An Empirical Analysis of the Relationship between Road Development and Residential Land Development

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There has been much debate regarding the nature of the relationship between transportation and land use. Numerous studies have examined the impact of transportation on land use by studying the economic impacts of transportation investments (for examples, see: Harman 1996; Rietveld 1994; Baird and Lipton 1990; Forkenbrock and Foster 1990). Many others have examined the impact of land use on transportation by studying the impact of urban form on travel patterns (for examples, see: Kockelman 1997; McNally and Kulkarni 1997; Handy 1993). While other approaches have also been taken, the results continue to raise questions regarding the direction and strength of this relationship. Despite the plethora of research, no prior study has attempted to isolate and quantify the direction or strength of the transportation-land use relationship as this study does.

The goal of the research is to quantify the strength of both directions of the transportation-land use relationship to determine if the relationship is uni-directional or bi-directional. The objectives of this paper are two-fold. First, the paper...
examines the impact of road development on residential land development. Second, in order to test for bi-directional causality between transportation development and land development, the paper examines the impact of residential land development on road development.

The conceptual underpinnings of the first objective are based on the hypothesis that road development influences land development by changing the spatial pattern of accessibility. Changes to the road network lead to changes in accessibility. In simple terms, accessibility is the potential for interaction. Most measures define accessibility as a function of a measure of attractiveness and the transportation system. The measure of attractiveness reflects the spatial distribution of activities. The transportation system reflects the ease of travel between different locations. This ease of travel is typically measured by travel distance, time, or cost. Both the structure and capacity of the road network influence the accessibility of different locations. Thus, the construction of a new road or the widening of an existing road will increase accessibility because of the resultant changes in travel distances, times, or costs.

Increases in accessibility may then influence land development. Given the transportation and attractiveness elements of the accessibility measure, locations with high accessibility are easier to get to and more attractive as destinations relative to other locations. Theory suggests that as the ease of travel between different locations increases, the propensity for interaction increases. Because of the increased propensity for interaction, locations with higher accessibility are more attractive to land developers. Thus, changes in accessibility may affect land development.

We test two hypotheses regarding the impact of road development on land development at different scales. The first hypothesis, testing the impact at a regional scale, is that the probability a given location will be developed is greater if the accessibility of that location increases. We devise a measure to capture the effect that road development has on accessibility at all points throughout the region. The second hypothesis, testing the impact at a local scale, is that the probability that a given location will be developed is greater if it is close to a high-speed road. We use network distance to a high-speed road to measure local impacts of road development on residential land development.

The second objective of the paper is to examine the other direction of the relationship; i.e., the impact of residential land development on road development. We conceptualize this direction of the transportation-land use relationship where land development results in the establishment of trip-generating activities. When land is undeveloped, it does not generate traffic. However, when land is developed, it then has an associated land use such as residential, commercial, or industrial. These land uses do generate trips, which can affect the road network. Trip generating activities lead to increased traffic on the road network. In response to this traffic, the network may be expanded. New roads will be built or existing roads will be expanded to accommodate the increased traffic. If land development occurs in the absence of road development, there may be political pressure to build more roads. However, if the network is not expanded and the increased traffic is greater than the capacity of the network, the result is a deterioration of travel conditions due to traffic congestion.

We test a third hypothesis that land development creates trip generating activities, which affect the expansion of the road network by formulating a base model that represents the relationship between land development and road development. Specifically, we use data pertaining to the development of the road network in the calculation of an accessibility measure, while we measure land development in terms of residential land development.

The conceptual framework of this research highlights the two possible directions of the transportation-land use relationship. However, the framework gives no indication of the strength of the relationship. Does the road network have a stronger impact on land development or does land development have a stronger impact on the road network? The models offered in this paper address these questions. The results of this research have important policy implications. Given the numerous environmental impacts of both road and land development, there is an increased urgency for policy makers to make informed decisions. With a better understanding of the relationship between road development and land development, the impacts of such development may be addressed.

The Study Area

The Halifax Regional Municipality covers a 6200 square kilometre area along the southern shore of the Province of Nova Scotia. Located within the municipality are the cities of Halifax and Dartmouth, and the town of Bedford. Because Halifax serves as the provincial capital and regional service centre, the regions' unemployment rate is low at 8.6% compared to the provincial rate of 13.3%. The region experienced a 6.4% population growth rate (annual average) over the period 1971 to 1996. The region had a population of approximately 356,000 in 2000. Figure 1 provides a map of the study area showing the locations of Halifax, Dartmouth, and Bedford. The map also spatially defines an urban core and an urban development boundary (UDB), both of which we discuss later in the paper. The urban core shown in the map corresponds to the urban core defined by the 1971 Census of Canada. An urban core is a large urban area around which a CMA (Census Metropolitan Area) is delineated, which by definition must have a population of at least 100,000.

