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T-communities and Sense of Community in a University Town: Evidence from a Student Sample using a Spatial Ordered-response Model

Kate E. Whalen, Antonio Páez, Chandra Bhat, Md Moniruzzaman and Rajesh Paleti

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Abstract

An emerging interest in transport research concerns the factors that can help to create strong, sustainable and 'livable' communities; however, relatively limited empirical work has been conducted to date. In this paper the perception of sense of community among neighbourhood residents is investigated. Drawing from research on tertiary street-communities (*t*-communities), the paper explores the effect of the urban landscape, particularly street networks, and neighbourhood and individual characteristics on sense of community. A sample of students at McMaster University in Hamilton, Canada, is used for the analysis. In addition to providing an opportunity to study sense of community, a student sample is interesting in its own right, as students are often a component of essential but at times uneasy relations between universities and towns. Analysis is based on the application of an ordered probit model with a spatial lag. The results provide evidence that *t*-community membership can influence sense of community.

Introduction

Transport policy-makers have recently turned their attention to the concept of 'livable communities' and three key societal goals affected by transport networks and services: a vital economy, a sustainable environment and vibrant communities (AASHTO, 2010). The impacts of transport on the economy and the environment (the first two societal goals just listed) have been extensively researched under the banner of

Antonio Páez (corresponding author), **Kate E. Whalen** and **Md Moniruzzaman** are in the School of Geography and Earth Sciences, McMaster University, 1280 Main St W., Hamilton, Ontario, L8S 4K1, Canada. E-mail: paezha@mcmaster.ca, whalenk@mcmaster.ca and monirrm@mcmaster.ca.
Chandra Bhat and **Rajesh Paleti** are in the Department of Civil, Architectural and Environmental Engineering, University of Texas at Austin, Austin, Texas, USA. E-mail: bhat@mail.utexas.edu and rajeshp@mail.utexas.edu.

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sustainable development (Black *et al.*, 2002). Less understood are the impacts of transport on the third goal related to the social fabric of communities—the things that make a community vibrant—even if the impacts of transport on individuals have become increasingly clear thanks to recent research on transport-related social exclusion (for example, Páez *et al.*, 2009). Underlying the policy interest are some questions in search of answers. Why is it that some neighbourhoods develop a strong sense of community and others do not? And how, if in any way, do transport infrastructure and services influence this sense?

Bearing on these questions is the sociological research of Rick Grannis on tertiary street networks and tertiary street-communities (or *t*-communities) (Grannis, 1998, 2009). The tertiary (i.e. local, low traffic) street network, deemed 'trivial' by early sociological models that considered transport (de Boer, 1986), is identified by Grannis as an important element impacting the formation of communities based on networks of neighbours. The idea that 'livable streets' can foster a sense of community is not entirely new. Jacobs (1961) had already argued for urban design for communities and Johnston (1974) provided evidence of the effect of proximity on social contact. Appleyard (1980) described the elements of livable streets in his manifesto for urban design for communities. More recently, Talen (1999) discussed the social agenda of the New Urbanism movement and Bramley *et al.* (2009) investigated the effect of urban form on social sustainability. One of Grannis' contributions is to explain theoretically the various steps that must take place before a collection of geographically proximate people become a community and to develop a canonical way of analysing communities in neighbourhoods.

In concrete terms, Grannis explains that communities emerge only after higher-order relationships have developed. The latter, in turn, begin with repeated casual encounters that in the course of time evolve into relationships of trust. An important explicative aspect is the simple, yet often overlooked, observation that urban landscapes are defined to a very large extent by their transport networks. These networks act as the bloodline for motorised traffic and are essential to provide connectivity in ever-expanding regions. At the same time, this feature of the built environment may create insurmountable barriers for local social interactions. That social interactions must happen before a community can emerge is a truism. A proposition then is that they happen primarily within so-called *t*-communities, areas connected by tertiary ('trivial') streets and delimited by major roads. These are the spatial entities where communities of neighbours can more easily emerge. In addition to the built environment, demographic factors are also thought to be important. For instance, children tend to be geographically circumscribed by their environment and their presence can greatly potentiate casual encounters. Mode of transport is important too, since face-to-face encounters are presumably more difficult to achieve if residents tend to zip in and out of their neighbourhood in their private cars for work, shopping, exercising and recreation, seldom slowing down enough to see a face. The theory of *t*-communities provides a coherent account of the emergence of communities and an intuitive explanation of the role of transport networks in the process. Grannis' own empirical work in California is persuasive, but still in need of testing in different settings.

Our objective in this paper is to investigate the factors that help to explain the sense of community, the perception that residents have of communities in their neighbourhoods. We do so in the city of

Hamilton in Canada, using a specific group of interest—namely, university students. While university students are not by any means representative of the general population of the city, in our case they provide an opportunity to explore first-hand the factors that help to generate or restrict the sense of community. Use of a student sample is, however, not purely opportunistic and, in fact, is valid in and of itself as college/university towns act as host communities and grapple with essential if sometimes uneasy relationships with educational institutions and their students (for example, Russo *et al*., 2007). Analysis is based on the application of an ordered probit model to analyse respondents' perception regarding 'sense of community', with a spatial lag to account for potential correlations for respondents residing within the same *t*-communities and/or in spatial proximity. Use of advanced spatial methods positions the application at the leading edge of urban analytics (Miller, 1999; Páez and Scott, 2004; Páez, 2007). The results help us to identify which variables have the most impact on residents' sense of community within their neighbourhood and give support to the proposition that road networks act, in conjunction with other variables, to influence the sense of community in neighbourhoods. The paper thus contributes to the emerging theme of *t*-communities in particular and to a larger body of research in transport that aims to inform policies related to livable community initiatives.

Background

A large body of literature in urban transport research is concerned with the effects of the physical (or the built) environment on travel behaviour (for example, Handy *et al*., 2005; Bhat *et al*., 2009). More recently, it has been noted as well that the social environment can have an important influence on travel behaviour. For instance, McDonald (2007) finds that measures of neighbourhood cohesion and trust, derived from attitudinal responses to statements such as 'people in this neighbourhood can be trusted', influence the decision of children to walk to school. Páez and Whalen (2010) find that enjoyment of active transport by university students is influenced by the perception of travel as a social activity (i.e. dislike of travelling alone) and sense of community in the neighbourhood. An emerging interest, which provides a counterpoint to previous research that investigates the effect of the social environment on travel, is the potential ways in which transport more generally can influence the social environment.

