Comparing Road Network Scaling Relations of Amalgamated and Non-Amalgamated Canadian Cities

By

Travis Fong

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Supervisor: Andrew Bergel

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AUTHOR: Travis Fong

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Signature of Author

This thesis is dedicated to my parents, Greg and Trudy Fong.

For your endless love, support, and wisdom.

And to our little blue dot, a miracle in the universe.

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This study compares the size of the road networks in amalgamated and non-amalgamated cities. According to Bettencourt et al., cities road networks follow a power scaling relation. Rui Yikangs model for urban development suggests that polycentric cities road networks are expected to be less efficient than monocentric cities. By arguing that amalgamated cities develop as polycentric cities, while non-amalgamated cities do not, this study attempts to test, if there is any statistically significant difference between amalgamated and non-amalgamated cities road network scaling relations. The findings of this study show that amalgamated cities road networks are larger than their non-amalgamated counterparts, suggesting links between maintenance cost, and energy use for transportation.

Definition of Terms

City – Urban cluster encompassing a population greater than 50,000.

Municipality – Incorporated administrative regional jurisdiction with powers of self governance.

Amalgamation – The combining and unification of multiple municipal bodies, including at least two cities, into a unified governing body.

Economies of Scale – Cost advantages obtained by an entity due to increasing size or scale.

Efficiency – Improvements in the ratio of useful work to resources used.

Scaling Relationship – Relationship between two variables where the dependent variable responds to a relative change in relative proportion to the dependent variable.

1. Problem

A city amalgamation is the combination of multiple administrative regions, involving two or more cities in close proximity, into a single administrative region, potentially including neighbouring non-urban areas. Municipal amalgamations were theorized to reduce the number of elected officials, and redundant agencies, while maintaining an equal level of services (Blom-Hansen, 2014). Restructuring of this nature was meant to produce cost savings, improve accountability, improve regional coordination, and increase equity. This is facilitated by the combination of the political entities which formerly governed over separate regions. The pressure to amalgamate arises as neighbouring cities become increasingly interdependent, necessitating cooperation in the provision of services rendered by neighbouring administrative entities. Amalgamation may be viewed as the dissolution of competing political entities in favour of the creation of a new, more cooperative entity. This restructuring, redefines the political and administrative processes that contribute to the fiscal and environmental sustainability of the city. For example, the distribution of water and waste services may be operated by a single, larger entity, as is the case in Edmonton and neighbouring St. Albert. As these joint arrangements become increasingly common, closely related neighbouring cities and municipalities are confronted with the question: Would these entities be a greater whole, rather than the sum of their component parts?

Could there be new opportunities in the material efficiency of the design and implementation of infrastructure such as roads, sewers, electrical cables, water supply, and telecommunications grid? Each of these infrastructure components represents a service provided by cities that may be affected by amalgamation. The material infrastructure of the city directly affects the conditions for environmental and fiscal sustainability in cities. For example, more efficiently designed, or less abundant roads will increase the per-capita population to length of the road network, offering greater incentive for cities to improve public transit; conversely more abundant roads may create a physical environment that encourages more automobile usage, and ultimately greater consumption. More efficiently designed water supply/sewer systems may open up financial resources for waste treatment. The problem, is that little has been observed of the differences in the infrastructure between amalgamated and non-amalgamated cities.

Despite numerous amalgamations, studies on the effects of amalgamations on municipal institutions is limited, and are typically directed towards the study of the financial restructuring of amalgamated municipalities' administrations relative to their non-amalgamated predecessors. Whether or not the infrastructure in amalgamated cities has large opportunities for economies of scale, and improvements to their financial and environmental sustainability has not been empirically examined (Meligrana, 2014, p. 2). However, once planning is centralized due to amalgamation, theorized improvement in regional coordination likely leads to changes in land-use and transportation planning. It is unlikely that an organization can be thoroughly centralized and retain its original behaviour. Despite this, the behaviour of these newly minted organizations has not been well examined in the context of changes to land-use and transportation planning. Where non-amalgamated cities by and large grow around a centre, an amalgamated city has been restructured, and more often than not has multiple centres.

Evaluating the differences in the physical footprint of a city following restructuring and reorganization of a political region will contribute to understanding the policy implications associated with amalgamation. Prior to amalgamation, each municipality maintained their own municipal governments, controlling local municipal development, including road network development and maintenance. The outlook of centralized development planning may be forced to differ from the more decentralized planning that existed prior to amalgamation. The addition of increased area, under a single jurisdictional unit, without the constraints of competitive administrations, suggests that following a course separate to that of a divided set of cities is an opportunity to improve the general efficiency of the road network system. Yet, research has primarily been focused on the creation of administrative efficiency (Meligrana, 2014).

Though there have been studies on the subject of amalgamation, there is considerable debate regarding the effectiveness of amalgamation in achieving economies of scale, but as already noted, this has typically been focused on administrative efficiency. This focus on administrative economies of scale ignores the possibility of economies of scale in infrastructure, despite the possibility that decreasing the fiscal burden of road networks is an avenue for amalgamated cities to improve their efficiency. Other services provided by governments would also require re-organization. It has been shown that cities share common scaling relationships for urban indicators such as energy consumption, economic activity, demographics, infrastructure, innovation, and relevantly, road network length (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). They found that infrastructure and material indicators in cities exhibit economies of scale in relation to population, that is, each additional person demands a lesser resource requirement (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). At a fundamental level then, amalgamation creates additional questions. If cities exhibit economies of scale for each individual person, then when multiple cities are combined in an amalgamation, had they already exhibited economies of scale? Perhaps cities are faced with an opportunity to retrieve those economies of scale after amalgamation, once they are freed from artificial political boundaries and competition.

