger variety of activity patterns. Although spatial developments take longer to evolve than individual activity and travel behaviour, these developments improve the accessibility of activity locations upon completion, and aid the feasibility of complex activity patterns. For instance, train stations in The Netherlands not only have a transportation function. In recent years, many train stations have expanded to include or join with adjacent shopping complexes, making these places a hub for activities. Activity patterns can become more complicated as there is more choice to participate in activities at the train stations before and after the train commute. These multiple land use developments at train stations have been a common sight in many Asian cities. Research has shown that Japanese commuters often divert from a direct work to home pattern, and engage in other activities located at the train station (Nishii and Kondo, 1992).

## 2.2 *Gender Differences in Activity & Travel Behaviour*

Despite the increase in the labour force participation of women, differences in the activity patterns between employed men and women still exist. Employed women are still the main care givers in their families, work fewer hours and have shorter work commutes than their male counterparts (Moen 2003; Portegijs et al., 2008). The Dutch national time use survey (Statistics Netherlands, 2005) reports that the average time spent on household activities is 103 minutes for men and 192 for women, between the age of 25 and 44 years. In terms of care-giving activities, the average duration for men and women in this cohort is 36 minutes and 69 minutes respectively. With regards to work activities, the average duration for men is 312 minutes, while women is 175 minutes. Also, the average male commuter travels 8 kilometers more than his female counterpart (StatLine, 2004). The differences in the activity patterns may be an indication of differences in space-time prisms and prism vertices.

While the space-time prism may constrain activity patterns, the choice of activities come with space-time constraints that may require a shift in the boundaries of the prism. Research has shown that the space-time fixity – the degree to which they are bound to particular times and places – of the activities undertaken by women is higher than that of men (Kwan, 2000; Schwanen et al., 2008). As many household and childcare tasks tend to be undertaken at home and most are conducted by women, an earlier return to home and consequently an earlier terminal vertex for the female space-time prism, compared to the male space-time prism, is likely.

The choice of activities is a choice under prevailing gender norms (Kandiyoti 1998; Lewis and Giullari 2005; Pfau-Effinger, 2000; Vincent et al., 2004), and gender differences in space-time prisms that encase these activities may be related to societal preferences for activities of men and women. The prevailing norms and values in the Dutch context have attributed a unique value to childcare performed by women and the woman's presence in the family (Portegijs and Keuzenkamp, 2008).

For men, their participation in household chores and childcare is laudable but voluntary (Hochschild 2003; Jordan et al 1992; McMahan 1995). A study by Schwanen (2007) suggests that in dual earner Dutch households fathers allocate time to childcare after accommodating the space-time constraints of work activities, while mothers allocate time to household and childcare tasks by renegotiating the timing and time allocated to paid work. Thus gender norms direct the gendered allocation of activities, which in turn influence the space-time prisms for men and women, including the location of the prism vertices.

### 3. Modelling Prism Vertices

As activity and travel takes place within the space-time prism, a trip commences after the origin vertex and concludes before the terminal vertex. Using activity and travel diaries, the start and end times of trips can be determined, but not for the prism vertices. Here an estimate of the location of the prism vertices will be derived from stochastic frontier models. In the absence of information on the activity timing preferences, the observed first departure time from home and final arrival time at home are used to estimate the origin and terminal vertices respectively. Earlier research by Lenntorp (1976) had also used realised timings, to identify the space-time prism and consequently to operationalise space-time accessibility. The stochastic frontier model relates these observed timings with individual characteristics and two random error terms, where one of the error terms ( $v_i$ ) represent random fluctuations in the sample and the other ( $u_i$ ) accounts for the random nature of the time interval between the observed timing and the prism vertex.

Following earlier studies (Kitamura et al., 2000; Kitamura et al., 2006; Nehra et al., 2004; Pendyala et al., 2002; Yamamoto et al., 2004), let the origin and terminal vertices be expressed with respect to the observed start and end times:

$$\text{Origin vertex:} \quad \tau_0 \leq t_0 \quad (1)$$

$$\text{Terminal vertex:} \quad t_t \leq \tau_t \quad (2)$$

where

$\tau_0$  is the origin vertex located along the time axis

$\tau_t$  is the terminal vertex located along the time axis

$t_0$  is the start time of the trip

$t_t$  is the end time of the trip.