The Models

To examine the impact of road development on land development, we developed a base model from which several variations were derived. This base model is described as:

$$\Delta P = f (T, X)$$

(1)
The number of new parcels developed in grid cell \( i \) during time period \( t \), a measure of transportation development in grid cell \( i \) (accessibility or distance), a vector of other explanatory variables

We also formulated a base model to represent the impact of land development on road development. From this base model, we derived several variations. The base model is described as:

\[
\Delta A_i = f(P_i, X_i)
\]

where

\[\Delta A_i = \text{the change in accessibility in grid cell } i \text{ over time period } t\]

\[P_i = \text{a vector of land development variables in grid cell } i \text{ (aggregate, current, previous)}\]

\[X_i = \text{a vector of other explanatory variables}\]

With the specification of the base models, we now examine the data employed in the models.

**The Data Set**

**Transportation**

We collected data regarding the evolution of the arterial and collector road network from provincial transportation reports and regional planning documents for the period 1971 to 1996. Over the time period, numerous projects were completed. However, the nature and scale of the transportation projects changed. In the 1970s, the majority of the projects involved new road construction, particularly the construction of regional expressways and highways in the periphery. In the 1980s and 1990s, new road construction was much more limited and smaller in scale. The majority of the construction projects involved the widening of existing roads. For each of the projects, the year of completion is known.

Although information pertaining to the evolution of the road network is available in hardcopy for all years between 1971 and 1996, only the 1996 network was available in a digital format. The digital network file contains attribute information for every link in the network. We used speed limit data and length of link data to calculate travel times for each link in the 1996 road network.

Because the digital network file contained no information regarding link capacity, we adjusted speed limits to capture the effect of network improvements such as road widening. For example, if a highway was expanded from 2 lanes to 4 lanes in 1995, the links would be assigned 80 km in 1995 and 1996, and only 60 km in all years prior to the expansion. It is plausible that travel speeds on links are less than the posted speed limit because of congestion. Once the link is widened, travel speeds would increase. While this method of capturing the effect of road widening may not be optimal, it was the most consistent method given the available data.

Using the digital 1996 network and the road construction data obtained from the transportation reports, a digital copy of the road network was created for each year over the time period. Starting with the 1996 network, we altered the network for each year. For example, if a new road was built in 1995, the 1995 and 1996 networks would include the new road but the road was deleted from the 1994 network. For each year, every alteration (deletion of new roads and road widening) that we made to the network was carried back to the previous years. The result is that the 1971 road network has none of the 43 improvements, while the 1996 network has all of the improvements.

Given the evolution of the road network, we required a way to measure the impact of the road improvements. To accomplish this, we calculated two different measures. First, we calculated an accessibility measure to capture the regional impact of road improvements. Several studies support the use of accessibility measures in examining the transportation-land use relationship (for examples see Geurs and van Wee 2004; Suxia and Xuan Shu 2004). Second, we used the network distance from given locations to a high-speed road to capture the local impact of road improvements.

A methodological issue in examining the relationship between road development and land development is the fact that we are dealing with both line and point
features. To reconcile this, we adopted a grid cell approach. We overlaid a lattice of 1 km by 1 km grid cells on a map of the road network. Grid cells of this size are small enough that each cell captures the homogeneity of the underlying transportation, land use, and population characteristics. We used the grid cell as the spatial unit of analysis. Figure 2 illustrates this grid cell approach.

Accessibility is a function of the extent of the road network and a measure of attractiveness. We calculated a gravity-type accessibility measure as follows (Hansen 1959):

$$A_i = \sum_j \frac{w_j}{d_{ij}}$$

where:

- \(A_i\) = the accessibility of location \(i\)
- \(w_j\) = a measure of attractiveness
- \(d_{ij}\) = the distance or travel time between location \(i\) and \(j\)

Unlike other measures, this integral accessibility measure allows for the calculation of accessibility at numerous points throughout the region rather than focusing on one point such as the central business district.

We used distance or travel time to represent the friction of distance and employment density and population density as measures of attractiveness. Because the impact of road improvements is of interest, it is the change in accessibility over a time period that is required rather than the absolute value of accessibility. In order to capture only changes in the road network rather than changes in population or employment density, we held the measure of attractiveness constant when calculating the change in accessibility. For example, we computed the change in accessibility between 1991 and 1996 as follows:

$$\Delta A_{1991-1996} = \sum_j \frac{w_j}{d_{ij}^{1991}} - \sum_j \frac{w_j}{d_{ij}^{1996}}$$

Because the employment density and population density data used in the accessibility measure were obtained from census data, we calculated the change in accessibility over each of the 5 inter-censal time periods: 1971-1976, 1976-1981, 1981-1986, 1986-1991 and 1991-1996.

Figures 3a-b show the spatial pattern of accessibility in 1971 and 1996, respectively. Figure 4 shows the percent change in accessibility over the time period 1971-1996. The accessibility measure does not have an intuitive unit of measurement; it is the relative values of accessibility that are of interest. Figures 3a-b clearly illustrate that the area with the highest level of accessibility is the urban core. However, the area that experienced the greatest change in accessibility is the periphery.

The change in accessibility is employed as the dependent variable in the model that examines the impact of land development on road development. We use the change in accessibility as the dependent variable because there were no data available regarding trip generation. We hypothesize a positive relationship between the number of parcels developed in the grid cell and the change in accessibility. We expect grid cells that have greater changes in accessibility to be more
desirable for land development.