This thesis will apply an existing method to compare the scaling relations between the road network size in non-amalgamated Canadian cities, and amalgamated Canadian cities. This analysis will provide quantitative evidence determining whether amalgamated cities differ in size in terms of their road networks compared to non-amalgamated cities. This thesis will apply an existing methodology for examining scaling relationships, in order to compare the differences between amalgamated and non-amalgamated cities based on the relative size per population of infrastructural services. This will help enable a quantitative debate about amalgamation and the efficiency of the provision of infrastructure related services.

2. Limitations of the Study

This study will draw on studies previously shown in "The Origin of Scaling in Cities" where cities appear to be included when they have populations greater than approximately 50,000 (Bettencourt, The Origin of Scaling in Cities, 2013b). For this reason, only cities with a population exceeding 50,000 will be included in the analysis. It is also important to define between amalgamated cities and non-amalgamated cities. For our purposes, a city will be considered non-amalgamated if it was amalgamated before 1990. Although there are 17 amalgamated Canadian cities, there are only 12 that fit these parameters. A small sample size may decrease the probability of finding a significant relationship, as well as the representativeness of the sample with the population, particularly due to the fact that the sample size of amalgamated cities is less than 30, while the sample size of non-amalgamated cities is 59.

The differences between amalgamated and non-amalgamated road network size have not been explored quantitatively, within Canada or otherwise. The results of this study will best inform the differences between Canadian cities within the context of Canadian amalgamations. The organization and jurisdiction over the expansion of road networks may not be subject to the same forces in other states, and as a consequence results of this study could prove less valid.

This study will examine these cities only at a single moment in time, and thus is observational, rather than predictive. The study will only identify the differences between amalgamated and non-amalgamated cities road network size, and thus network efficiency. It may suggest implications for policy decision making, however it will not identify whether or not those decisions are already presently being made by those administrative and planning bodies.

3. Purpose

There is a clear gap in the literature regarding the physical footprint of amalgamated and non-amalgamated cities infrastructure. The purpose of this study is to identify whether there exists a significant difference in road network size per population between amalgamated and non-amalgamated cities. A power law scaling relation allows the comparison of a wide range of road network lengths and population data.

If amalgamated cities road network size differ significantly, controlling for the growth in population, it may signal the need for a shift in the behaviour of municipal development planning. A difference in transportation network outcomes would have theoretical implications regarding jurisdictional size and built-environment factors associated with the combination of local governmental bodies. A larger road network signals greater capacity for a city to accommodate automobiles. This signals to consumers and developers to adopt more car-friendly practices. Given the high rates of consumption incurred by automobiles, the sustainability of more car-friendly regions is questionable, and cause for investigation. Identifying the need for a decrease in the rate of road network growth would suggest an avenue for developing into more sustainable cities. This would result in an increase in the number of residents per kilometre of road within the network, suggesting that density is increasing, creating more favourable conditions for public transit.

Aside from environmental considerations concerning the energy demands associated with transportation, there are fiscal considerations associated with the creation and maintenance of a large road network. Each additional kilometre of road creates long-term costs explicitly in the form of road maintenance, winter clearing, and to a large degree implicitly waste management, electric and water infrastructure. If a significant difference is identified in the size of the road networks, then these topics would be worthwhile areas for exploration.

Comparing road network scaling relations in these two city types will allow for more constructive debate. Firstly, identifying separate road network scaling relations will allow for more concrete observations about the preferences for different forms of transit, as well as differences in potential capabilities of public transit, contributing to the discussion on topics such as coverage versus rapidity. Secondly, this study will be examining amalgamated and non-amalgamated cities, which can be perceived as polycentric and monocentric city types. Allowing for observations to be made about the effects of these two patterns of growth.

4. Research Questions

The central hypothesis directing this research is that amalgamated cities will exhibit different scaling relationships with regard to the size of road networks. Thus, if amalgamated cities behave the same as all cities with regards to material infrastructure scaling relations, this establishes the basis for a null hypothesis. The research question is: Do amalgamated cities have the same power scaling relationship in their road networks as non-amalgamated cities? In this comparative analysis, the dependent variable is road network length; the independent variable is population. The two groups in this comparative analysis will be amalgamated cities and non-amalgamated cities.

Where amalgamated cities' road networks are quite literally the combined road networks of multiple smaller cities, and Bettencourt et al. (2007), found that larger cities use less material per person, amalgamated cities' road networks might appear significantly less efficient than their equivalently populated non-amalgamated counterparts. The null hypothesis is then, that the size of road networks in amalgamated cities do not differ from those in non-amalgamated cities.

5. Literature Review

Municipal amalgamations throughout Canada have contributed to a discussion regarding the appropriate size of institutions in local governance. The two poles of this discussion are defined by centralization and decentralization. The proponents of decentralization argue that smaller, more local government better addresses the needs of its citizens (Miljan & Spicer, 2015); that too expansive municipal boundaries results in government too rural to accommodate urban issues, and too urban to accommodate rural issues. Meanwhile arguments for amalgamation and centralization have stemmed from greater efficiency in government due to economies of scale, as well as economic development in a global context (Sancton, James, & Ramsay, 2000). Arguments discussing amalgamation have typically not examined land-use changes, in this case, road network expansion. This review of the literature will be divided into three parts:

i. Competing Theories Discussing Centralization vs. Decentralization
ii. Studies on the Effects of Amalgamation
iii. Road Network Expansion and the Scaling Behaviour of Cities