Figure 1 illustrates the space-time prism and the positions of  $\tau_0$ ,  $\tau_t$ ,  $t_0$  and  $t_t$ .

Next, the unobserved prism vertices are further defined as

$$t_0 = \tau_0 + u_0 \quad (3)$$

$$t_t = \tau_t - u_t \quad (4)$$

where  $u_0$  and  $u_t$  are non-negative random variables.

The general form of the stochastic frontier model (Aigner et al., 1977) which is suitable for the relationships in equations (3) and (4) can be expressed as

$$Y_i = \beta' X_i + \varepsilon_i = \beta' X_i + v_i + u_i \quad (5)$$

where

$i$  is the observation

$Y_i$  is the observed dependent variable

$\beta'$  is a vector of coefficients

$X_i$  is a vector of explanatory variables

$v_i$  and  $u_i$  are random error terms

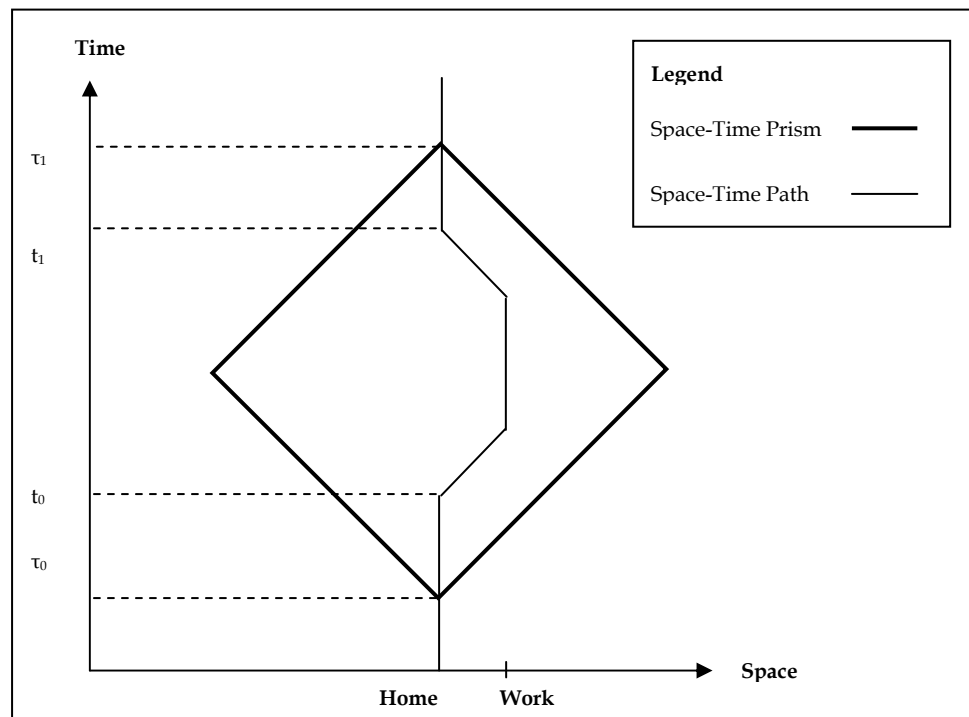


Figure 1. Illustration of the space-time prism

In this paper, the location of the origin vertex is expressed as a cost frontier model,

$$Y_i = \beta' X_i + v_i + u_i = \beta' X_i - \varepsilon_{oi} \quad (6)$$

The terminal vertex can be derived similarly, in the form of a production frontier model,

$$Y_i = \beta' X_i + v_i - u_i = \beta' X_i + \varepsilon_{ti} \quad (7)$$

One possible distribution of  $u_i$  is the half-normal and the other is the negative exponential (Aigner et al., 1977), where both have been shown to result in comparable coefficient estimates (Yamamoto et al., 2004). Although models of both distributions were tested, this study proceeds to show results based only on the half-normal distribution. This choice was made by comparing the results from both distributions, where the exponential distribution produced better models in terms of plausible expected values of the vertex locations. Below,  $\varepsilon_i$  could represent either  $\varepsilon_{oi}$  or  $\varepsilon_{ti}$ , and the half-normal distribution gives its distribution as

$$h^{HN}(\varepsilon_{ai}) = \frac{2}{\sigma_a} \phi\left(\frac{\varepsilon_{ai}}{\sigma_a}\right) \left[ 1 - \Phi\left(\frac{\varepsilon_{ai} \lambda_a}{\sigma_a}\right) \right] \quad -\infty < \varepsilon_{ai} < \infty, a = o, t, \quad (8)$$