The second transportation measure is the network distance from the centroid of a grid cell to a high-speed road. We define high-speed roads as roads with speeds greater than or equal to 80 km/hr. In ArcView, we overlaid the centroids of each grid cell on the digital road network maps for the years 1971, 1976, 1981, 1986, 1991, and 1996 and calculated the network distance from each centroid to the closest high-speed road. Through time, these distances reflect improvements to the road network such as the construction of new expressways and highways, and the widening of existing highways (recall that the effect of widening was captured by changing the speed limit of links). We hypothesize a negative relationship between the distance to a high-speed road and land development. We expect grid cells that are closer to a high-speed road to be more desirable for development as they provide better access in terms of shorter travel times to other locations.

Land Development

We employ time series data on residential land parcel development in the region between 1971 and 1996 to represent land development. Each individual land parcel
of land development.

The availability of sewer and water service is an important consideration for land development. The Metropolitan Area Planning Commission established an urban development boundary (UDB) in 1976 (Figure 1). All land contained within the boundary has access to sewer/water service, while areas outside of the UDB are not part of the municipal sewer/water system and do not have such service. While the UDB has expanded since 1976, time series data pertaining to boundary expansions are not available. Thus, the 1976 urban development boundary is used for all time periods. We represent data pertaining to sewer and water service by a dummy variable. Grid cells are assigned a 1 if they are within the urban development boundary and 0 otherwise. We hypothesize a positive relationship between the sewer/water dummy variable and land development. We also hypothesize a positive relationship between the change in accessibility and the sewer/water dummy variable, again because these improvements may occur in anticipation of development.

We employ several socio-economic variables to account for demographic variations that may influence land development and reflect where developers will develop. All of the data are from the Census of Canada. Data such as average family income, average household income, medium family income, median household income, average monthly housing payment, and average household size are defined by grid cell. We hypothesize a positive relationship between all of the census variables and land development.

We also hypothesize a positive relationship between the census variables and change in accessibility. Higher income households tend to have a greater demand for transportation as they make more trips than low income households (Hanson and Schwab 1995) and may also have greater political influence. For these reasons, higher income areas tend to receive more investments than low income areas (Hodge 1995).

The Results

Impact of Road Development on Land Development

Using the base model specified earlier to represent the impact of road development on land development, we derived several variations. Because the dependent variable, the number of residential land parcels developed in a grid cell, is not a continuous variable, standard regression analysis could not be used to estimate the model. Poisson regression is commonly used for count data, but the nature of the parcel data violates the assumptions of the model. A more appropriate approach is to estimate a discrete choice model. Other studies have used a similar approach (Sanchez 2004; McDonald and McMillen 2000). For complete model specification, see the technical appendix.

Specifically, the ordered probit model is used when the dependent variable is ordinal in nature and when there are 3 or more alternative choices. To transform the land parcel data into an ordinal variable, we classified each grid cell depending on the number of parcels that were developed in the grid cell during the time period. The initial classification, Code 1, was established by creating histograms of the land parcel counts by grid cell for each time period. The frequency distributions of the number of parcels per grid cell were very similar for each time period. Given this similarity, we used the natural breaks apparent in the 1991-1996 histogram to create ranges for the classification categories. From the initial classification scheme of Code 1, we created and tested other classification schemes as outlined in Table 1.

Table 2 provides the results for the models that include the change in accessibility as the transportation measure. As the table indicates, there is consistency over time in the nature of the relationships between the dependent variable and many of the explanatory variables. The most inconsistent variable in terms of the direction of the relationship with the dependent variable is the change in accessibility measure.

For several time periods, the results indicate a negative relationship between change in accessibility and land development. The results suggest that grid cells that experience smaller changes in accessibility experience more land development. However, the change in accessibility coefficients are not significant for two of those time periods. Two other time periods show a positive and significant relationship between the change in accessibility and land parcel development. Grid cells with a larger change in accessibility experience more land parcel development.

For all time periods except the first, for which the number of parcels developed in the previous time period is unknown, there is a positive relationship between the number of parcels developed in the previous time period and land development in the current time period. These results are intuitive given the nature of land development process. Residential land development usually occurs in phases. Once development is initiated in an area, further development is likely, given the availability of developable land. Grid cells with a higher number of parcels developed in the previous time period are more attractive for future development.