i. Competing Theories Discussing Centralization vs. Decentralization

Discussions surrounding centralization and decentralization began to develop following Jane Jacob's *The Death and Life of Great American Cities* (Jacobs, 1961). Although amalgamation is never discussed in Jacobs, the nature of the action is sufficiently similar to allow the discussion to be grounded in similar theory. Jane Jacobs was thoroughly against centralization. Andrew Sancton (Sancton, Jane Jacobs on the Organization of Municipal Government, 2000) addresses her position in regarding the nature of the debate surrounding amalgamation of municipalities in the context of today's increasingly dominant city-regions. Sancton (2000) asks whether the ideas posited by Jacobs in 1961 are still relevant today? For Sancton, Jacobs was concerned that the "bigness" of the city administration may disconnect it from the wants and needs of the local population. Sancton (2000) notes, "Jacobs is quite explicit in arguing that we must start by thinking of city districts as units for administration and service delivery" (p. 465). Sancton concludes by arguing that there is a lack of evidence of greater efficiency following municipal reorganization and rejects the notion that reorganization is necessary to continue to function in an economic world largely comprised of city-states (Sancton, 2000).

Luis Bettencourt furthers another discussion of Jane Jacobs "Death and Life of Great American Cities" in "The Kind of Problem a City Is", Bettencourt recounts that Jacobs was on the frontier of describing cities as complex systems, however he argues, "defining the kind of problem a city is goes well beyond a principled rejection of the urban renewal planning practices of Jane Jacob's day" (Bettencourt, 2013a, p. 2). Bettencourt points out that her observations stemmed mainly from her experience in New York's West Village in the 1950's. While this was too small a sample size, her challenge to describe the complex system that a city has endured (Bettencourt, 2013a). In this essay, Bettencourt recounts that the development of a more scientifically grounded quantitative body of empirical research now exists on the topic of cities as complex systems, and that there is a new "unified model of urbanization… supported quantitatively by an enormous body of empirical research, characterizing thousands of cities across the globe at very different levels of development" (Bettencourt, 2013a, p. 3). Bettencourt continues to argue that while the definition of a "city" varies, with each doubling of a population there is a 10-20% reduction in per capita infrastructure volume, and that "these findings apply to the *city as a whole*, conceived as mixing populations or unified labor markets" (Bettencourt, 2013a, p. 6). Under Bettencourt's predictions, infrastructure volume grows at a rate faster than that of land area. Bettencourt adds that, "In practice, this means that in larger cities infrastructure network volumes become a larger and larger part of space… Thus, planning for incommensurate changes in land and infrastructure footprints with city size is necessary to enable growth, especially of large dense cities" (Bettencourt, 2013a, p. 9).

Though Bettencourt et al., do not directly address amalgamation, this discussion of planning for changes in land and infrastructure footprints scaling with city size in order to enable growth implicates amalgamation as a potential product of this force. The evidence provided by Bettencourt (2013) show that infrastructure network volumes become an increasingly large proportion of the area under a city-region and is of particular importance to the arguments surrounding centralization and decentralization, and city growth. With this in mind, the notion that individually organized districts, as Sancton (2000) suggests Jacobs may prefer, comes into conflict with the potential for planning for increasingly large land and infrastructure footprints. Though Sancton (2000) suggests that there is no evidence to suggest that larger reorganized administrations are more capable of coping with the global economic environment, he does not address whether or not individual districts and neighboring municipalities working collaboratively will be able to overcome the demands created by the expansion of infrastructure.

ii. Studies on the Effects of Amalgamation

Analysis on economies of scale has been typically focused on financial and administrative questions. For example, Jens Blom-Hansen (2014) engaged in an analysis of the economies of scale effects for municipalities in Denmark. They found a result indicating that there are, in fact, positive returns to scale associated with the administration as you increase the size of the municipality through amalgamation (Blom-Hansen, 2014). The authors estimate that the finding that amalgamation reduced administration costs by about 10% is conservative, but Blom-Hansen warns readers not to extrapolate these findings for regions above 100,000 people (Blom-Hansen, 2014).

The Fraser Institute conducted an analysis of municipal amalgamation in Ontario and found that following amalgamation, rural residents demanded more urban services (Miljan & Spicer, Municipal Amalgamation in Ontario, 2015). Arguments hypothesizing improved economies of scale were used as a key argument for amalgamation within Ontario in Mike Harris' 1995-2002 "Common Sense Revolution" (Kusher & Siegel, 2003). The Frasier Institute, typically considered a right wing think tank, found no such returns to scale in smaller municipalities throughout Ontario (Miljan & Spicer, Municipal Amalgamation in Ontario, 2015). This report finds the opposite finding from Blom-Hansen (2014) These findings contribute to the controversial nature of the arguments for and against amalgamation.

In "Amalgamation vs. Inter-municipal cooperation: Financing and Infrastructure Services", Andrew Sancton, Rebecca James, and Rick Ramsay justify their research by arguing that there are no Canadian studies equivalent to those conducted in the United States on annexation, agglomeration, and amalgamation (2000). The focus of this paper was the provision of services through two types of agreements: Amalgamation and Inter-municipal cooperation. The authors argue that if there is significant mutual cooperation or dependence providing services, there is an argument for amalgamation; conversely, if there is a great deal of disagreement between two municipal entities, amalgamation may serve as a way to "prevent delays and extra expense caused by inter-municipal bickering" (Sancton, James, & Ramsay, 2000, p. 1). The authors consult 8 cases, 4 of amalgamation, 4 and of inter-municipal cooperation. In the case of Laval, an area composed of 14 separate municipalities, the area had some 3,000 septic tanks, and prior to amalgamation a report outlined the "need for a single authority to capture economies of scale" (Sancton, James, &

Ramsay, 2000). With regard to sewers, this provides a clear example of economies of scale used as a justification for amalgamation. By contrast, in Edmonton, the neighbouring municipalities purchase water and sewage treatment, while constructing and designing their own water and sewage infrastructure (Sancton, James, & Ramsay, 2000). In contrast to the case in Edmonton, London Ontario tripled its land-area during the amalgamation of Westminster, which had been driven to amalgamate by the need to create water and sewage infrastructure as well as a wave of municipal restructuring in Ontario (Sancton, James, & Ramsay, 2000). Excluding a brief mention in the case of St. Johns, complaints that suburban road users benefit at the expense of the urban tax base, the subject of roads is not addressed. Further, the subject of land-use planning and regional road networks are not addressed.