where  $\sigma_a^2 = \sigma_{u_a}^2 + \sigma_{v_a}^2$ ,  $\lambda_a = \frac{\sigma_{u_a}}{\sigma_{v_a}}$ ,  $\phi$  and  $\Phi$  are the standard normal density and cumulative distribution functions respectively,  $v_{ai} \sim N(0, \sigma_{v_a}^2)$  and  $u_{ai}$  has the density function,

$$g^{HN}(u_{ai}) = \frac{2}{(2\pi)^{1/2} \sigma_{u_a}} \exp\left(-\frac{u_{ai}^2}{2\sigma_{u_a}^2}\right), \quad u_{ai} \geq 0, a = o, t. \quad (9)$$

The expected value,  $E(u_i)$  and the variance of  $u_i$  are respectively,

$$E^{HN}(u_i) = \left(\frac{2}{\pi}\right)^{1/2} \hat{\sigma}_u \quad (10)$$

$$\text{var}^{HN}(u_i) = \left(1 - \frac{2}{\pi}\right) \hat{\sigma}_u^2 \quad (11)$$

where  $\hat{\sigma}_u$  is an estimate of  $\sigma_u$ .

Without information on the individual's perception of their activity timing thresholds, there is some uncertainty if the stochastic frontier method definitely provides the location of the prism vertices. However, it does offer a way to estimate the earliest possible start time and latest possible end time for activity or travel (Pendyala et al., 2002), which is an alternative estimate of the prism vertices from using observed activity start and end times. Through the explanatory variables, it is also useful in identifying the factors that relate strongly to the timing thresholds.

## 4. Data

The data set used in this study was extracted from an activity and travel survey conducted in the Amsterdam-Utrecht region of The Netherlands in 2000. The survey was part of the AMADEUS program which focused on the effects of multimodal transport systems on activity and travel patterns (Timmermans et al., 1998). In total, 2033 households filled out a 2 day activity and travel diary. As this study is undertaken in the context of developing a household accessibility measure, only weekday diaries of households which had both the female and male adults of the same day were considered. After screening, 1940 person-days could be used for the empirical analysis.

As the 1940 person-days were chosen based on complete information on the persons and their partners, the sample is evenly divided into 970 females and 970 males. Of the 1940 person-days, 1378 of these observations came from employed persons. High household income lies in the range of 2 or more times of the modal income. As only a minority of households have more than two vehicles in this sample, most spouses share and thus do not have full access the use of the vehicle. After preliminary tests, population density was chosen to represent the spatial setting as it appeared to give better results when compared to other indicators such as contour accessibility measures to jobs

or inhabitants. Using the zip code of the residential location, the population density of the home neighbourhood can be determined. Table 1 gives an overview of the sample characteristics while Table 2 details how the variables have been recoded for model estimation.

**Table 1. Summary of Sample Characteristics**

Variable	Female	Male
N	970	970
Age in years (Average)	43	46
High Household Income	61%	61%
Presence of Child (0-10 years old)	38.7%	38.7%
Full Car Access	8.7%	5.7%
Employed	64.1%	78.5%
Average number of inhabitants per km <sup>2</sup> at residential location	3491	3491

**Table 2. Definition of Explanatory Variables**

Variable	Definition
Age	Age in years
Gender	1 if Male 0 if Female
Income	1 if annual household income is 2 or more times modal (approximately $\geq 45000$ EUR in 2000) 0 otherwise
Child	1 for the presence of the youngest child whose age is 0-10 years 0 otherwise
Car	1 if having full car access 0 otherwise
Work	1 if person is employed 0 otherwise
Density	Number of inhabitants per km <sup>2</sup> at the residential location

## 5. Results

### 5.1 *Origin Vertices*

In this section the estimation of the prism vertices is presented. Figure 2 shows the distribution of the first departure time and the distribution of the estimated origin vertex for males and females. The observed first departure time for females is most frequent at 9 A.M. while it is 8 A.M. for males. Despite this difference, the estimated origin vertex for both males and females falls mainly at 7 A.M. From Table 3, the  $E(u)$  value is 200 for females and 160 for males. This implies that the first departure time from home is on average 200 minutes and 160 minutes after the origin vertex, for females and males respectively. These  $E(u)$  values may seem large, but the estimated origin vertex is concentrated at 7 A.M., and Figure 2 shows that there are still a large number of people departing late throughout the day, who are likely to have a longer interval between their origin vertex and first departure from home compared to those who depart earlier. Figure 2 also shows that more females than males depart later in the day, thus the  $E(u)$  value for females is higher than that of the males.