The research reported in this paper is inspired by the sociological work on 'trivial streets' and *t*-communities (Grannis, 1998, 2009). The relevant theory provides clear and testable hypotheses of the relationships between the built environment and the emergence of communities in neighbourhoods. According to the theory, communities are formed from a hierarchy of neighbour relations of different qualities. These relationships develop in a natural sequential order, from original passive, mostly casual encounters, and on to form higher-order neighbour relations built on the willingness to interact and form trusting relationships. The greater proportion of higher-order neighbour relations there are within a neighbourhood, the greater chance exists that residents will develop a sense of community. A pre-condition to higher-order neighbour relationships—those conducive to the formation of communities—is geographical proximity, as residents living in the same geographical area become familiar—i.e. able to identify each other. Geographical proximity alone, however, is not sufficient and a key element is the presence of physical barriers, especially major streets that may hinder the first stage in the sequence by making casual encounters between individuals on opposite sides of the obstruction less likely. The concept is proposed of *t*-communities, defined as discrete segments of the urban environment that fully encompass all elements of the tertiary road network that are bounded by major streets or other obstacles.

In addition to the features of the built environment, Grannis (2009) identifies other factors that facilitate the formation of communities. These include the presence of children (see Tonucci and Rissotto, 2001) and the use of active transport modes (see du Toit *et al.*, 2007; and Wood *et al.*, 2010). Other research provides valuable insights into the factors that may affect the social environment in neighbourhoods. For instance, Talen (2010) has investigated the strength and sustainability of diverse neighbourhoods with a focus on four factors including the following: social bonds and connections to the neighbourhood; and strengths and weaknesses of the neighbourhood/community. The results provide evidence that the existence of neighbourhood social networks and built environment characteristics such as parks helps to foster strong and sustainable communities, where residents have a positive perception and sense of place. Baum *et al.* also find that

> net of the other variables, individuals with higher scores on the social contacts variable have an increased likelihood of being 'satisfied' rather than 'less than satisfied' with their neighborhood (Baum *et al.*, 2010, p. 475).

And that

> regarding perceptions of neighborhood conditions, individuals who reported that neighbors helped each other were much more likely to report satisfaction with their neighborhood (p. 475).

Social factors of residents' views and perceptions of their neighbourhood are shown to influence residents' perception and satisfaction with their community. Furthermore, and providing support for Grannis' ideas that children help to create a sense of community in a neighbourhood, Nordstrom (2010) investigates the child's perspective of what makes a 'livable community' by asking 12-year-old adolescents 'What is a city like which is friendly to children? Please write down what you find to be a child-friendly city'. The results indicate that children wanted safety and security as well as more parks to play in, places to walk and bike and low traffic speeds. The children's responses in Nordstrom's study relate to the neighbourhood and built environment factors of their community as well as those aspects that would contribute to a more 'friendly' place to live.

In what follows, and informed by this research, we consider the factors that influence the way sense of community is perceived by individuals in neighbourhoods. In addition to individual attitudes and attributes, we concentrate on various aspects of the built environment, with a particular focus on *t*-communities and the social, economic and demographic characteristics of the neighbourhood. The case study is described next.

Data

Study Context and Data Sources

The study is based on a sample of university students enrolled in McMaster University during the winter of 2008. McMaster University is located in Hamilton, in the Canadian province of Ontario, and is a land-locked urban campus with a total student population of approximately 23 000 at the time of the study. The university is a partner of the Campus Town Association, an incorporated group that includes business-owners' and residents' interests. This association states as its objective to improve community relationships and to make the area around campus one of the most livable near-campus communities in the region.[1] The university has recently made commitments to sustainability targets and has created an Office of Sustainability that seeks to promote a culture of sustainability at the university that includes not only the environmental, but the economic and social dimensions as well. To support the activities and initiatives of the Office of Sustainability, a student travel behaviour survey was conducted between the months of February and March of 2008 that asked questions about travel choices, demographic attributes and various attitudes towards travel, including opinions about the environment, taxation to support transit and various social aspects of transport such as travelling alone, living in a safe neighbourhood and feelings towards being exposed to strangers when travelling by transit.

The student survey provides a rich source of attitudinal and individual information about respondents. In addition, we are interested in neighbourhood socioeconomic and demographic variables (obtained from the Canadian census at the level of dissemination areas, which is the smallest publicly available geography) and built environment variables (obtained from parcel-level land use inventory and road networks). The various sources of data are discussed in detail next.

Individual Data

Individual data were collected from students using an instrument inspired and informed by the original survey design of Mokhtarian *et al.* (2001). The survey was designed as a web-based instrument, which helped to keep the cost of the research low[2] and greatly facilitated the processing of the data. A concern with web-based surveys is that they may suffer from bias since they fail to reach people who lack access to computers or the Internet. In our case, the instrument was appropriate because the target population was the student body in an institution of higher education where all students are familiar with computer technology and have access to computing equipment in campus, and where most own personal computers. The invitation to participate in the survey was sent electronically by e-mail to all students in a database provided by the university that included all students registered for the academic term in 2008. The response rate was 22 per cent which is within the range of common rates in transport research (Larson and Poist, 2004).

The survey asked respondents about their basic socio-demographic information, including age and gender, programme and level of studies, and employment status. With respect to living arrangements, students were asked if their place of residence during the academic term was with their family, in a university residence or in other shared or solo accommodation outside campus. Observations were geo-referenced using a variety of methods, including postal code conversion and/or nearest intersection. The majority of respondents were determined to be local, but there were some commuters from the Greater Toronto area and the Niagara region as well. We cleaned the database to remove students who lived in university residences, since these residences are within the campus boundaries and are physically isolated from the surrounding neighbourhoods. We also removed incomplete surveys and nonsensical responses. Finally, we extracted the respondents living within the Hamilton region, to obtain a total of $n = 1230$ useable records. This number of responses is very similar to that reported in Redmond and Mokhtarian (2001). The value is well within standards for sampling errors of less than 3 per cent and represents slightly better than a 5 per cent sample of the student population in our case study.

