Appendix 1: Methodology – Non-Technical Summary

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Incorporating Externalities in Transportation Investments

The short-term transportation infrastructure plan amounts to a subsidy to transportation users. That subsidy enables broader urban agglomeration, creating a social benefit. However, it will induce an increase in travel demand, which will result later in congestion on the new transportation infrastructure (Duranton and Turner 2011). The long-term plan of the Mayors' Council is to introduce comprehensive road pricing to address traffic congestion.

The standard approach to identifying the economic benefit of an externality is to compare the market outcome to the socially optimal outcome. The market outcome is that in which travellers only take into account their private costs and own demand. In the graphs in Figure A-1, the market outcomes are at the price P_m and the amount of travel is Q_m. When there is congestion, the optimal outcome, however, is that in which the total cost to travellers also includes the social cost of travel. In the left hand graph of Figure A-1, the optimal amount of travel is Q_{cc} and the total price is Pcc. The congestion charge amount equates the private cost with the social cost and eliminates the deadweight loss of congestion.

In the presence of a positive agglomeration externality, the optimal amount of travel is higher, at Qs and the private cost to travellers to induce them to travel that amount is P_s. The subsidy to travellers, such as building additional transportation infrastructure, to equate their private demand with social demand eliminates the deadweight loss due to a lack of agglomeration-enhancing infrastructure.

How do the positive agglomeration externality and the negative congestion externality interact? The first step of introducing a congestion charge will result in a lower amount of travel to Q_{cc}. However, using the funds to subsidize transportation infrastructure will result in an increase in demand. If the relative size of the positive agglomeration externality is the same as the negative congestion externality, the optimal amount of travel is the current amount Q_m at the current net private cost P_m. The government should subsidize transportation infrastructure in addition to having a congestion charge put back into transportation infrastructure. This framework suggests that some cross-subsidization between areas in which agglomeration and congestion externalities have different strength is welfare enhancing. See Arnott (2007) for a discussion on this.

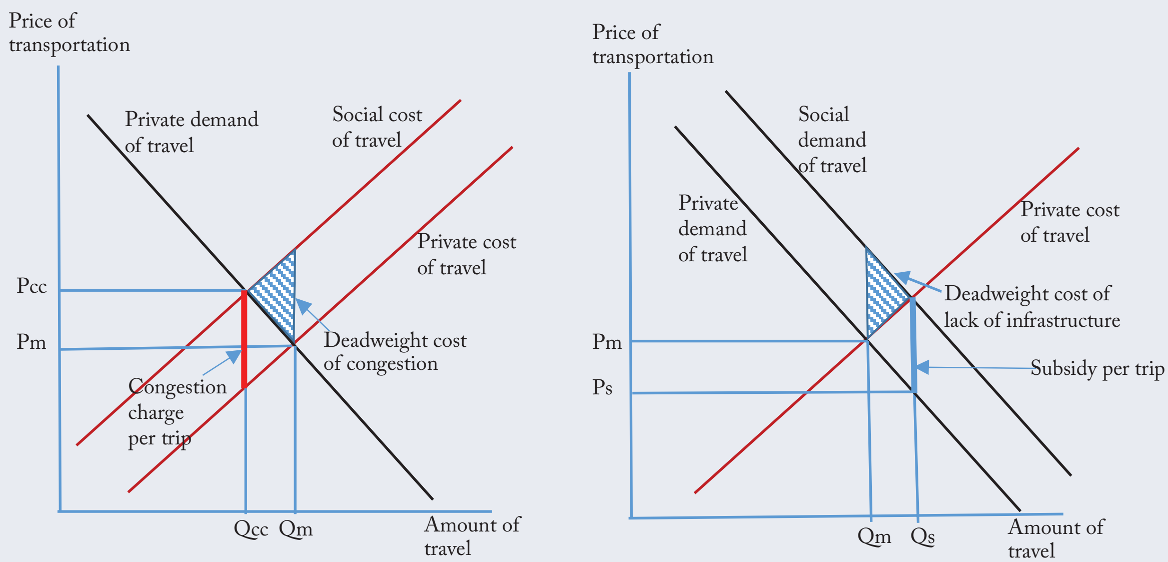
Measuring Agglomeration Externalities

I calculate the linear distances between the geographical centre points of Census Tracts (CTs) within 100 kilometres of each other. For each CT, I calculate the sum of the total number of people in the labour force over the age of 15 in all of the surrounding CTs in the surrounding 100 kilometres.[1] I conducted regressions

In this Appendix, I show first how agglomeration and congestion externalities work, and how I measure the economic costs of congestion.

1 The regressions here are an update from the 2006 Census data used in Dachis (2013).

Figure A1: Positive and Negative Transportation Externalities



Source: x

at various geographic distances. I only present two representative regressions in Table A-1 of surrounding population within 40 kilometres and 80 kilometres of a CT.