A negative relationship between the amount of developable land and land parcel development is apparent for all time periods. The results suggest that grid cells with less developable land experience more land development. These results
### TABLE 2 Results of Ordered Probit Model (accessibility measure)

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<tbody>
<tr>
<td>Constant</td>
<td>-1.3710**</td>
<td>-1.0621**</td>
<td>-1.2322**</td>
<td>-1.8009**</td>
<td>-0.5307*</td>
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<tr>
<td>Change in accessibility</td>
<td>-54.0454**</td>
<td>-39.7444**</td>
<td>71.2606**</td>
<td>-142.762**</td>
<td>15.6146**</td>
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<tr>
<td># of parcels developed in previous time period</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amount of developable land</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aggregate number of parcels in cell</td>
<td>0.1037**</td>
<td>0.07502*</td>
<td>0.0787**</td>
<td>0.05137**</td>
<td>0.03264*</td>
</tr>
<tr>
<td>Aggregate number of parcels in cell squared</td>
<td>-0.00069**</td>
<td>-0.00043**</td>
<td>-0.00043**</td>
<td>-0.00023**</td>
<td>-0.00011**</td>
</tr>
<tr>
<td>Sewer/water service in cell (dummy)</td>
<td>1.20581**</td>
<td>1.02936*</td>
<td>0.79480**</td>
<td>1.22497**</td>
<td>0.87012*</td>
</tr>
<tr>
<td>Change in avg. major monthly housing payment</td>
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<tr>
<td>Change in avg. household size over time period</td>
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<td></td>
</tr>
<tr>
<td>Change in average household income</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Change in avg. major monthly housing payment</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Average household size at beginning of time period</td>
<td></td>
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<tr>
<td>Cut points</td>
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</tr>
<tr>
<td>( \lambda_1 )</td>
<td>2.20654**</td>
<td>1.24516**</td>
<td>3.59072**</td>
<td>2.02516**</td>
<td>2.10953**</td>
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<tr>
<td>( \lambda_2 )</td>
<td>3.67837**</td>
<td>1.87751**</td>
<td>4.38381**</td>
<td>3.31663**</td>
<td>3.12226**</td>
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<tr>
<td>( \lambda_3 )</td>
<td>2.18290**</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</table>

Number of observations 1144 1144 1144 1144 1144
Chi-square 806.96 741.55 881.49 740.32 612.47
Degrees of freedom 5 5 6 6 5
Log likelihood (beta) -695.58 -632.96 -571.26 -828.84 -808.44

Note: \(*=P<0.1, **=P<0.01\)

There is a positive relationship between the sewer/water dummy variable and land development. Grid cells with sewer and water service experience more land development, after controlling for other factors. The values of the sewer/water interaction terms suggest that the effect of the aggregate number of land parcels on new land development is stronger outside the UDB than inside the UDB. The results in Table 2 show other explanatory variables that have significant impacts on land development.

Table 3 provides the results for models that include the distance to a high-speed road variable. As expected, the results indicate a negative relationship between the distance to a high-speed road and land development. Grid cells that are closer to a high-speed road experience more land development. However, the distance coefficients are only significant for two time periods. The behaviour of the other explanatory variables is, in most cases, consistent with the previous models and the interpretations remain the same. However, some of the explanatory variables did drop out of the models.

### TABLE 3 Results of Ordered Probit Model (distance measure)

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<tr>
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</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-0.00244</td>
<td>-0.23244**</td>
<td>-0.41518**</td>
<td>-0.81055**</td>
<td>-0.02200</td>
</tr>
<tr>
<td>Distance to a high-speed road</td>
<td>-0.00001</td>
<td>-0.00006**</td>
<td>-0.00005</td>
<td>-0.00007**</td>
<td>-0.00003</td>
</tr>
<tr>
<td># of parcels developed in previous time period</td>
<td>-0.00832**</td>
<td>0.01819**</td>
<td>0.00388**</td>
<td>0.00702**</td>
<td></td>
</tr>
<tr>
<td>Amount of developable land</td>
<td>-0.97465**</td>
<td>-0.85745**</td>
<td>-0.88595**</td>
<td>-0.83458**</td>
<td>-0.6514**</td>
</tr>
<tr>
<td>Aggregate number of parcels in cell</td>
<td>0.01239**</td>
<td>0.01098**</td>
<td>-0.01337</td>
<td>0.00162**</td>
<td>0.00706**</td>
</tr>
<tr>
<td>Aggregate number of parcels in cell squared</td>
<td>-0.00001**</td>
<td>-0.00001**</td>
<td>-0.00001**</td>
<td>0.00003**</td>
<td>-0.00001**</td>
</tr>
<tr>
<td>Change in avg. household size</td>
<td>0.00011**</td>
<td>0.00011**</td>
<td>0.00011**</td>
<td>0.00011**</td>
<td>0.00011**</td>
</tr>
<tr>
<td>Change in avg. major monthly housing payment</td>
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<tr>
<td>Change in avg. household size at beginning of time period</td>
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<tr>
<td>Cut points</td>
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</tr>
<tr>
<td>( \lambda_1 )</td>
<td>1.56740**</td>
<td>0.95296**</td>
<td>3.02832**</td>
<td>1.39497**</td>
<td>1.8664**</td>
</tr>
<tr>
<td>( \lambda_2 )</td>
<td>2.99530**</td>
<td>1.49114**</td>
<td>3.97990**</td>
<td>2.91346**</td>
<td>2.90498**</td>
</tr>
<tr>
<td>( \lambda_3 )</td>
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</tr>
</tbody>
</table>

Number of observations 1144 1144 1144 1144 1144
Chi-square 432.92 360.33 654.94 437.63 419.41
Degrees of freedom 5 5 6 6 5
Log likelihood (constant) -1099.06 -1281.59 -1012.01 -1199.02 -1114.68
Log likelihood (beta) -882.06 -1001.42 -684.54 -980.20 -904.98

Note: \(*=P<0.1, **=P<0.01\)

The hypothesis of an inverted U-shaped effect is not supported by the results. There is a negative relationship between the distance to a high-speed road and land development.