A detailed discussion of the data collection approach can be found in Páez and Whalen (2010). A key aspect of the survey that bears commenting on is the set of questions regarding the attitudes of respondents towards travel and the environment. Information about attitudes was collected after Mokhtarian *et al.* (2001) by means of statements that respondents were asked to assess using a five-point, Likert-type scale from 'strongly disagree' to 'strongly agree'. The key variable for us is the response to the following statement: 'There is a sense of community in my neighbourhood'. This is similar to the statement 'Living in my neighbourhood gives me a sense of community' used by du Toit *et al.* (2007) and Wood *et al.* (2010), and found by Wilkinson (2007) to capture more completely the psychological sense of community with the highest communality/lowest uniqueness of all factors considered. We hypothesise that other attitudes can influence the individual's perception of the community in the neighbourhood. This includes responses to the following statements: 'I like to live in a neighbourhood where there is a lot going on', which reflects an attitude towards the range of activities available locally; 'I know my neighbours well'; and 'I like travelling alone', as an indicator of the attitude towards travel as a social activity.

In addition to asking survey respondents questions related to their travel attitudes, individual variables such as residential status, age, citizenship, year of study, employment status and presence of children and mode of transport were obtained. Our expectation is that students who live in their own house will find it more valuable to take the time to meet their neighbours and build trusting relationships, and will therefore have a greater sense of community. Students who rent, in contrast, may only be planning to live in that location for a short period of time and therefore will not be that invested or may lack the time to create those relationships. Age may have an impact on sense of community based on the findings from Baum *et al.* that

> the demographic variable of age was significantly associated with neighbourhood satisfaction. Compared with respondents aged over 64 years (reference category), those in the youngest cohort (less than 25) were only half as likely to be satisfied with their neighbourhood (Baum *et al.*, 2010, p. 473).

This provides evidence that age may also impact sense of community. Age is also found to associate positively with sense of community by du Toit *et al.* (2007).

The data include information on visa status to distinguish international students. We do not have a strong expectation regarding the effect of this variable, but it is potentially valuable to discriminate between the cultural background of Canadians and recent immigrants in Canada whose experience can be influenced by factors such as language, culture and time spent living in a neighbourhood or future plans to live elsewhere. The year of academic study of the student provides information on the minimum number of years the respondent has lived locally. In addition, it is anticipated that students attending full-time classes at McMaster will generally live in the same general area for the duration of their studies and will therefore influence the amount of time available for casual encounters to take place and relationships to form. Employment status for students is important to determine if they live, work and study locally, which will provide evidence of the amount of time spent in their neighbourhood and the investment they may have put forth in establishing themselves within their community and forming relationships.

Neighbourhood Data

In addition to individual attributes, we consider other variables that describe the profile of neighbourhoods. Canadian census data were utilised to obtain both the neighbourhood socioeconomic and demographic data. Census information at the dissemination-area level was utilised because it is the smallest unit of publicly available census geography that provides the relevant information required for the study. Grannis (2009) shows that presence of children in a neighbourhood is a propitious factor for the generation of networks of neighbours. Findings by Baum *et al*. (2010) show that demographic variables of age, household income and country of birth are all significantly associated with neighbourhood satisfaction. This provides support for neighbourhood demographic characteristics having an impact on sense of community in their neighbourhood, as it is expected that neighbourhood satisfaction and sense of community are closely correlated.

Given previous findings about the relevance of neighbourhood attributes, a number of socio-demographic variables are considered for the analysis. Four of these are of a demographic/travel nature: percentage of recent movers, percentage of immigrants, percentage of households with children and transport mode shares. It could be argued that residents in a neighbourhood with a high percentage of recent movers would have a smaller time-frame for casual encounters to have taken place with other local residents, while residents in a neighbourhood with few recent movers would have had sufficient time to have multiple casual encounters with other residents to form trusting relationships. Findings from Baum *et al*. (2010, p. 474) show support for a positive perception on their place of residence for long-term residents in that "individuals who have been long-term residents of the neighbourhood are more likely to be satisfied". A neighbourhood with a high percentage of immigrants may not have a strong sense of community because they may be new not only to the neighbourhood, but also to the culture and language. Therefore, engaging in casual conversation and building trusting relationships would be more difficult for a recent immigrant. This impact may be compounded if there are immigrants in an area from different countries in the world, as there may be more of a difference in cultural and language familiarity across such residents. On the other hand, it is quite common to find that immigrants from the same country tend to cluster together in communities, so they can band together and maintain a sense of community in an otherwise foreign land. When combined with the fact that immigrants (particularly recent ones) also are more likely to rely on non-motorised forms of transport (Tal and Handy, 2010), the result could be a higher sense of community in neighbourhoods with a high percentage of immigrants. Households with children are expected to have a positive impact on sense of community in that the presence of children will facilitate casual encounters of parents and care takers in locations such as parks and school bus stops. As mentioned by Grannis (2009), parents may begin to build trusting relationships with other parents in the neighbourhood by asking them to babysit, or pick up their child from the bus stop. Finally, the percentage of workers at the dissemination-area level that travel by different modes of transport to work was also incorporated in the model. It is assumed that areas where car or transit use is more prevalent will have less sense of community. They have to maintain a fixed time schedule to get on the bus and they usually follow a fixed walking route to go to the nearest bus stop. They do not have enough time to stop and chat for a while with neighbours. A higher share of walking to work in contrast is expected be conducive to the kind of encounters that may lead to the formation of communities.

Two other variables are of an economic nature—namely, median household income and unemployment rate in the area. The expectation is that higher levels of income provide the means to allow residents to engage in various types of social activities in and around their neighbourhood, which may increase their sense of community. Unemployment rate, defined as the percentage of individuals looking for a paying job but not having one, is expected to impact the feeling of sense of community in a negative way. It is expected that unemployed individuals are lacking an income that they desire and may be living in an undesirable neighbourhood or feeling disconnected with neighbours who may or may not be in the same financial position.