For the regressions in Table A-1, my dependent variable is the Census Tract average after-tax family income in 2010 reported from the 2011 National Household Survey. The non-mandatory National Household Survey may not be representative, especially for some CTs. However, Metro Vancouver-wide National Household Survey income statistics are close to those of taxfiler data (Hulchanski and Maaranen 2014). Both the income variable and the labour-force size are in logs, making these elasticity estimates. I add controls for the province where each Census Metropolitan Area centre is located. That controls for province-specific effects on income. I also add controls of the share of the CT's population with a college or university degree and the share of the population without a high-school degree. I calculate agglomeration benefits using total population only. However, other studies that have access to sector-specific information find that agglomeration benefits have different effects by sector (Faggio et al. 2014).

In order to test which way the causality runs, a number of studies (Ciccone and Hall 1996 and Combes et al. 2010) find that by looking at cities that are large for some historical reason – such as soil quality, which may have driven urban growth long ago, but not now – larger populations result in higher incomes, and not vice-versa. They do this using what is known as an instrumental variable technique. This deals with the potential issue in which a factor that researchers cannot control for is correlated with both urban size and incomes. After using instrumental variables to isolate a factor that determines urban size, but not incomes, these studies show that the causality predominantly runs from larger city size to higher incomes, and not vice versa.

Table A-1: Effect on Average Family Income of Increasing Labour Force Size, Census Tract Level, 2011 National Household Survey

Dependent Variable: Average Family Income ($2010)	Surrounding 40km Around Census Tract		Surrounding 80km Around Census Tract	
Total Labour Force Over 15	0.0387*** [0.00381]	0.0291*** [0.00300]	0.0379*** [0.00360]	0.0406*** [0.00306]
Controls – Effect on Income Relative to Atlantic Canada				
Quebec		-0.162*** [0.0196]		-0.194*** [0.0197]
Ontario		0.103*** [0.0180]		0.0590*** [0.0186]
Manitoba/Saskatchewan		0.0744*** [0.0227]		0.0686*** [0.0226]
Alberta		0.242*** [0.0205]		0.228*** [0.0204]
British Columbia		-0.00365 [0.0203]		-0.0268 [0.0202]
Share of Population over 15	*Population in Census Tract*			
With College or University Degree		0.562*** [0.0955]		0.596*** [0.0948]
Without High School Degree		-1.898*** [0.127]		-1.876*** [0.126]
Constant	10.75*** [0.0502]	10.87*** [0.0824]	10.75*** [0.0490]	10.71*** [0.0840]
Observations	5,263	5,263	5,266	5,266
R-squared	0.017	0.416	0.017	0.423

Notes: *** p<0.01, Standard errors in brackets. Source: Author's calculations from Statistics Canada.

The Relationship between Commuting Time and Incomes

I estimate the average commute distance in Metro Vancouver using the public use microdata file (PUMF) of the 2011 National Household Survey, which is a 1 percent sample of the observations from the larger survey that has been modified for confidentiality.[2]

2 Thanks to Mark Krass for implementing all work using the PUMF. All work in this section is joint with Mark Krass.

The NHS includes a question asking respondents to estimate the straight-line distance between their homes and their workplaces. In the PUMF, these responses are then coded into categories of 5-kilometre ranges, such as 0-5 kilometres, 5-10 kilometres, and so on. Statistics Canada top-codes responses greater than 30 kilometres into a single category. I translated these categories into actual values using two methods. In the first method, I simply assumed that every observation was on the lower bound of its category's range. So someone who reported travelling 4.7 kilometres would be recorded as travelling 0 kilometres, and someone who reported travelling 5.1 kilometres would be recorded as travelling 5 kilometres. Using this method, I estimate that the mean commuting distance for the Vancouver CMA is 7.612 kilometres, with a standard error of 0.412 kilometres. I use a mean commute of 7.6 kilometres as the existing range of surrounding job opportunities in the scenarios of estimating the lower bound of commuting distance. This estimate is in line with Statistics Canada's 2006 Census analysis of commuting, which estimated that average commuting distance in the Vancouver CMA was 7.6 in 2001 and 7.4 in 2006.[3] The Vancouver CMA has equivalent borders of the area formerly known as the Metro Vancouver Regional District, now Metro Vancouver.

In the second method, I estimated quasi-continuous values of the responses using a kernel density estimator. The kernel density produces an approximate probability that I will observe any given value between 0 and 30 kilometres. For each observation, I randomly chose a value within the observed category, with each possible value weighted according to the kernel density estimate. The second method yields a result that is significantly higher than previous Statcan estimates; the smoothed data suggest a mean commuting distance of 9.662 in the Vancouver CMA, with a standard error of 0.420 kilometres. I use this as the upper bound estimate of current commute distances.

In order to assess the effect of the Mayors' Council's investment plan on job accessibility, I use a starting point of the Mayors' Council's estimate of 2045 baseline travel speeds. TransLink provided me with these baselines for the morning peak and average peak. These base-case speeds are the travel speed commuters would have if the Mayors' Council's made no investments. TransLink also provided me with estimates of the effect of their current ten-year plan on travel times thirty years from now. The 2045 projections assume that some investment will continue to occur beyond 2025, and that transportation demand management policies will be introduced. I calculate the difference in travel time for the Mayor's Council's plan, with a range of effects between a 6.1 percent increase in travel speeds and an 8.5 percent increase in travel speeds. I calculate the increase in available jobs by first calculating the current average time that commuters are travelling given current commute times and base case travel speeds. I then calculate, assuming that people will be willing to spend the same amount of time travelling, how far they will be able to travel at this higher speed. For the purpose of creating a range of estimates, I apply the low percentage increase in commuting times to the low baseline commute distance and I apply the high commuting distance increase to the high baseline commute distance.