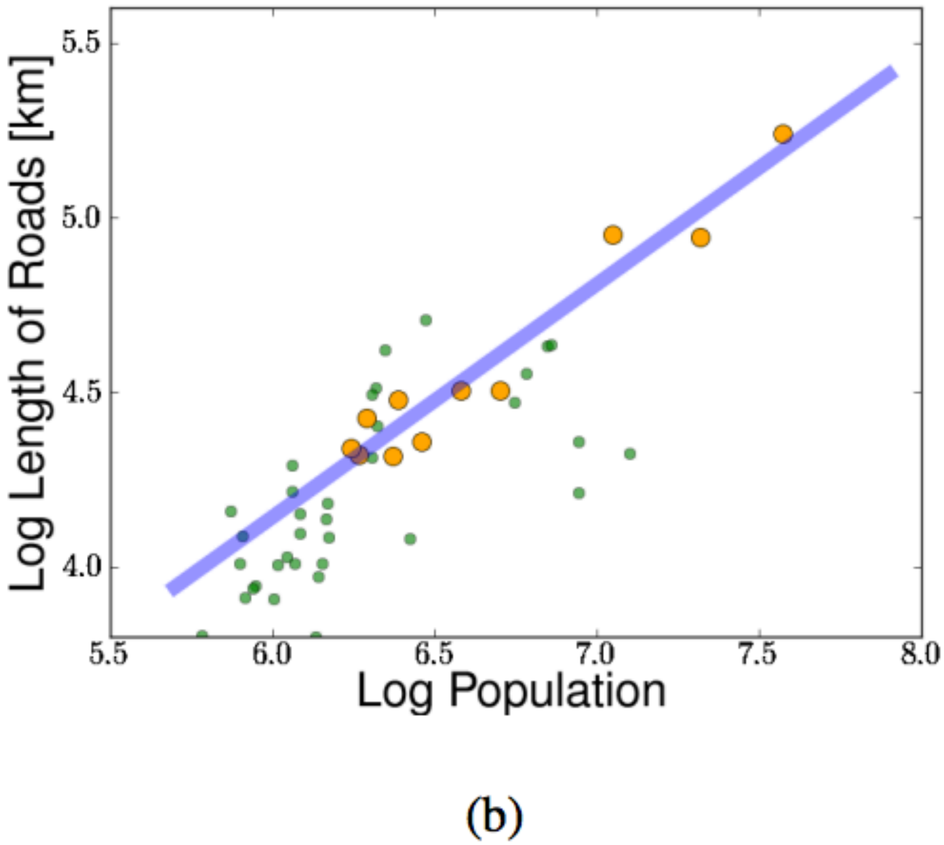
Regarding economies of scale as they pertain to roads, in an analysis of municipal amalgamation in New Zealand, authors Rouse and Putterill state, “Since road construction and maintenance are capital intensive, road maintenance management should form a good starting point for an investigation into efficiency gains and economies of scale arising from amalgamation” (Rouse & Putterill, 2005, p. 439). The authors employed a quantitative analysis of road maintenance costs and performance and found no evidence of economies of scale (Rouse & Putterill, 2005). This indicates that the expected costs of road network construction should remain relatively constant between periods before and after amalgamation. For this reason, it may be assumed that it is no more affordable to construct or maintain a road-network after amalgamation than before. Findings that show a difference in the size of road networks will consequently suggest a difference in the fiscal burden between these two city types.

Discussion of amalgamation in order to create economies of scale in sewage and water treatment suggests that economies of scale may be created through the more efficient planning and construction of infrastructure. However, the suggestion that more efficient planning and construction of the road network is possible after amalgamation is thoroughly absent in the literature. The finding that road maintenance is unaffected by administrative and technical efficiency by Rouse and Putterill (2005) suggests that the controversial debate surrounding administrative economies of scale between Blom-Hansen (2015), and authors Spicer and Miljan of the Frasier Institute (2014), will have reduced relevance regarding economies of scale being used to increase road construction. However, the idea that simply avoiding the construction of unnecessary infrastructure may derive economies of scale remains unaddressed. The discussion of "bigness" providing positive returns to scale and "smallness" creating diseconomies of scale (Rouse & Putterill, 2005; Sancton, Jane Jacobs on the Organization of Municipal Government, 2000) may be set aside for our purposes to discuss the possibility of changed governance due to "bigness" and "smallness".

iii. Road Network Expansion and the Scaling Behaviour of Cities

The Santa Fe Institute has contributed to a significant body of work on scaling relations in cities in "Growth, innovation, scaling, and the pace of life in cities" (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). The work done at the Santa Fe Institute on scaling in cities quantitatively shows that many urban infrastructure indicators display power scaling relations associated with population (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). While economic and social indicators such as average income and crime show super-linear growth (increasing per capita with population), material indicators such as road length show sub-linear growth with population, suggesting that as a city's population grows, its resource use becomes more efficient. In their analysis, Bettencourt et al. attempt to use a "definition of cities that is as much as possible devoid of arbitrary political or geographic boundaries…" (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007, p. 7302). Unfortunately, a uniformly defined set of cities with a compiled dataset does not appear readily available to Bettencourt et al., and resulted in their use of USA Metropolitan Statistical Areas, as well as European Large Urban Zones, and Japanese Prefectures across their analyses. Given the relationships, and the definition by Bettencourt et al., as well as their units of analysis, amalgamation should not change the city as a whole, and can be thought to be an independent variable. Naturally, the government must plan and approve the construction of roads. Thus, the debate between "bigness" and "smallness" of the administrative units and their land-use patterns as they govern over cities comes into view.