Built Environment Data

With regards to the built environment, variables such as street classification, density of intersections, sidewalks, land use mix, density of development and the presence of parks and malls are expected to influence the opportunity for casual encounters to occur. A neighbourhood with many higher-order street networks and higher-order intersections with substantial traffic would be expected to have a negative impact on sense of community because these characteristics may discourage walking and cycling for leisure and therefore not provide ideal opportunity for casual encounters on which to build neighbourly relationships. A greater number of activities available locally, such as malls and shops, is expected positively to impact sense of community because it would provide more opportunity to meet local vendors and neighbours, as well as encourage residents to conduct aspects of their lives locally and become familiar with their neighbourhood. Having amenities such as parks in a community would be expected to provide a destination for residents to walk and bring their children and dogs to play. In this example, the destination would provide greater opportunity for casual encounters to occur, compared with a community without a park.

These attributes are shown to affect positively the sense of community by du Toit *et al.* (2007) through the construction of a walkability index (Frank *et al.*, 2003). Here, we prefer to analyse the various aspects of the built environment separately. Data were collected from different sources. The Hamilton parcel map 2009 from the GIS Planning and Analysis Section, Planning and Economic Development Department, City of Hamilton, was used for land use information. Density of intersections, sidewalks, street classification and the presence of parks and malls were collected from the geographical file labelled "Hamilton GIS vector data 2006" provided by the GIS Services, Information Technology Services, City of Hamilton. Built environment variables were not readily available, but were extracted at the dissemination-area level from the geographical files already listed using a geographical information system. The variables are defined in a straightforward fashion and the only composite variable is land use mix, a measure of the number of different land uses within a given area. For calculating land use mix in this paper, five types of land use were considered—namely, residential, commercial, office, institutional and parks/open spaces. The values of land use mix range from 0 to 1, with values approaching 0 indicating more homogeneity in the land use mix and values closer to 1 indicating greater land use diversity.[3]

A key characteristic of the built environment in our investigation is the definition of *t*-communities, which serve to place respondents in their respective spatial context. The basic unit to build *t*-communities is the 'tertiary faceblock' which

> includes all the dwellings that front on the same segment of the same street, which has been designed and maintained by governing authorities to promote local and pedestrian traffic, situated between any two cross streets. It has only one lane on each side and no median. It does not share a right-of-way with a rail line and does not go through an underpass or tunnel (Grannis, 2009, p. 34).

Intersections are places where faceblocks terminate, but which also connect faceblocks. Intersections are tertiary if all faceblocks contiguous with them are tertiary and are non-tertiary if at least one of the faceblocks contiguous with them is non-tertiary.

These two definitions provide the building-blocks to define a *t*-community as a maximal contiguous network of tertiary faceblocks and tertiary intersections (Grannis, 2009). For the purpose of this research, we relax the requirement that *t*-communities can only extend beyond neighbourhoods if there is a connecting tertiary street. Through investigation of many common neighbourhood connections and thoroughfares, we hypothesise that connections are made between seemingly disconnected neighbourhoods, using parks, trails, pathways and private road networks, which are not defined as part of the municipal road network data. To accommodate this, street networks were dissected along major roadways to create a tertiary street network that would represent our *t*-community (see Figure 1).

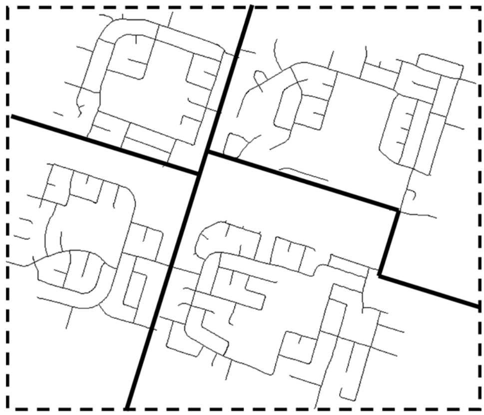

Figure 1. Examples of *t*-communities: thin lines are tertiary streets; thicker lines are boundaries between *t*-communities, frequently non-tertiary streets.

Methods

The variable of interest concerning the sense of community (i.e. different degrees of agreement or disagreement with the statement 'there is a sense of community in my neighbourhood') is both categorical and ordinal. An appropriate model for this type of variable is the ordinal probit model. In addition to the factors that influence the opinion regarding the sense of community, we are interested in the potential effect of membership in a given *t*-community. Thus, if the theory of Grannis is correct regarding the effects of the built environment on the formation of communities, we would expect that members of the same *t*-community would be more likely to have a similar opinion of their neighbourhood due to spillover effects caused by interactions. In technical terms, it is possible that the perceptions of individuals regarding their neighbourhood will be interdependent and that the level of interdependence will follow a spatial pattern conditioned by the boundaries of *t*-communities. In order to account for possible patterns of spatial dependence caused by spillovers, we use an ordinal probit model with a spatially lagged variable. The use of spatial lags is by now common in linear regression analysis of spatial data—for instance, in spatial statistics and econometrics (for example, Anselin, 1988; Griffith, 1988; Haining, 1990; LeSage and Pace, 2009). Yet it is an approach that has not found much application in the case of ordered-response categorical variables, mainly because the usual maximum likelihood estimation of spatial lag ordered-response models is infeasible except in the case of very restrictive spatial structures (more on this in the next section).

The reader will note that there is an important conceptual difference between spatial lag models and spatial error models in terms of the nature of spatial dependence modelled. In a spatial lag model, the spatial dependence is assumed to arise from direct interactions between decision agents, so that individuals are directly impacted by the underlying opinions/perspectives of their peers (Páez and Scott, 2007; Dugundji *et al.*, 2008). Thus, spatial dependence stems from both the systematic and unobserved components being inter-related due to spatial/network proximity effects. On the other hand, a spatial error model is based on the notion that any spatial dependence is a nuisance (spurious) dependence due to spatial proximity-based correlations in unobserved factors determining choice (Bhat and Sener, 2009). In the context of social interactions within *t*-communities, the more direct interaction model between individuals is appropriate. Details about the spatial lag formulation and the estimation approach we use in the current paper are described next.