For all time periods, there is a positive relationship between the aggregate number of parcels developed in the grid cell and land development in the current time period. Alternatively, there is a negative relationship between the aggregate number of parcels developed in the grid cell and land development in the previous time period. This counterintuitive result may be due to the nature of the amount of developable land variable. We calculated the variable by removing areas from the grid cells that were considered undevelopable. Such areas included water bodies and parks, both of which could be considered amenities. Grid cells that have less developable land may have more water bodies and parks. Such grid cells would be desirable in terms of residential land development.

For all time periods, there is a positive relationship between the sewer/water dummy variable and land development. Grid cells with sewer and water service experience more land development, after controlling for other factors. The values of the sewer/water interaction terms suggest that the effect of the aggregate number of land parcels on new land development is stronger outside the UDB than inside the UDB. The results in Table 2 show other explanatory variables that have significant impacts on land development.
Impact of Land Development on Road Development

We formulated a base model to represent the impact of land development on road development. From this base model, we derived several variations. To deal with spatial autocorrelation, we estimated a spatial lag model for each time period. For complete model specification, see the technical appendix. The results of the spatial lag model are summarized in Table 4. The most important result is the variables that are not significant. We forced the land development variables (aggregate, previous and current) into the models but the variables are not significant. The signs of the coefficients are not as expected, or the signs are inconsistent between time periods. Of particular interest is the previous land development variable. If residential land development has an impact on the change in accessibility, land parcels developed in the previous time period should be a significant variable in the model. Consider also that the aggregate number of parcels is significant but with a positive sign on the coefficient, and the amount of developable land enters the model with a negative sign on the coefficient. An examination of the sewer/water dummy variable and the location of road improvements that occurred during this time period help to explain this result.

The results for the earlier time periods suggest that grid cells located within the UDB experience the greatest change in accessibility. However, as Figure 5 illustrates, these grid cells are not necessarily located in the urban core. The UDB actually extends beyond the urban core and into the periphery. There are grid cells with sewer/water service located in the periphery. However, grid cells with the highest aggregate number of parcels are located in the core. In the early time periods, most of the road improvements were located in peripheral areas, particularly the areas lying between the UDB and the urban core. Thus, a negative relationship between the change in accessibility and the aggregate number of parcels, and a positive relationship between the change in accessibility and the sewer/water dummy variable are explained for the two earliest time periods.

The results suggest that both the time period and the location of the road improvement influence the relative impact of the change in accessibility. Given the nature of the road improvements over time (new road construction versus expansion), the relative impact over time is not consistent. With new road construction in the periphery in early time periods, the greatest relative change in accessibility is in peripheral grid cells where accessibility was initially low. Because grid cells with the highest aggregate number of parcels are located in the core, a negative relationship with the change in accessibility is apparent. As accessibility increases over time due to subsequent road improvements, the relative difference between accessibility in the core and the periphery decreases. In later time periods, road improvements consist mainly of capacity expansions to existing roads in both the core and areas directly adjacent to the core. Although accessibility is still the highest in the core, the relative difference between accessibility in the core and periphery has decreased. In the final time period, the greatest change in accessibility resulting from the capacity expansions to existing roads is to grid cells in the core and adjacent to the core. Because grid cells with the highest aggregate number of parcels are located in the core, a positive relationship is apparent.

For the first four time periods, there is a positive relationship between the sewer/water dummy variable and the change in accessibility. Even with the changing scale and location of road improvements over time, the results indicate that grid cells with sewer/water service experience greater changes in accessibility. The 1991-1996 results are interesting in that the sewer/water dummy variable drops out of the model. Consider also that the aggregate number of parcels is once again significant but with a positive sign on the coefficient, and the amount of developable land enters the model with a negative sign on the coefficient. An examination of the sewer/water dummy variable and the change in accessibility. Given the nature of the road improvements over time (new road construction versus expansion), the relative impact over time is not consistent. With new road construction in the periphery in early time periods, the greatest relative change in accessibility is in peripheral grid cells where accessibility was initially low. Because grid cells with the highest aggregate number of parcels are located in the core, a negative relationship with the change in accessibility is apparent. As accessibility increases over time due to subsequent road improvements, the relative difference between accessibility in the core and the periphery decreases. In later time periods, road improvements consist mainly of capacity expansions to existing roads in both the core and areas directly adjacent to the core. Although accessibility is still the highest in the core, the relative difference between accessibility in the core and periphery has decreased. In the final time period, the greatest change in accessibility resulting from the capacity expansions to existing roads is to grid cells in the core and adjacent to the core. Because grid cells with the highest aggregate number of parcels are located in the core, a positive relationship is apparent.