Figure 1 Scaling of Road Lengths in Japanese Prefectures (Bettencourt, The Origin of Scaling in Cities, 2013b)



In an analysis of road network lengths in Japan by Bettencourt et al. (Bettencourt, The Origin of Scaling in Cities, 2013b), the unit of analysis provides an additional suggestion that the scaling behaviour may already exist in amalgamated regions. Prefectures are large areas containing an urban core with close economic ties to the surrounding region and cities, similar to the form that amalgamated municipalities take. Here Bettencourt et al. found a sub-linear relationship showing that as population increased, the additional amount of road length per person declined. Within the supplementary text, Figure S1b shows a similar scaling relationship in Japan, where β = 0.67 (95% confidence interval [0.55, 0.78] R^2 = 0.94) (Bettencourt, The Origin of Scaling in Cities, 2013b).

iv. Conclusion of Literature Review

Neither The Fraser Institute (2015) nor Blom-Hansen (2014) address the land-use behaviour or responses of institutions within their analyses of amalgamation. The limitations of their studies are created by necessity, as the behaviour of the amalgamated regions cannot be simulated through time while simultaneously being amalgamated in the real world. Further, the analyses by both the Fraser Institute (2015) and Blom-Hansen (2014) surround the hypothesized financial benefits associated with the amalgamation of regions. The concern of this paper is with regards to the growth of road network length in cities.

Given the definition of city provided by Bettencourt et al. (2007) the city should not behave differently after amalgamation, thus the sub-linear scaling they proposed by Bettencourt et al may already be reflected in the road network size in both pre- and post-amalgamated cases.

Scaling behaviour, as presented by Bettencourt et al., (2007) should be present within Canadian, and North American cities. Although there can be no analysis of both amalgamated regions and their component parts through the same time period, the scaling laws provided by Bettencourt et al. the material economies of scale suggested to exist should not emerge as the new institutions begin to act within their new frameworks, given that the organizational unit has only changed on paper and is as “devoid of arbitrary political or geographical boundaries” as possible (Growth, innovation, scaling, and the pace of life in cities, 2007, p. 7302). Therefore, determining whether amalgamation has an effect on the construction of roads may be compared against a scaling behaviour that can be quantified across a given sample of cities. As previously noted, given the definition of cities by Bettencourt et al. (2007) amalgamation *should not* be associated with a change in the scaling behaviour of cities. A method exists to determine whether or not we can reject the hypothesis that amalgamated cities should not differ in terms of their scaling behaviour compared to non-amalgamated cities. Additionally, amalgamation has the dual effect of providing a natural experiment concerning polycentric and monocentric cities, and in our case can be used to view whether amalgamated cities exhibit different road network size scaling than typical cities through the analysis of road network size.

6. Methods

This paper seeks to establish whether the scaling of road network size with population in amalgamated cities differs significantly from typical non-amalgamated cities. This analysis seeks to characterize behaviour of municipal governments and their jurisdiction over roads, however it will only be able to identify whether the scaling relationship differs between amalgamated and non-amalgamated cities. Findings from Bettencourt et al. suggest that all cities exhibit scaling behaviour such as the one displayed in Figure 1 Scaling of Road Lengths in Japanese Prefectures (Bettencourt, The Origin of Scaling in Cities, 2013b). It should be recognized that transportation infrastructure differs considerably between Canada and Japan in terms of road network length, therefore a new sample must be drawn that is representative of the non-amalgamated Canadian context for the purposes of comparison. The analysis will focus on whether this scaling relationship differs between the groups (amalgamated cities, non-amalgamated cities).

7. Data Collection Procedure

Data will be drawn from a total of 71 Canadian cities according to limitations described in section 2, and the data will be composed of two groups, amalgamated and non-amalgamated: A non-probabilistic sample will draw from 12 amalgamated Canadian, while a simple random sample will draw the remaining 59 non-amalgamated cities.

First, the road network data was retrieved using data from GeoGratis' National Road Network data, and isolated using Statistics Canada Census Subdivisions using Esri's Geographic Information Systems (GIS). Using GIS, the road network length of each census subdivision was measured. Population data was drawn from Statistics Canada Census Subdivisions. For simplicity, large informally defined metropolitan areas like the Greater Toronto Area were divided into their component cities under the Census Subdivisions recorded by Statistics Canada. This division is relevant due to the nature of city governments and their jurisdiction over roads, which is directly related to the question of amalgamation and its effects on institutions.

8. Data Analysis

A multiple multivariate regression was used to determine the relationship between amalgamation, population, and road network size. This research design draws on the methods used by Bettencourt et al. Both the independent and dependent variables were log transformed; as this was the method used by Bettencourt to achieve linearity in a simple linear regression (2013). Thus the equations are:

1. $Y(N) = Y_0 N^{\beta}$

As shown by Bettencourt et al.