Model Formulation

Let q ($q = 1, 2, \ldots, Q$) be the index to represent individuals and let k ($k = 1, 2, 3, \ldots, K$) represent the levels of the dependent variable. In the current empirical context, this dependent variable is the 'sense of community' which is defined on a $K = 5$ point scale in response to the following statement: "There is a sense of community in my neighbourhood": (1) strongly disagree, (2) disagree, (3) neutral, (4) agree and (5) strongly agree. Then, in the usual ordered-response framework, the qth individual's latent (unobserved) continuous 'sense of community' propensity variable (y_q^*) may be written as a function of a spatial lag term (to account for spatial interaction) and a $(H \times 1)$-vector of exogenous variables x_q (not including a constant) as follows:

$$y_q^* = \rho \sum_g w_{qg} y_{q'}^* + \boldsymbol{\beta}' \mathbf{x}_q + \xi_q; \xi_q \sim N(0,1), |\rho| < 1 \quad (1)$$

and

$$y_q = k \text{ if } \psi_{k-1} < y_q^* < \psi_k \quad (2)$$

where, $\boldsymbol{\beta}$ is a $(H \times 1)$-vector of coefficients to be estimated; ξ_q is a standard normal error term that is independently and identically distributed across individuals q; and ψ_k is the upper bound threshold for discrete level k ($\psi_0 < \psi_1 < \psi_2 \ldots < \psi_{K-1} < \psi_K$; $\psi_0 = -\infty, \psi_K = +\infty$).

The first term in Equation (1) represents the spatial lag term, with ρ being the spatial autoregressive coefficient and w_{qg} being a spatial weight that characterises the degree of spatial proximity between individuals q and g, with $w_{qq} = 0$ and $\sum_g w_{qg} = 1 \; \forall \; q$ (i.e., the matrix is row standardised). The propensity equation (1) may be equivalently written as

$$y_q^* = [(\mathbf{I}_Q - \rho \mathbf{W})^{-1} x\beta]_q + [(\mathbf{I}_Q - \rho \mathbf{W})^{-1} \xi]_q \quad (3)$$

where, $\mathbf{x}$ is a $Q \times H$ matrix $(x_1, x_2, \ldots x_Q)'$; $\mathbf{I_Q}$ is an identity matrix of size Q; $\mathbf{W}$ is a spatial weight matrix of size $Q \times Q$ with zero values along the diagonal and the entry w_{qg} in its qth row and the gth column; ξ is a vertically stacked vector of the ξ_q terms of size $Q \times 1$; and $[.]_q$ indicates the qth element of the column vector [.].

From equation (3), it is also straightforward to note that the $(Q \times 1) -$ vector $\mathbf{y}^* = (y_1, y_2, y_3, \ldots y_Q)'$ is distributed multivariate normal with a mean vector $\mathbf{B}\left[(\mathbf{I_Q} - \rho\mathbf{W})^{-\mathbf{1}}\mathbf{x}\boldsymbol{\beta}\right]$ and a variance matrix Σ given by:

$$\Sigma = (\mathbf{I}_Q - \rho\mathbf{W})^{-1}(\mathbf{I}_Q - \rho\mathbf{W}^{'})^{-1} \quad (4)$$

The spatial weight matrix $\mathbf{W}$ can include the effects of multiple covariates characterising spatial proximity, such as whether individuals q and g are in the same t-community, whether the two individuals are in neighbouring t-communities and the geometric distance between individuals q and g (regardless of whether the two individuals are in the same/adjoining t-community or not). This can be achieved by parameterising $\mathbf{W}$ as a finite mixture of several weight matrices: $\mathbf{W} = \sum_{r=1}^{R} \phi_r \mathbf{W}_r$, where ϕ_r is the weight on the rth covariate in determining overall spatial dependency between individuals $(\sum_{r=1}^{R} \phi_r = 1)$ and $\mathbf{W_r}$ is a measure of spatial proximity between individuals on the rth covariate. To maintain the restriction that $\sum_{r=1}^{R} \phi_r = 1$, one can parameterise ϕ_r as

$$\phi_r = \frac{e^{\lambda_r}}{\sum_{r'} e^{\lambda_{r'}}} \quad (5)$$

where, $\lambda_r (r = 1,\ 2,\ \ldots\ R-1)$ are the parameters that are actually estimated (λ_R is set to zero for normalisation). Once estimated, the estimated values of ϕ_r may be recovered from the estimated values of λ_r and the standard errors of ϕ_r may be computed from those of λ_r using the familiar delta method.

Model Estimation

The parameters to be estimated in the spatial model discussed in the previous section include the following: the ψ vector, which is a vector of all the threshold bounds $\boldsymbol{\psi} = (\psi_1, \psi_2, \cdots \psi_{K-1})'$; the β vector; the vector $\boldsymbol{\phi} = (\phi_1, \phi_2, \cdots \phi_{R-1})$; which is implicitly obtained through estimation of the $\lambda_r (r = 1,\ 2,\ \ldots\ R-1)$ parameters; and the spatial autoregressive coefficient ρ. To write the likelihood function for estimation, assume that the actual observed discrete (ordinal) level of response to the 'sense of community' question for individual q is m_q (m_q may take one of K values;—i.e., $m_q \in (1, 2, \ldots, K)$). Then, the likelihood function for the sample may be written as follows:

$$\begin{aligned} L_q(\boldsymbol{\psi}, \boldsymbol{\beta}, \boldsymbol{\phi}, \rho) &= \Pr\ (y_1 = m_1, y_2 \\ &= m_2, \ldots, y_Q = m_Q) \\ &= \int_{v_1 = \alpha_{m_1 - 1}}^{\alpha_{m_1}} \int_{v_2 = \alpha_{m_2 - 1}}^{\alpha_{m_2}} \cdots \int_{v_Q = \alpha_{m_Q - 1}}^{\alpha_{m_Q}} \\ & f_Q(v_1, v_2, \ldots, v_Q | \textstyle\sum) dv_1 dv_2 \ldots dv_Q \end{aligned} \quad (6)$$

where, $\alpha_{m_q} = (\psi_{m_q} - [B]_q)$; and where f_Q is the standard multivariate normal density function of dimension Q.