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The results for the earlier time periods suggest that grid cells located within the UDB experience the greatest change in accessibility. However, as Figure 5 illustrates, these grid cells are not necessarily located in the urban core. The UDB actually extends beyond the urban core and into the periphery. There are grid cells with sewer/water service located in the periphery. However, grid cells with the highest aggregate number of parcels are located in the core. In the early time periods, most of the road improvements were located in peripheral areas, particularly the areas lying between the UDB and the urban core. Thus, a negative relationship between the change in accessibility and the aggregate number of parcels, and a positive relationship between the change in accessibility and the sewer/water dummy variable are explained for the two earliest time periods.

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Discussion

Impact of Road Development on Land Development

A comparison of the ordered probit model results indicates inconsistencies in the behaviour of the two transportation measures. While the signs of the change in accessibility coefficient vary between time periods, the signs for the coefficients on the distance measure are consistently negative. However, the significance of the coefficients for both measures is not consistent for all time periods. Despite these inconsistencies, an interesting pattern emerges.

With the exception of 1971-1976, for time periods when the coefficients of the change in accessibility are positive and significant, the coefficients of the distance measure are not significant. Alternatively, when the coefficients of the distance measure are significant, the coefficients of the change in accessibility variable are negative and not significant. Given the nature of the transportation variables in terms of spatial scale, these results suggest that through time, the scale of the impact of road development on land development may vary.

For the time periods 1981-1986 and 1991-1996, the results indicate a significant and positive relationship between the change in accessibility and land development. These results suggest that the impact of road development on land development is at a regional scale. The coefficients of the change in accessibility are positive and significant and the distance coefficients are not significant. For the time periods 1976-1981 and 1986-1991, the results suggest that the impact of road development on land development is at a local scale. The coefficients for the distance to a high-speed road variable are significant while the coefficients for the change in accessibility are not significant.

The results for the earliest time period indicate a negative and significant relationship between the change in accessibility and land development, suggesting that grid cells with a smaller change in accessibility experience more land development. There is also a negative relationship between the distance to a high-speed road and land development but the relationship is not significant.

The results of the four most recent time periods show that road development has a significant impact on land development. However, the scale of the impact varies between time periods. A possible explanation of this variation is related to the intensity of land development. Table 5 shows the average, over five years, of the annual percent change in the number of residential land parcels. The annual number of residential land parcels developed over those time periods is significantly higher when the change in accessibility coefficient is positive. Over the period 1981-1986, the annual number of residential land parcels developed increased by 118% while over the period 1991-1996, the annual number increased by 28.4%. Alternatively, the annual number of residential land parcels developed increased only marginally between 1976-1981 and decreased between 1986-1991 when the distance to a high-speed road coefficients are significant.

This potential relationship between the type of transportation measure and intensity of annual residential land development suggests that road development has a local impact on land development when land development was less intense. Alternatively, road development has a regional impact on land development when land development was more intense. A possible explanation of these relationships is based on the spatial pattern of land development.

When land development is intense, it is more spatially extensive; that is, there are more grid cells throughout the region with a higher number of parcels being developed. Because of this spatial pattern, the change in the accessibility measure, which is regional in nature, is more effective in capturing the impact of road development on land development. However, when land development is less intense, the development is less spatially extensive and much more localized. Thus, for time periods of less intense land development, the local transportation variable - the distance to a high-speed road - is more effective in capturing the impact of road development on land development.

The effectiveness of the two transportation variables for different time periods may also be influenced by the nature of the road improvements completed in the associated time period. When the local transportation measure is effective in capturing the impact of road development on land development, the majority of the
road improvements were located in the periphery. When the regional transportation measure is effective, the majority of the road improvements were located in the core or adjacent to the core. While this pattern may seem counterintuitive, an explanation of the relative impact of the road improvements will show otherwise.

An examination of Figure 2 clearly illustrates that the road network is much more dense and well developed in the core area. In terms of accessibility, the core has a much higher level of accessibility than the periphery. When roads are improved in the periphery, a greater relative impact will be felt in peripheral locations where accessibility is lower. Although the improvement will affect locations throughout the region, the local impact will be much stronger. Because this impact is more localized, the local transportation measure is more effective in capturing the impact of road development on land development. Alternatively, when roads are improved in and around the core area, the impact will be felt on a regional scale. Because the road network is well developed in the core, the relative impact of an improvement will not be as strong. However, given the nature of the accessibility measure, a road improvement in the core will also have an impact in the periphery. This improvement will have a greater relative impact in the periphery because the accessibility is lower compared to the core. Thus, the regional transportation measure is more effective when the road improvements are in the core area.

Given all of these possible relationships (spatial scale of the transportation measure, intensity of land development, location of road improvements), is there a direct relationship between road development and residential land development? The data suggest that when road development is directed to the periphery, land development is less intense. On the other hand, when road development is directed to the core, land development is more intense. Table 6 shows the percent of residential parcels developed in the core and the periphery for each time period. While the majority of the parcels are developed in the periphery, in those time periods when road improvements were directed to the core, the percent of land parcels developed in the core did increase slightly.