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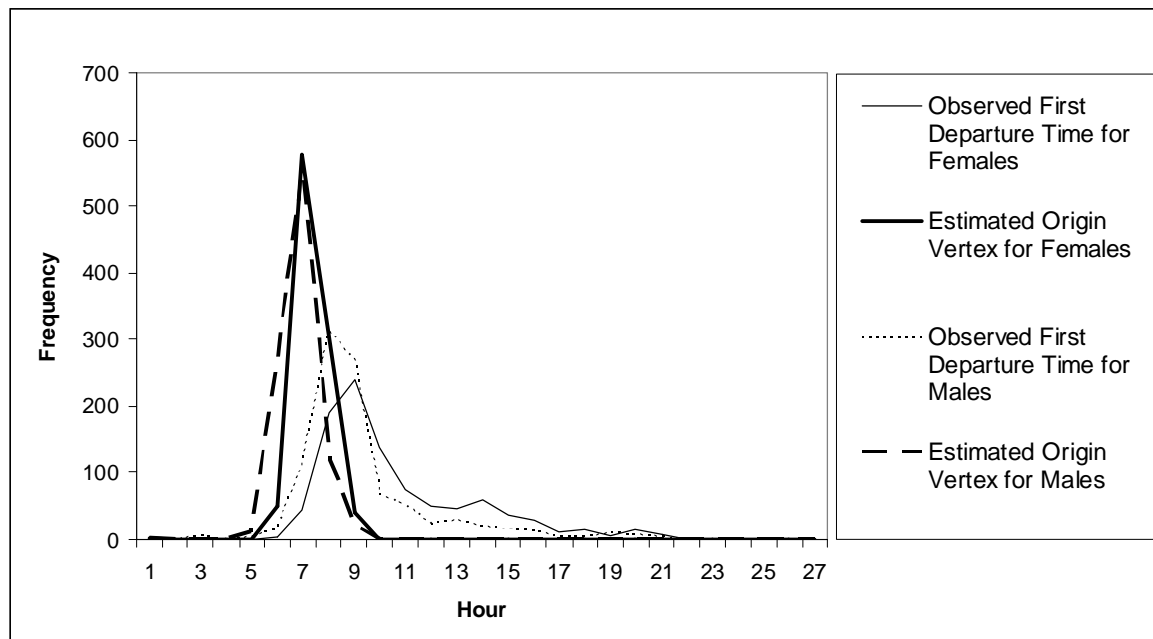
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Figure 2. Distribution of estimated origin vertex location and first departure from home for females and males

Table 3. Stochastic Frontier Models for the Origin Vertex

Variable	Female		Male	
	Coef.	<i>t</i> -stat	Coef.	<i>t</i> -stat
Constant	378.233	11.06	257.223	9.77
Age	1.533	2.40	2.803	6.22
Income	6.591	0.55	22.359	2.66
Child	21.653	1.78	14.831	1.56
Car	-46.985	-3.11	10.311	0.50
Work	-56.795	-5.16	-37.626	-4.36
Density	-0.0000265	-0.01	0.001	1.62
$L(\beta)$	-6327.17		-6088.72	
$L(C)$	-6355.18		-6128.33	
$\chi^2$ (df)	28.007		39.61	
$E(u)$	200		160	
N	970		970	