In the general case, the likelihood function involves a Q-dimensional integral, unless restrictive assumptions are pre-imposed on the model structure, such as assuming *a priori* that there is spatial interaction only within t-communities and no spatial interaction whatsoever among individuals residing in different t-communities. Such cluster assumptions simplify the likelihood function, but are also rather unrealistic to impose *a priori*. In fact, in the empirical analysis in the current paper, the results indicate statistically significant global spatial dependence that is based on spatial proximity of individuals, regardless of *t*-community membership (in addition to a strong *t*-community based spatial dependence). However, accommodating such global spatial dependence leads to a situation where traditional simulated maximum likelihood estimation methods become infeasible even for moderate values of Q. In the current empirical context, the likelihood function of equation (6) entails a 1230-dimensional integral, which is well beyond the ability of accurate approximation within a practically feasible period of time for computer-intensive simulation techniques in an iterative maximum likelihood estimation context.

In this paper, we use an alternate composite marginal likelihood (CML) estimation approach proposed by Bhat and colleagues for discrete choice model estimation (see Bhat *et al.*, 2010; Bhat, 2010). The CML method, which belongs to the more general class of composite likelihood function approaches (see Lindsay, 1988), is based on forming a surrogate likelihood function that compounds easy-to-compute, lower-dimensional, marginal likelihoods. For spatial data, one can, for example, use the pairwise likelihood function formed by the product of the likelihood contributions of all pairs (or couplets) of individuals. Alternatively, the analyst can also consider larger subsets of observations, such as triplets or quadruplets or even higher-dimensional subsets. In general, the issue of whether to use pairwise likelihoods or higher-dimensional likelihoods remains an open, and under-researched, area of research. However, it is generally agreed that the pairwise approach is a good balance between statistical and computation efficiency (see Bhat and Sidharthan, 2010; and Paleti and Bhat, 2010, for recent empirical assessments of the performance of the pairwise approach).

In the spatial lag model context of the current paper, the pairwise likelihood function takes the following form:

$$L_{PL}(\boldsymbol{\psi}, \boldsymbol{\beta}, \boldsymbol{\phi}, \rho) = \prod_{q=1}^{Q-1} \prod_{g=q+1}^{Q} \left[\Pr\left(y_q = m_q, y_g = m_g\right)\right] \tag{7}$$

Since the joint distribution of the latent variables $\mathbf{y}^* = (y_1^*, y_2^*, \ldots y_Q^*)$ is multivariate normal $y^* \sim MVN(\mathbf{B}, \Sigma)$, the above pairwise likelihood function only contains bivariate cumulative standard normal distribution function evaluations as follows:

$$L_{PL}(\boldsymbol{\psi}, \boldsymbol{\beta}, \boldsymbol{\phi}, \rho) = \prod_{q=1}^{\mathbf{Q}-1} \prod_{g=q+1}^{\mathbf{Q}} \left[\begin{array}{l}\Phi_2(\delta_{m_q}, \delta_{m_g}, \tilde{\rho}_{qg}) - \Phi_2(\delta_{m_q}, \delta_{m_g-1}, \tilde{\rho}_{qg}) \\ -\Phi_2(\delta_{m_q-1}, \delta_{m_g}, \tilde{\rho}_{qg}) + \Phi_2(\delta_{m_q-1}, \delta_{m_g-1}, \tilde{\rho}_{qg})\end{array}\right] \tag{8}$$

where

$$\delta_{m_q} = \frac{\psi_{m_q} - [B]_q}{\sqrt{Var\left(y_q^*\right)}}$$

and

$$\tilde{\rho}_{qg} = \frac{Cov\left(y_q^*, y_g^*\right)}{\sqrt{Var\left(y_q^*\right)}\sqrt{Var\left(y_q^*\right)}}$$

In this expression, $Var(y_q^*)$, $Var(y_g^*)$ and $\tilde{\rho}_{qg}$ are obtained by selecting the appropriate (2×2) sub-matrix of the covariance matrix of $(y_1^*, y_2^*, \ldots y_Q^*)$ given in expression (4).

The pairwise likelihood estimator $\hat{\boldsymbol{\theta}} = (\boldsymbol{\psi}', \boldsymbol{\beta}', \boldsymbol{\phi}', \rho)'$ obtained by maximising the logarithm of the function in equation (8) is consistent and asymptotically normally distributed with the asymptotic variance matrix vector given by the inverse of Godambe's (1960) sandwich information matrix

$$V(\theta) = [G(\theta)]^{-1} = [H(\theta)]^{-1} J(\theta) [H(\theta)]^{-1} \quad (9)$$

where

$$H(\theta) = E\left[\frac{-\partial^2 \log L_{PL}(\theta)}{\partial\theta\, \partial\theta'}\right]$$

and

$$J(\theta) = E\left[\left(\frac{\partial \log L_{PL}(\theta)}{\partial\theta}\right)\left(\frac{\partial \log L_{PL}(\theta)}{\partial\theta'}\right)\right]$$

These matrices can be estimated at the CML estimate $\hat{\theta}$ in the sample as follows

$$\hat{H}(\hat{\theta}) = \left[\frac{-\partial^2 \log L_{PL}|\theta}{\partial\theta\, \partial\theta'}\right]_{\hat{\theta}} = -\left[\sum_{q=1}^{Q-1} \sum_{g=q+1}^{Q} \frac{\partial^2 \log \Pr(y_q = m_q, y_g = m_g)}{\partial\theta\, \partial\theta'}\right]_{\hat{\theta}} \quad (10)$$

and

$$\hat{J}(\hat{\theta}) = \left[\left(\frac{\partial \log L_{PL}(\theta)}{\partial\theta}\right)\left(\frac{\partial \log L_{PL}(\theta)}{\partial\theta'}\right)\right]_{\hat{\theta}} \quad (11)$$

Results and Discussion

In this study, we considered three different covariate weight matrices $\mathbf{W}_r$ to represent spatial proximity and then combined these into a composite spatial weight matrix $\mathbf{W} = \sum_{r=1}^{R=3} \phi_r \mathbf{W}_r$. The first weight matrix $\mathbf{W}_1$ corresponded to membership in *t*-communities. Since *t*-communities are mutually exclusive by definition, the value w_{qg} in the matrix was set to 1 if individuals q and g were in the same *t*-community and 0 otherwise. The second weight matrix $\mathbf{W}_2$ corresponded to the inverse of the distance on the tertiary network for members of the same *t*-community. If two individuals were in the same *t*-community, the corresponding matrix element was the inverse of the network distance between them. A distance of '0' appears for matrix elements corresponding to individuals q and g not connected through the tertiary network. The third matrix $\mathbf{W}_3$ was based on the inverse Euclidean distance matrix, where the matrix elements w_{qg} represent the inverse of the Euclidean distance between individuals q and g, irrespective of *t*-community membership. This is the most global definition of spatial proximity used in the paper. We estimated several models to explore the spatial dependence among individuals by specifying the overall weight matrix **W** as a mixture of these three matrices. However, our results indicated that a two-matrix mixture of $\mathbf{W}_1$ and $\mathbf{W}_3$ was most effective, with the second weight matrix $\mathbf{W}_2$ not contributing significantly to the overall spatial weight matrix **W**.