2. $logY(N) = logY_0 + \beta logN$

The form taken by the regression line, which given a dummy variable becomes:

$$3.\quad logY(N) = logY_0 + \beta_1 logN + \beta_2 T + \varepsilon$$

Where β_2 is the dummy variable, and T is coded for amalgamation 1, and non-amalgamated 0.

Population N is the measure of city size at t, Y can denote material resources (infrastructure i.e. roads), Y_0 is a normalization constant, and exponent β reflects general dynamic rules at play across urban systems (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). The relationship used for this comparison was shown in an analysis of Japanese Prefectures, where Bettencourt et al. show a best fit to the scaling relation between population and road miles, where $\beta = 0.67 \pm 0.12$ [95% confidence interval, $R^2 = 0.94$] (Bettencourt, The Origin of Scaling in Cities, 2013b). This linear regression allows for the comparison of jurisdictions' relationships between population and road network length.

9. Results

Data was collected from 71 cities, 12 amalgamated, 59 non-amalgamated. A multiple regression analysis was conducted, examining the relationship between population and road length, it found that amalgamation is a significant predictor of road network size, with $p = 0.013$, $\beta = -0.221$ for non-amalgamated cities. In total, this analysis finds 3 significant ($p < 0.05$) relationships:

1. Amalgamation is a significant predictor of the scaling relationship between the two groups
2. There exists a sub-linear scaling relationship between population and road network size in amalgamated cities

3. There exists a sub-linear scaling relationship between population and road network size in non-amalgamated cities

Regression Statistics	
Multiple R	0.7703
R Square	0.5934
Adjusted R Square	0.5814
Standard Error	0.2476
Observations	71

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	6.0832	3.0416	49.6136	0.0000
Residual	68	4.1688	0.0613		
Total	70	10.2520			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.24486	0.43590	-0.56174	0.57614	-1.11467	0.62496
LogPopulation	0.62276	0.08573	7.26392	0.00000	0.45169	0.79384
Type	0.21999	0.08634	2.54790	0.01310	0.04770	0.39228

Our regression results indicate that amalgamated cities are less efficient than non-amalgamated cities at significance $p < 0.05$. These results indicate that amalgamated cities' road networks are larger than their non amalgamated counter parts. As expected, our results show a significant relationship between population and road length, as per the findings of Bettencourt et al. This analysis also explains a moderate to strong amount of variability within the data, with an R-squared of 0.59. Additionally, a bivariate linear regression excluding the variable categorizing type returns significance, and an $R^2 = 0.55$. The small difference between the explanatory power of a model including amalgamation versus excluding amalgamation is likely related to the fact that amalgamation is dictated by population to a limited extent.