More important however, is the effectiveness of the models in capturing the impact at both a local and a regional scale, for different locations of road development, and for different intensities of land development. When land development is intense and road development occurs in the core, the change in accessibility measure captures the impact of road development on land development. When land development is less intense and road development occurs in the periphery, the distance to a high-speed road variable is more effective. For every time period, with the exception of the earliest, the results indicate that road development does influence residential land development.

### Impact of Land Development on Road Development

The objective of the spatial lag model is to quantify the impact of residential land development on road development. If land development does drive road development, it follows that a significant relationship should exist between the change in accessibility and the land development variables, particularly the number of parcels developed in previous time period. As the results indicate, this relationship is not apparent.

The change in accessibility does not appear to be a function of actual land development. There is no significant relationship in any time period between the change in accessibility and the number of residential land parcels developed in the previous time period or current time period. Three of the time periods do have a significant land development variable in terms of the aggregate number of parcels but the direction of the relationship is not consistent. Given the negative relationship between the aggregate number of parcels and the change in accessibility in the early time periods, road improvements were not occurring in areas of existing developed land. Given the nature of the planning process, the possibility exists that road development is occurring in anticipation of land development.

Given the absence and inconsistency of the various land development variables, the results do not support the hypothesis that residential land development drives road development. However, the inclusion and significance of the sewer/water dummy variable suggests that road development may actually lead residential land development. The availability of sewer and water service as captured by the dummy variable represents the potential or conditions for development. The results indicate a positive relationship between the change in accessibility and sewer/water service. Grid cells with the potential or conditions for land development experience the greatest change in accessibility. This suggests that road development leads land development as confirmed by the results of the ordered probit model.

A possible explanation of the absence and inconsistency of the various land development variables in the models is the possibility that road improvements are occurring in anticipation of residential land development that is expected to occur in the future. Because the planning process can take time, there may be a lag between the date of planning approval and actual land development. However, it is important to note that approval does not necessarily imply development; projects may be approved but for whatever reason, development does not occur. The model in this paper tests the hypothesis that road development is influenced by contemporaneous or lagged residential land development. Although we do not have data pertaining to dates of planning approvals, we believe that data on land parcels better represents land development given the fact that approval does not imply development.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Core</th>
<th>Periphery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971-1976</td>
<td>24.5</td>
<td>75.5</td>
</tr>
<tr>
<td>1976-1981</td>
<td>25.5</td>
<td>74.7</td>
</tr>
<tr>
<td>1981-1986</td>
<td>33.4</td>
<td>66.6</td>
</tr>
<tr>
<td>1986-1991</td>
<td>27.5</td>
<td>72.5</td>
</tr>
<tr>
<td>1991-1996</td>
<td>28.2</td>
<td>71.8</td>
</tr>
</tbody>
</table>
Implications

Collectively, the results of the models provide extremely important insight into the transportation-land use relationship. Numerous studies have examined this relationship but the results have been inconclusive. However, no prior study has examined both directions of the transportation-land use relationship by examining the spatial pattern of development as this one has. By quantifying both directions of the transportation-land use relationship, the results of this study fill an important gap in the literature. The results support the hypothesis that in the case of the Halifax-Dartmouth region, road development has an impact on residential land development, but not the hypothesis that residential land development has an impact of road development. Moreover, the results suggest that road development leads land development.

More important are the policy implications of the research. Many governments invest in transportation infrastructure to address a variety of concerns. Some governments use transportation investments as a method to stimulate economic activity, while others use investments to deal with traffic congestion problems. Such investments may have little success without fully understanding the relationship between transportation and land use.

The continued expansion of road networks has several ramifications. Wegener (1986) argues that the location and capacity of transportation infrastructure have very long-term implications with respect to urban form. The literature suggests that the expansion of transportation infrastructure contributes to the decentralization of urban areas (Ding 2004; Muller 1986; Adams 1970). Decentralized development encourages travel by private automobile. Because of the increased dependency on automobiles, many urban areas are facing severe traffic congestion problems. A common response to these problems is new road construction or capacity expansions.

Environmental implications of automobile dependence and decentralization include increased energy consumption and air emissions. Miller and Ibrahim (1998) note that energy consumed by the transportation sector depends directly on the level and spatial distribution of activities within the urban area. Thus, understanding the relationship between transportation and land use is imperative. Because the spatial distribution of activities has become more dispersed, the total number of vehicle kilometres traveled is increasing (Miller and Ibrahim 1998). Increased energy use and vehicle kilometres traveled translates into increased air emissions. Highway vehicles account for nearly three-quarters of total transportation energy use and are the largest source of transport related pollutants for nearly every type of pollutant (Transportation Research Board 1995).

Understanding the transportation-land use relationship is essential for effective policy formulation. This research provides important insight by quantifying the strength of both directions of the relationship. The results provide much stronger evidence that road development has an impact on residential land development than residential land development has on road development. Thus, policies related to the provision of transportation infrastructure may be more effective in dealing with several issues currently facing urban centres.