Table 3 shows the similarities and differences in the factors relating to the origin vertices for males and females. One similarity is that older people tend to have later origin prism vertices than younger people. Another similarity is that employed persons have earlier origin vertices than those who are not employed. As Table 1 shows that most people in the study are employed, senior workers are likely to have more discretion and autonomy in their work start times than younger workers. In the case of men, this seniority may also be expressed in terms of income, where men in higher income households tend to have later prism vertices too. Unlike for men, high household income is not

significantly related to women's origin vertices. Even if household incomes are high, women often work part-time in The Netherlands, and their incomes are usually lower than their spouses. Furthermore, part-time work is not likely to be in high level positions with high incomes, which would have given women more power over their work start times (Odihi, 1999). In terms of having full access to a car, this does not make any significant difference to the origin vertices of men, but it relates to significantly earlier origin vertices for women. These may be a result of female car users having a longer commute than other females. The results also show that the presence of a young child does not significantly influence the origin vertices for females and males. Some may expect that the origin vertices for mothers, if not the fathers', should be pushed earlier, if the child is to be sent to day-care or school. However, changing the timing threshold is one coping strategy which may not be effective as there may be still a clash in start times of day-care and the start times of work (Schwanen and de Jong, 2008). Thus other coping strategies that do not need a change in the prism vertices may be at work. For the variable density, no significant relationship was found for the origin vertices. Although in the Dutch context, residential density relates closely to the spatial availability of shops and services, most of these places are not opened early in the morning. In addition, people are more inclined to undertake maintenance and discretionary activities after work rather than before work (Golob, 1986; Pendyala and Bhat 2004; Schwanen 2004), which helps to explain why density is not a significant factor in the models for the origin vertices.

## 5.2 Terminal Vertices

Figure 3 shows the distribution of the final arrival times, more concentrated first at 6 P.M. for both males and females and a smaller concentration of arrival times at 10 P.M. for females and 11 P.M. for males. This distribution implies that there is more than one temporal threshold for the final arrival time at home. As the stochastic frontier method estimates one threshold, a separation of the two peaks in the distribution of the final arrival times is required before the stochastic frontier model can be applied. In this case, if the two peaks of the final arrival times are not separated, the results of the stochastic frontier model would place the terminal prism vertices before the later peak in arrival times. This would be erroneous because terminal prism vertices occur at or after the final arrival at home, as specified in Equation 2. For the separation of the two peaks, an arbitrary truncation could split the two peaks, but this will not improve our understanding of the behavioural underpinnings of final arrival times. Instead, activity patterns are used to segregate the sample, from which the distributions of final arrival times are inspected for a second time, to identify sub-groups with single temporal thresholds. Admittedly, the segregation of the sample according to activity patterns is not ideal, and it raises the issue of cause and effect between the choice of activity pattern and location of prism vertices. It is likely that activity patterns and prism vertices influence each other, but to different degrees, depending on the individual and circumstances. This is an issue for further research. Nevertheless, by segregating the sample in this way, the final arrival times can be clearly associated with specific activity patterns, and this would lend insight to the activity preferences and consequently the prism vertices of the sub-groups.

The search for sub-groups with single temporal thresholds required the investigation of different types of activity patterns, including single purpose or multiple purpose trip chains undertaken after work. The work activity is an important structuring element of weekday activity patterns. From the 1940 males and females, 1226 were working. Although the direct work to home activity pattern yielded a sub-group with one peak in the distribution of final arrival times, a grouping based on workers' in-home dinner pattern was used. This is because it was not only successful in disentangling the two peaks, but it captured more respondents within the sample. In addition, for

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the Dutch context, there is not a strong culture of eating dinner outside the home, especially on weekdays (Van den Broek and Breedveld, 2004). The sample also shows a strong tendency to have in-home dinner on weekdays with 1013 out of 1226 workers following this trend. This lends further support that binding space-time constraints are associated with in-home dinner activity, which makes it an important boundary on the space-time prism. The work by Damm (1982) also notes that workers may have another smaller space-time prism after dinner. Thus using in-home dinner patterns has strong relevance in identifying a sub-group, at least in the Netherlands. Of the 1013 workers that have in-home dinner, 818 workers have their final arrival at home before in-home dinner, while 195 workers have their final arrival at home after in-home dinner. As the final arrival times for the sub-group of 818 workers is clearly a single peak distribution, the stochastic frontier model was applied separately to the males and females in this sub-group. For the other 195 workers, the final arrival times still exhibited a multi-peak distribution and the division of workers by gender resulted in 72 and 123 observations for females and males, which were too few for model estimation. These are shown in Table 4 and Figure 4.