Figure 2 Scaling of Urban Infrastructure

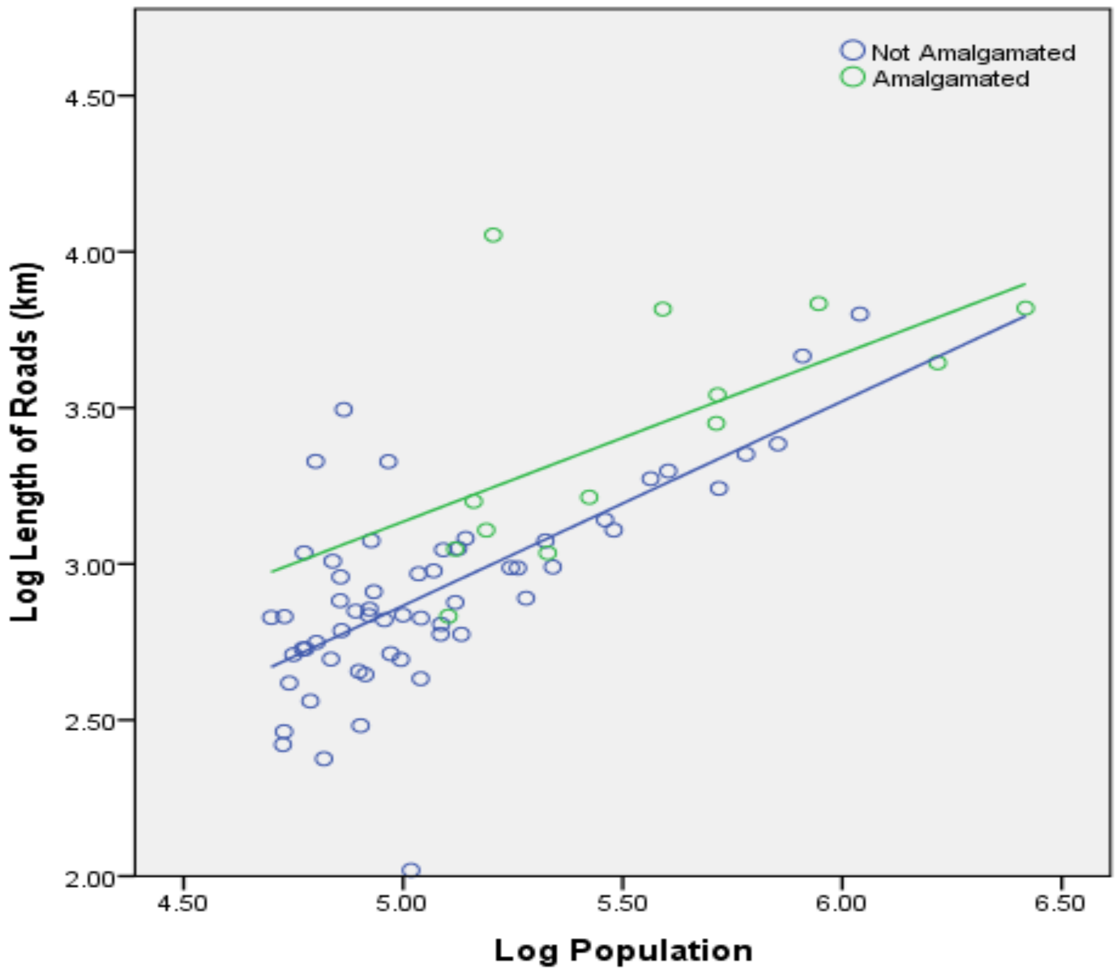


Figure 2 shows the lines of best fit in both amalgamated and non amalgamated cases. A single outlier was removed (Langley, B.C.). Both amalgamated and non-amalgamated cities show moderate to strong, significant relationships between population and road length. Our model represented by the equation:

$$logY(N) = logY_0 + \beta_1 logN + \beta_2 T + \varepsilon$$

at sig. $p < 0.05$ returns:

$$logY(N) = 0.62logN + 0.22T + \varepsilon$$

Given the results, the null hypothesis that the scaling relationship in amalgamated cities and non-amalgamated cities are the same can be rejected.

10. Discussion

This discussion will address the literature in three parts, first in relation to scaling and the factors that influence the theorized scaling exponents within the research of Bettencourt et al., as well as efficiency by Rui Yikang (Bettencourt, The Origin of Scaling in Cities, 2013b; Yikang, 2013), second in relation to the financial burden of road networks, as described by Rouse and Putterill (Rouse & Putterill, 2005), and finally a discussion of the relations and implications of these results within the context of the amalgamation debate within Canada and abroad.

The components used by Bettencourt et al, to estimate the road network size in cities suggest that the costs per person to keep populations mixing were higher as a result of land-area, and the power spent in transportation processes. This is roughly confirmed by our analysis which is centred around road network size, wherein larger road networks exist to reduce the "mixing costs" of transporting people between multiple centres. It is possible that many of these roads have been constructed in recent years, however, this analysis does not examine the time dimension of road network scaling. Further, roads are the product of growth over time, as well as relics of former development. It is possible that as smaller cities amalgamate, such that their populations appear larger, that the combined smaller (less efficient) cities appears as a significantly less efficient amalgamated city. This adds evidence to support Rui Yikang's model where polycentric cities had less efficient road networks. This analysis suggests that the more populous amalgamated cities in the sample will grow more efficiently. The cities which eventually amalgamated grew less efficiently as displayed in Figure 2 Scaling of Urban Infrastructure, amalgamated cities are expected to have considerably larger, less efficient road networks. Sancton's discussion of inter-municipal cooperation leading to amalgamation helps suggest that pressure to amalgamate intensifies as the cities grow into one another, for reasons related to the financial burden of excessive road networks, or otherwise. The cases of small amalgamated cities are also interesting, given the prediction, we can expect much larger road networks in amalgamated cities. Indeed, road networks in non-amalgamated cities of less than a million people would have to expand by more than 50% to compare to those in amalgamated cities.

Another suggested finding from this study is the difference in scaling relations in polycentric and monocentric cities. This study found separate scaling relations in material indicators in a group of polycentric cities versus monocentric cities. This suggests that other material indicators differ as well. Further, there is a possibility that non-material indicators differ due to the different structures present in these two city types. For example, Bettencourt et al., found that both crime, and per capita income scaled super-linearly as population increased (Bettencourt L. M., Lobo, Helbing, Kuhnert, & West, 2007). Is it possible that in these cases, polycentric cities behave more like smaller, lower population cities, and thus would show lower rates of crime, as well as lower incomes? Using the same methodology as here, these questions could be posed and examined.

Rouse and Putterill found that there was effectively no difference in the maintenance and construction costs of road networks in the amalgamated regions throughout New Zealand (Rouse & Putterill, 2005). The capital and labour costs do not exhibit economies of scale, and thus the only savings are in road network maintenance and construction. Blom-Hansen found these economies of scale existed in their planning and administration costs (Blom-Hansen, 2014), which ultimately is not as significant as the former costs. These findings show that the size of road networks in amalgamated cities are considerably larger than their non-amalgamated counterparts, and thus, the expected fiscal burden of maintenance is expected to be higher per capita in amalgamated cities. This fiscal burden, in the context of Bettencourt et al. (2013), is essentially the cost (in units of energy) to mix the populations in a polycentric city.

There are two key sustainability related aspects to this finding: first, from an environmental standpoint, transportation authorities should seek to reduce these energy costs, second, according to Bettencourt et al. (Bettencourt, The Kind of Problem a City Is, 2013a), from an economic standpoint, economic growth in cities occurs when the rate of population mixing increases. This analysis suggests that the transportation network growth methodologies used in monocentric cities does not necessarily apply in the same way for polycentric cities. This is a potential argument for mass transit focus on reducing the energy costs for transit between city centres. Further, mass transit oriented towards directing passengers to a single city centre may be misguided, as multiple centres have already emerged within the transportation network in amalgamated cities.

Within Canada, much of the policy debate relates to loss of identity, and the possibility that the administrative economies of scale simply put, do not exist. Financial analyses have been performed by multiple think-tank's, and there is a general lack of consensus as to whether or not there has been a positive or negative change in administration costs as a result of amalgamation. Further, much of the remaining “evidence” is simply anecdotal, and has no quantitative backing. These results do not engage in that debate, they simply provide an observation related to the road network size in amalgamated and non-amalgamated Canadian cities, and identify arguments for improvements in transit between centres, as well as an easing up on the expansion of road networks within amalgamated cities in order to negate excess maintenance costs.