Technical Appendix

Ordered Probit Model

Discrete choice models calculate the probability that a decision-maker will choose a particular alternative from a set of alternatives. In this paper, we consider the decision-maker the land developers, while the set of alternatives is the number of land parcels to develop. The land developers, modeled as a group with a common utility function, select the alternative with the highest utility. Utility is defined as follows:

$$U_n = V_n + \epsilon_n$$  \hspace{1cm} (5)

where

- $U_n = \text{total utility that decision-maker } n \text{ (land developers) derives}$
- $V_n = \text{the systematic or observed utility}$
- $\epsilon_n = \text{a random component}$

The observed utility, $V_n$, is defined as a linear function of attributes that influence the choice decision:

$$V_n = \beta X_n$$  \hspace{1cm} (6)

where

- $\beta = \text{a vector of parameters associated with the explanatory variables}$
- $X_n = \text{a vector of explanatory variables}$

In terms of examining the impact of road development on land development, we used an ordered response model. In general terms, the ordered response model estimates the probability that a given number of land parcels, $j$, are developed in a grid cell. The utility of choosing a certain number of parcels is assumed to be a linear function of the explanatory variables that are related to each grid cell.

The ordered response model assumes local utility maximization as opposed to global utility maximization. Global utility maximization occurs when all alternatives in the choice set are considered simultaneously. Local utility maximization reflects a choice situation where each binary decision consists of whether to accept the current value or “take one more” (Ben Akiva and Lerman, 1985). For example, the land developers must decide whether to develop zero parcels or to develop the number of parcels in the next range. The decision to “take one more” is based on the definition of several “cut points” that represent each of the possible outcomes, $0, 1, 2, 3...j$. These cut points, $\lambda_i$, are defined such that no parcels will be developed in a given grid cell if $U < \lambda_i$, or:

$$P_{n0} = Pr(\beta X_n + \epsilon_n \leq \lambda_i)$$  \hspace{1cm} (7)
where

\( P_{00} \) is the probability of zero parcels being developed.

The probability of one or more parcels being developed in a grid cell is defined as the probability that \( U_i > \lambda_1 \), but less than a second cut point \( \lambda_2 \), or:

\[
\text{In general,} \\
P_{ni} = \text{Pr}(\lambda_i < \beta X_n + \epsilon_n \leq \lambda_{i+1}) \\
\text{for} \ j = 1, \ldots, j-1
\]

and

\[
P_{nj} = 1 - \text{Pr}(\beta X_n + \epsilon_n \leq \lambda_j)
\]

For an ordered probit model, the assumption is that the random components are normally distributed. The functional form of the distribution is as follows:

\[
P_{nj} = \Phi(\beta X_n - \lambda_j)
\]

where

\[
Z = \sum \beta X_n
\]

\( \Phi \) = standardized cumulative normal distribution (Aldrich and Nelson 1984).

Given these assumptions, the choice probabilities are as follows:

\[
P_{n0} = \Phi(\beta X_n - \lambda_1)
\]

\[
P_{n1} = \Phi(\beta X_n - \lambda_2) - \Phi(\beta X_n - \lambda_1)
\]

\[
P_{nj} = \Phi(\beta X_n - \lambda_{j+1}) - \Phi(\beta X_n - \lambda_j) \\
\text{for all} \ j = 0, 1, \ldots, J-1
\]

\[
P_{nj} = 1 - \Phi(\beta X_n - \lambda_j)
\]

Estimates of \( \beta \) and \( \lambda_1, \ldots, \lambda_J \) were obtained using Maximum Likelihood Estimation in an econometrics software package called LIMDEP. Unlike the multinomial probit, the ordered probit model does not require alternate specific parameters for each possible outcome. Because each outcome is essentially the same (i.e. number of land parcels to develop) but of a different magnitude (i.e. develop 0 parcels, 1-

50 parcels etc.), only common parameters plus cut points are estimated.

Spatial Lag Model

The spatial lag model, also referred to as a mixed regressive spatial autoregressive model, includes a spatially lagged dependent variable, \( W_{Y} \), as one of the explanatory variables. \( W \) is a spatial weights matrix based on either a rook (common boundaries) or queen (common boundaries and common corners) contiguity structure. Following the notation of Anselin (1992), the form of the spatial lag model is as follows:

\[
y = \rho W y + X \beta + \epsilon
\]

where

\( y = N \) by 1 vector of observations on the dependent variable

\( W y = N \) by 1 vector of spatial lags for the dependent variable

\( \rho = \) spatial autoregressive coefficient

\( X = N \) by \( K \) matrix of observations on the explanatory variables

\( \beta = K \) by 1 vector of regression coefficients

\( \epsilon = N \) by 1 vector of normally distributed random error terms

Anselin (1992) compares the presence of the spatial lag coefficient to the inclusion of endogenous variables on the right hand side in systems of simultaneous equations. The spatial lag model is estimated by maximum likelihood because the inclusion of the spatial lag causes OLS results to be inconsistent. Because the spatial autoregressive coefficient is unknown, it is estimated simultaneously with the regression coefficients. The inclusion of the spatially lagged dependent variable allows for the assessment of the significance of the other explanatory variables while controlling for spatial dependence.

References


Application to Travel Demand. Cambridge: MIT Press.