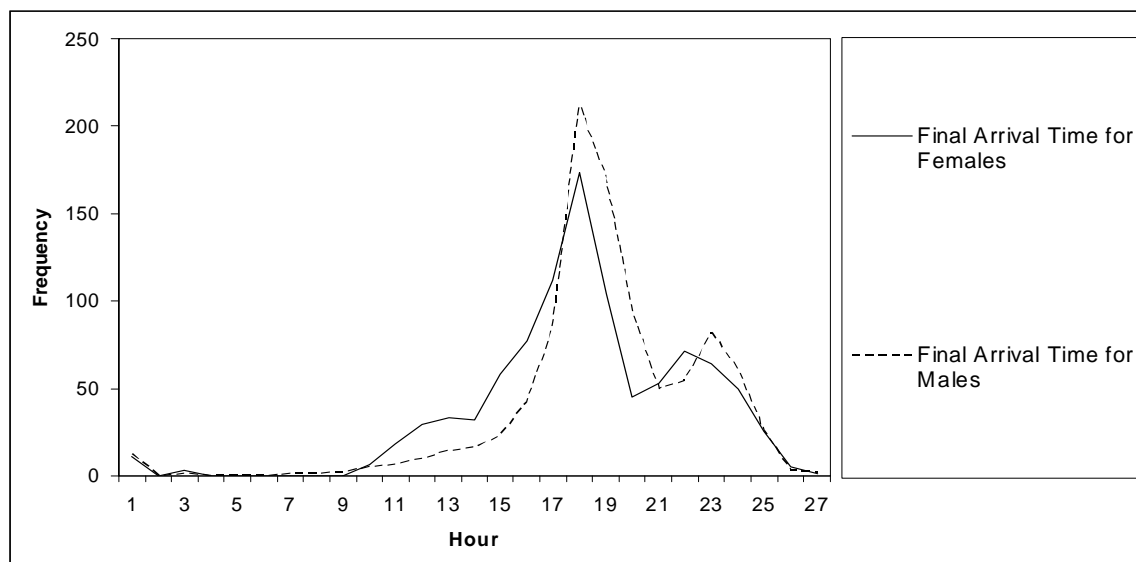


Figure 3. Distribution of final arrival at home for females and males

Table 4. Number and Proportion of Observations by Activity Pattern & Gender

Activity Pattern	Gender		
	Male	Female	
Final Arrival at Home			
After in-home dinner pattern <sup>1</sup>			
Number	123	72	195
(Proportion by activity pattern)	(19.68%)	(18.56%)	
Before in-home dinner pattern <sup>2</sup>			
Number	502	316	818
(Proportion by activity pattern)	(80.32%)	(81.44%)	
Sub-Total of Observations by Gender	625	388	

<sup>1</sup> This is further illustrated by Figure 4

<sup>2</sup> Prism vertex estimation results are shown in Table 5 and Figure 5

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Figure 5 illustrates the final arrival times and estimated terminal vertices of male and female workers who make their final arrival at home, before in-home dinner. The observed final arrival time at home is most frequently at 6 P.M., and the estimated terminal vertices are concentrated at 8 P.M. for men and women. The estimated terminal vertices give an indication of the time of completion of out-of-home activities. As the in-home dinner time in The Netherlands is commonly at 6 P.M., it coincides with the large number of observed final arrival time. Furthermore, the partaking of dinner is usually a joint affair between spouses, thus it is not very surprising that the prism vertices of men and women coincide. The  $E(u)$  values for the terminal vertices from Table 5 indicate that the final arrival time at home is on average two hours before the terminal vertices for men and women, and is the same as the difference between the peaks in observed final arrival time and estimated terminal vertex.