The first two rows of Table 1 provide the results of this two-matrix specification. The estimated value of $\phi_1 = 0.7062$ on $\mathbf{W}_1$ is highly statistically significant, with a t-statistic (with respect to zero) of 5.48. Correspondingly, the implicitly estimated value of $\phi_3 = (1 - \phi_1) = 0.2938$ on $\mathbf{W}_3$ (this estimate is not shown in Table 1, because this is derived from the estimated value of ϕ_1) is also statistically significant, with a *t*-statistic (with respect to zero) of 2.28. Further, the spatial autoregressive parameter ρ is positive and equal to 0.2858, indicating that there is a moderate level of spatial dependence among individuals in their perceptions of 'sense of community'. That is, the latent 'sense of community' perception of any individual is positively (negatively) influenced by an increase (decrease) in the corresponding perception of other individuals, with the intensity of this spatial

Table 1. Model results

Variable type	*Variable*	*Estimate*	*T-statistic*
Spatial Dependence	ϕ_1 parameter	0.7062	5.48
	ρ parameter	0.2859	3.75
Transport (individual)	Vehicle available	−0.1029	−2.84
	Use transit to commute	−0.1483	−3.41
Attitudinal (individual)	I like to live in a neighbourhood where there's a lot going on (SD)	−0.7026	−5.04
	I like to live in a neighbourhood where there's a lot going on (D)	−0.2677	−5.19
	I like to live in a neighbourhood where there's a lot going on (SA)	−0.1659	−2.59
	I know my neighbours well (SD)	−1.0531	−17.84
	I know my neighbours well (D)	−0.5022	−10.99
	I know my neighbours well (A)	0.4937	8.50
	I know my neighbours well (SA)	1.3238	10.38
	I feel safe and secure when walking in my neighbourhood (SD)	−0.5634	−3.20
	I feel safe and secure when walking in my neighbourhood (A)	0.2287	4.87
	I feel safe and secure when walking in my neighbourhood (SA)	0.4755	8.29
	Having shops and services within walking distance of my home is important to me (SA)	0.1755	4.76
	I like travelling alone (SD)	0.2610	2.33
	I like travelling alone (SA)	−0.2452	−2.18
Demographic (individual)	Female	0.1075	2.82
	Canadian	−0.2601	−4.15
Neighbourhood (DA)	Median household income	0.0270	3.80
	Percentage of population by mobility status: less than 1 year since moved to DA	1.2315	5.03
	Percentage of workers commuting by transit	−0.9128	−2.48
Built environment (DA)	Street density (km/square km)	0.0246	5.19
	Composite maximum likelihood	−1 812 774.00	
	ADCLRT statistic	2.97	
	Number of observations	1230	

influence being highest among individuals within a *t*-community, although there is an additional residual spatial interdependence effect based on geographical proximity of individuals (regardless of membership or non-membership in a *t*-community).

This is in accordance with theoretical expectations that spatial dependency effects would be strongest within *t*-communities, but there would also be a generic spatial dependency effect based on geographical proximity. Further, formal adjusted composite maximum likelihood ratio tests (ADCLRT) proposed by Pace *et al.* (2011) were undertaken to compare the one-mixture spatial ordered-response model (i.e., with only $\mathbf{W}_1$) with the simple ordered-response model, and the two-mixture spatial ordered-response model (*i.e.*, with $\mathbf{W}_1$ and $\mathbf{W}_3$) with the one-mixture spatial ordered-response model with only $\mathbf{W}_1$. The ADCLRT test statistic for the first and second comparisons turned out to be 5.24 and 2.97 respectively, both of which are higher than the critical χ^2 value of 2.70 with one degree of freedom at the 90 per cent confidence level. In summary, the estimated two-mixture spatial-ordered response model is clearly superior in data fit to the non-spatial ordered-response model, highlighting the importance of accounting for spillover effects in perceptions of 'sense of community'. In the rest of this section, we present and discuss the two-mixture spatial ordered-response model results.

Several different variables, representing individual data (including transport-related variables, attitudinal variables and demographic variables), neighbourhood data and built environment data, were considered in the analysis to explain perceptions of 'sense of community'. The final specification was based on intuitive considerations, statistical testing of alternative functional forms for variables as well as different variable specifications, and parsimony considerations in representing variable effects. The final specification included 21 explanatory variables, each statistically significant at least at the 0.05 level of significance. The threshold values (and corresponding *t*-statistics) in the final specification were as follows: threshold between the 'strongly disagree' and 'disagree' ordinal categories: −1.4606 (−8.59); threshold between the 'disagree' and 'neutral' ordinal categories: −0.1805 (−1.09); threshold between the 'neutral' and 'agree' categories: 0.8873 (5.31); and threshold between the 'agree' and 'strongly agree' categories: 2.5746 (14.88). These threshold values do not have substantive interpretations and simply serve to map the latent continuous 'sense of community' propensity into the observed observed ordinal responses.

The individual transport-related variables in the final specification include the availability of a vehicle in the individual's household and whether or not the individual used transit to commute (see Table 1 under the label 'Transport (individual)'). The coefficients on both of these variables are negative, which indicates that respondents in those situations are generally less likely to agree with the statement about sense of community. Transit users have a slightly stronger negative coefficient than those who have a vehicle available to them. Those who take, or have the option to take, a vehicle may not be as likely to employ an active mode of transport as they may opt to utilise the available vehicle. Those who take transit may not feel that their commuting trip is enjoyable, as suggested in previous research by Páez and Whalen (2010), and do not engage in casual conversations while travelling to and from transit facilities.