This thesis has shown that there is a significant difference in the size of road networks in amalgamated and non-amalgamated cities. With supporting evidence from Rui Yikang (2013) suggesting that it is not simply inefficiency, but rather the nature of combining multiple smaller cities, as they are described by Bettencourt et al., (2013b). Given the lack of economies of scale, as shown by Rouse and Putterill (2005), the results offer insights into how amalgamated cities should move forward, and allocate their resources for sustainable urban development. This thesis has focused primarily on road network scaling, these results suggest additional relationships associated with material indicators, which may also contribute to the sustainability of a city. As amalgamated cities are polycentric, while non-amalgamated are more monocentric, in the future, the use of this framework to examine both material and human scaling relations between the two city types could open a greater frame for debate about how to construct a more optimal, and efficient urban area.

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Appendix

Table 1 Cities and Road Network Lengths (Amalgamated Cities In Bold)

	City	Total Road Network Length (KM)	Population	UTM Zone
1	Calgary (Alta.)	6313.07	1096833	11N
2	Mississauga(Ont.)	2423.77	713443	17N
3	Brampton (Ont.)	1746.1	523911	17N
4	London (Ont.)	1874.53	366151	17N
5	Windsor (Ont.)	1184.679	210891	17N
6	Oakville (Ont.)	970.43	182520	17N
7	Lévis (Que.)	1207.39	138769	19N
8	Barrie (Ont.)	594.96	135711	17N
9	Guelph (Ont.)	595.64	121688	17N
10	Kelowna (B.C.)	950.23	117312	11N
11	Saanich (B.C.)	670.53	109752	10N
12	Langley (B.C.)	104.41	104177	10N
13	Delta (B.C.)	685.5	99863	10N
14	Strathcona County (Alta.)	2126.17	92490	12N
15	Clarington (Ont.)	1186.85	84548	17N
16	Nanaimo (B.C.)	716.86	83810	10N
17	Lethbridge (Alta.)	684.45	83517	12N
18	Brossard (Que.)	452.85	79273	18N
19	Chilliwack (B.C.)	706.2	77936	10N
20	Prince George (B.C.)	908.29	71974	10N
21	Drummondville (Que.)	762.35	71852	18N
22	Moncton (N.B.)	1021.03	69074	20N
23	New Westminster (B.C.)	237.62	65976	10N
24	Granby (Que.)	560.48	63433	18N
25	Norfolk County (Ont.)	2131.51	63175	17N
26	Medicine Hat (Alta.)	535.48	60005	12N
27	Caledon (Ont.)	1086.49	59460	17N
28	Halton Hills (Ont.)	534.1	59008	17N
29	Fredericton (N.B.)	512.16	56224	19N
30	Grande Prairie (Alta.)	415.55	55032	11N
31	Edmonton (Alta.)	4634.45	812201	12N
32	Vancouver (B.C.)	2246.23	603502	10N
33	Laval (Que.)	1984.51	401553	18N
34	Markham (Ont.)	1284.53	301709	17N

35	Vaughan (Ont.)	1383.66	288301	17N
36	Kitchener (Ont.)	977.7	219153	17N
37	Richmond (B.C.)	776.72	190473	10N
38	Burlington (Ont.)	972.27	175779	17N
39	Abbotsford (B.C.)	1121.54	133497	10N
40	St. Catharines (Ont.)	753.11	131400	17N
41	Kingston (Ont.)	1110.33	123363	18N
42	Whitby (Ont.)	641.04	122022	17N
43	Ajax (Ont.)	429.08	109600	17N
44	Thunder Bay (Ont.)	930.26	108359	16N
45	Waterloo (Ont.)	494.53	98780	17N
46	Brantford (Ont.)	515.86	93650	17N
47	Red Deer (Alta.)	662.35	90564	13N
48	Kamloops (B.C.)	815	85678	10N
49	Repentigny (Que.)	442.34	82000	18N
50	Newmarket (Ont.)	303.44	79978	15N
51	Kawartha Lakes (Ont.)	3122.67	73214	17N
52	Sarnia (Ont.)	611.64	72366	17N
53	Saint-Jérôme (Que.)	495.84	68456	18N
54	St. Albert (Alta.)	363.72	61466	12N
55	North Bay (Ont.)	678.07	53651	17N
56	Blainville (Que.)	290.4	53510	18N
57	Aurora (Ont.)	263.81	53203	17N
58	Shawinigan (Que.)	673.8	50060	17N
59	**Halifax Regional Municipality (N.S.)**	**6554.88**	**390096**	**20N**
60	**Toronto (Ont.)**	**6597.6**	**2615060**	**17N**
61	**Cambridge (Ont.)**	**680.09**	**126748**	**17N**
62	**Greater Sudbury (Ont.)**	**11312**	**160274**	**17N**
63	**Hamilton (Ont.)**	**3481.12**	**519949**	**17N**
64	**Gatineau (Que.)**	**1635.77**	**265349**	**18N**
65	**Longueuil (Que.)**	**1084.05**	**213409**	**18N**
66	**Montreal (Que.)**	**4408.14**	**1649519**	**18N**
67	**Quebec City (Que.)**	**2820.73**	**516622**	**19N**
68	**Saguenay (Que.)**	**1586.54**	**144746**	**19N**
69	**Sherbrooke (Que.)**	**1283.31**	**154601**	**19N**
70	**Trois-Rivieres (Que.)**	**1115.13**	**131338**	**18N**
71	**Ottawa (Ont.)**	**6817.43**	**883391**	**18N**