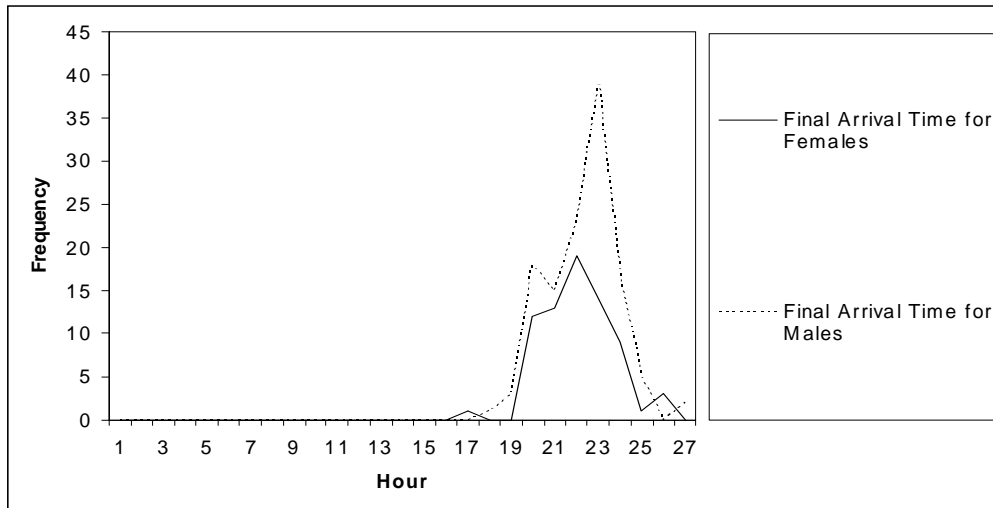


Figure 4. Distribution of final arrival at home for male and female workers, of activity pattern with out-of-home activities after dinner at home

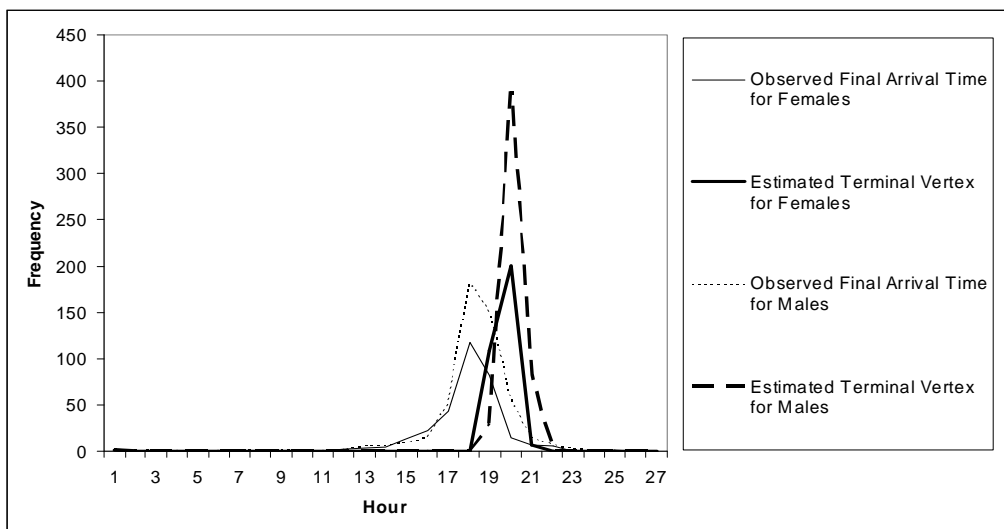


Figure 5. Distribution of estimated terminal vertex location and final arrival at home for female and male workers, of activity pattern with no out-of-home activities after in-home dinner

**Table 5. Stochastic Frontier Models for the Terminal Vertex**

Variable	Female		Male	
	Coef.	<i>t</i> -stat	Coef.	<i>t</i> -stat
Constant	1197.680	32.66	1219.350	45.78
Age	-1.194	-1.53	-1.578	-2.82
Income	4.382	0.34	33.722	3.57
Child	-46.895	-3.13	-18.595	-1.79
Car	4.734	0.22	-26.839	-1.05
Density	0.004	2.43	0.004	2.99
L( $\beta$ )	-1901.55		-3048.83	
L(C)	-1913.71		-3063.48	
$\chi^2$ (df)	12.166		14.647	
E(u)	110		127	
N	316		502	

Despite having similar outcomes in terms of estimated terminal vertices, the results of the explanatory variables indicate that different factors relate to these outcomes for men and women. For men, age and high household income are significant, but this is not the case for females. Older men tend to have earlier terminal vertices while men with higher household income tend to have later terminal vertices. The former could be related to after work activity patterns, as a further examination of this data reveals that older men are likely to make a direct trip from work to home, while younger men are more likely to engage in out-of-home activities after work. Men with high household income may have later terminal vertices due to heavier work responsibilities in higher paying jobs. For women, the presence of a young child pushes her terminal vertex on average earlier by approximately 45 minutes. This factor does not show a significant relationship for men. Research has shown that mothers are mainly responsible for fetching the children from school or day care to home (Molnar, 2005), which may explain the earlier terminal vertices for women with young children. The results also show that car availability is not a significant factor for the terminal vertices of men and women. In addition, the results reveal that the effect of residential density is significant on the terminal vertices for men and women. In areas of higher residential density, more shops and services are located, providing more opportunities where people may engage in maintenance and discretionary activities, after work and before their in-home dinner (Damm, 1982; Golob, 1986; Schwanen and Dijst 2003).