Thirteen individual attitudinal variables were found to be statistically significant. Twelve of these variables relate to the local environment and one relates to travel preferences of the individual. Those who strongly disagree with the variable 'I like to live in a neighbourhood where there's a lot going on' are less likely to agree that a sense of community exists in their neighbourhood. This is sensible since those who do not want to live in a busy community are probably not concerned with building relationships with neighbours and engaging in the broader community. There is a consistent pattern with responses to this question as those who disagree have a slightly weaker negative correlation to sense of community, −0.7026 versus −0.2677 (the variables are dummies and the scales of the coefficients are directly comparable). Strong agreement with wanting to live in a neighbourhood where there is a lot going on still has a negative, if weaker, coefficient of −0.1659. A possible explanation for an individual having a strong desire to live in an area where there is a lot going on but not feel that there is a sense of community may be because places that are very busy and have the hustle and bustle of city living may not be the same areas that develop a sense of community for a variety of possible reasons including noise and other disamenities.

For the attitudinal variable 'I know my neighbours well', each of the responses of strongly disagree, disagree, agree and strongly agree was statistically significant. The sign and magnitude of the coefficients for the various responses are consistent with the notion that good knowledge of the people in the neighbourhood is conducive to the development of a sense of community. In addition to this variable having the most number of significant responses in the Likert range of options, it also provides both the strongest negative and positive coefficients with the sharpest confidence intervals, indicating the strong connection between knowing one's neighbours and having a sense of community.

Respondents who are more in agreement with the statement 'I feel safe and secure when walking in my neighbourhood' are more likely to have a positive perception of sense of community, possibly because community relationships are built upon the establishment of trusting relationships between neighbours (Grannis, 2009). That is, lacking a feeling of safety and security when walking about one's neighbourhood would signify that there may not be many trusting relationships between members of the community.

Those who strongly agree with the statement 'Having shops and services within walking distance of my house is important to me' have a positive relationship to sense of community. This relationship can be understood in that those who plan to walk to amenities and engage in aspects of daily life, such as shopping, in the local vicinity will have greater opportunity for casual encounters to occur and therefore for forming neighbourly relationships and a sense of community.

The level of agreement with the statement 'I like travelling alone' is negatively associated with sense of community, suggesting that those who feel strongly about enjoying time alone are also unlikely to go out of their way to meet neighbours and engage in aspects of the local community.

Individual demographic variables of gender and citizenship are found to be statistically significant. With respect to gender, females generally have a more positive feeling of sense of community than do males. Being Canadian is negatively correlated with the statement of sense of community compared with being a non-Canadian citizen, perhaps because of immigrants clustering together to form a community outside their home country (as discussed earlier in the paper).

Three neighbourhood variables (at the dissemination-area or DA level) are found to be statistically significant. A higher median household income level in a neighbourhood is positively associated with sense of community. This finding is consistent with the finding of Baum *et al.* (2010). The 'percentage of population by mobility status: less than one year since moved to DA' variable has a strong positive correlation to sense of community. This finding is interesting in that it was anticipated that recent movers would not have had a significant amount of time to form community relationships. These findings are also inconsistent with findings from Baum *et al.* (2010). However, together with the finding regarding Canadian citizenship, this result raises the possibility that newer residents may lack other social contacts and may compensate by more actively developing new ties with their neighbours. The variable 'percentage of workers commuting by transit' shows the expected negative correlation with sense of community, which relates to the explanation provided earlier regarding individual transit users. Finally, under the built environment category, street density was found to be positive and significantly associated with sense of community. Since a vast majority of streets are tertiary, this is consistent with the theory that streets provide the public spaces required to foster a sense of community.

Summary and Conclusions

Exploring the relationship between individual, neighbourhood and built environment variables and their effect on feeling a sense of community is a promising area of research that connects with current policy interests on the role of transport to foster livable communities. In this paper, we have drawn from sociological work on *t*-communities to motivate an investigation of sense of community and its relationships to individual and neighbourhood variables. The case study indicates that students in a university town are more likely to agree that there is a sense of community in their neighbourhood when there is a confluence of various personal and environmental factors. The personal factors include basic attitudes towards social activities, cultural background and, intriguingly, gender. Availability of a car and use of transit in contrast are more likely to reduce the likelihood of feeling a sense of community. Neighbourhood characteristics include positive factors such as higher median household income and a measure of demographic dynamics (percentage of recent movers), while the importance of transit as a mode of transport in the area had a negative impact. Finally, our findings are generally supportive of the theory on *t*-communities. In particular, after controlling for a host of factors, we find that there tends to be a spatial coherence in terms of the quality of responses to sense of community. In this respect, simple proximity is a relevant, but weaker, explicative factor compared with membership in the same *t*-community.

The results of this research indicate a link that has heretofore been overlooked. In sociological research, the importance of 'trivial' streets and, in transport research, the effect of transport on the social environment. The results indicate that urban design, in particular the configuration of street networks, can have an important impact on the development of networks of neighbours that can be appropriately called communities. Given previous research indicating that the social environment in turn can also influence travel behaviour (McDonald, 2007; Páez and Whalen, 2010), this topic should be of interest to travel behaviour analysts as well. More broadly, we would suggest that our findings should be informative to policy-makers and planners if the objective is to implement initiatives to support vibrant and livable communities.

It bears noting again that the case study is limited to university students. There are no particular reasons to believe that the processes described by the theory would operate in a significantly different way for the general population. That being said, a direction for future research would be to replicate the survey and analysis in different settings. Given the means at our disposal, the next iteration of the university travel survey will be planned for faculty and staff, in addition to students. This would bring a different perspective on the issues at hand. Since questions about attitudes are not usually asked in major travel surveys, other sources of information would be required to conduct analysis. This could include new purposive more local data collection efforts for other population segments. In particular, qualitative approaches appear well suited to flesh out more completely the insights provided by this analysis.

Notes

1. See http://www.awwca.ca/about/.
2. The total budget available to conduct this survey was Canadian $1000.
3. Land use mix = $(-1)^{*}\sum[P_n{}^{*}\ln(P_n)]/\ln(N)$ where, N = the number of different land uses, P_n = the proportion of acres of the nth land use within the DA.

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