## 6. Conclusion

This study analysed the gender differences in the origin and terminal prism vertices using stochastic frontier models. In addition, a two-peak distribution of final arrival times was presented, highlighting the need for new approaches to estimate the prism vertices. As the stochastic frontier method is suitable to estimate one peak distributions, the disentangling of multiple-peak distributions is required. Here, the use of different activity patterns to identify sub-groups of one peak distribution was demonstrated. For the Dutch sample in this study, the majority activity pattern with one peak in its final arrival time distribution was a final arrival at home before in-home dinner.

Although the position of the origin and terminal prism vertices are similar for men and women, the results show differences in the underlying factors relating to the prism vertices. For the origin vertices, the factors that relate strongly for the female are employment status, followed by car

availability and age, while factors that are highly associated to the male vertices are first the age, then employment status and household income. For the terminal vertices, the residential density at the home location is the most significant factor for both males and females. In The Netherlands areas of higher residential density also have more shops and facilities and better transportation services. These imply that an increase in the availability of shops and services in residential areas is likely to influence the terminal vertices more than the origin vertices. Other differences between men and women are that women tend to have earlier terminal vertices if they have a young child, while this factor is not salient for men. Male terminal vertices are more strongly related to age and household income. The strong similarity of the estimated prism vertices of employed men and women suggest that there is enough of a temporal match for the exchange of tasks between spouses, even if both of them are working. Thus policies should focus on reducing the gendered nature of task and time allocation in households, both for the males and the females. Policies should also consider the younger cohorts if shifts towards gender equality are to be made and sustained. Studies on the young Dutch pupils have indicated that an equal division of tasks as an ideal is not as strongly sought for in girls than compared to boys (Portegijs et al., 2002). Unless active steps are taken throughout the population, gender equality will remain an ideal, not a reality.

One constraint from the 2 day activity and travel diaries is that the day to day variability of prism vertex location could not be explored. Working within these constraints, a check on the distribution of the first departure time from home and final arrival time at home for each weekday was performed. A similar pattern emerged across all weekdays, thus the analysis presented above is largely representative of weekday activity and travel behaviour. Another issue is whether an underestimation of true timing thresholds has occurred, as the use of observed timings in the estimation is not likely to be the maximum threshold. This can be addressed in two ways. First, the structure of the stochastic frontier model accounts for the random fluctuations in the data and in the gap between the observed timings and actual thresholds. Thus the observed timings are not the only information used to estimate the prism vertices, and the structure of the model has sought to identify the maximum thresholds. Second, the  $E(u)$  values from the results show that prism vertices are about two hours from the observed timings, which is not a trivial interval, thus the estimated prism vertices cannot be written off as an underestimation.

One of the uses of prism vertex estimation is to calculate space-time accessibility, and this has been demonstrated by Kitamura et al. (2001). From activity and travel diaries, there is seldom information on the fixity of activities, and prism vertex estimation can fill this gap to provide the temporal boundaries for accessibility measurement. While the position of the prism vertices may be an indication of prism size and in turn accessibility, a larger prism does not necessarily result in higher accessibility. For example, the incorporation of safety margins may enlarge the space-time prism but is actually a reduction in accessibility (Ashiru et al., 2003; Hall, 1983). In addition, the shifting of the start vertex to an earlier position is unlikely to increase the individual's accessibility as there may be a mismatch between the individual's time window and the opening hours of facilities or availability of public transport. However, converse to the start vertex, a larger prism due to a shift of the terminal vertex to a later position is more likely to indicate the individual's ability and choice for activity participation.

This study has provided a partial solution to the estimation of prism vertices from multiple peak distributions in arrival and departure times. One avenue for future research is to explore other ways to estimate vertices. Methods such as latent class modelling can be used to classify cases to their most likely sub-groups, which can be followed by an application of the stochastic frontier method to estimate the prism vertices for the different sub-groups. An alternative method to obtain the prism

vertices is to include questions regarding the temporal thresholds in activity and travel diaries. In this way, it would also be possible to investigate the difference between stated preferences of prism vertices and their estimated values.

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