Lastly, I conduct regression using three measures of individual income: pretax household total income, individual employment income, and individual pretax income. The variable of interest is how much an individual's income increases, after controlling for all other controllable factors, if he commutes a certain distance. The results show that, looking at all people recorded in the NHS PUMF across Canada with employment income, people who commute longer distances have higher incomes than those who commute short distances. For example (from column 3 of Table A-2), people who commute 5 to 10 kilometres have 5.8 percent higher

3 Statistics Canada, "Commuting Patterns and Places of Work of Canadians, 2006 Census," accessed online at http://www12.statcan.ca/census-recensement/2006/as-sa/97-561/pdf/97-561-XIE2006001.pdf on 10-12-2014.

Table A-2: Effect on Incomes of Increase in Commuting Length						
Dependent Variable:	**Log Household Income**		**Log Employment Income**		**Log Individual Income**	
	National	*Vancouver CMA*	*National*	*Vancouver CMA*	*National*	*Vancouver CMA*
Relative to people with less than 5km commute	*percent increase in income*					
Commutes 5-10 km	0.070 [0.004]	0.087 [0.014]	0.058 [0.004]	0.057 [0.014]	0.051 [0.004]	0.068 [0.015]
Commutes 10-15 km	0.093 [0.004]	0.123 [0.019]	0.074 [0.005]	0.080 [0.019]	0.064 [0.005]	0.070 [0.019]
Commutes 15-20 km	0.103 [0.005]	0.117 [0.022]	0.089 [0.006]	0.097 [0.022]	0.075 [0.006]	0.066 [0.023]
Commutes 20-25 km	0.116 [0.006]	0.163 [0.026]	0.112 [0.007]	0.143 [0.026]	0.103 [0.007]	0.129 [0.027]
Commutes 25-30 km	0.116 [0.008]	0.229 [0.032]	0.112 [0.008]	0.205 [0.032]	0.099 [0.008]	0.169 [0.033]
Commutes over 30 km	0.096 [0.006]	0.237 [0.032]	0.076 [0.006]	0.173 [0.032]	0.076 [0.006]	0.141 [0.033]
Other Controls	CMA, province, place of work status, industry, occupation, age group, highest degree, sex, moved in the past year, moved in the past five years, commuting not applicable					
Unweighted Observations	402,570	28,603	374,552	26,513	393,331	27,866
R-squared	0.133	0.098	0.445	0.424	0.417	0.381

Notes; All coefficients statistically significant at the 1 percent level. Standard errors in brackets. Source: Author's calculations from Statistics Canada.

employment incomes than people with commutes of less than five kilometres. People with commutes between 25 and 30 kilometres have 11.2 percent higher incomes than people with commutes of less than five kilometres.

Isolating the analysis to people within the Vancouver CMA and focusing on employment income, I find slightly larger effects on income of commuting. People with commutes of between 10 and 15 kilometres have 7.7 percent higher incomes than those who commute less than five kilometres. Those commuting more than 30 kilometres see an 18.3 percent increase in income relative to those who commute less than five kilometres.

I compute a weighted average income effect from a five kilometres increase in commutes for Canada as a whole and for the Vancouver CMA, based on the number of people within each commuting group. For example, 32 percent of commuters travel fewer than 5 kilometres to work. About 20 percent of people commute 5 to 10 kilometres, etc. From these groups, I estimate that the average effect within Metro Vancouver is a 0.9 percent increase in income for every additional kilometre of commuting. I apply one standard deviation to this estimate to create upper (1.1 percent) and lower (0.7 percent) bound estimates of the income benefit we can expect if people increase their commute length by an additional kilometre as a result of reduced congestion.

Estimating Agglomeration and Income Benefits

In my estimates of the economic benefits of reduced congestion, I make the assumption that the reduction in travel times that HDR (2015) predicts will occur in 2045 occur now. I make this assumption because I am not able to conduct an identical traffic and population extrapolation that HDR conducts. This assumption also simplifies the assumptions I need to make regarding discounting future benefits.

I estimate the total agglomeration benefit for people in each Census Tract as the product of the following elements:

- the percentage increase in surrounding population – specifically, the labour force above the age of 15 – the transportation improvement plan enables access to;
- the average individual employment income of people in that Tract; and
- the assumed rate of increase in income that results from an increase in access to surrounding population, as calculated in Table A-1 (see United Kingdom Department for Transport (DFT) 2005, page 22 for more details).

I then sum the benefits across all Census Tracts in the Vancouver CMA. The primary difference between my approach and that of DFT (2005) is that I use an aggregate, economy-wide estimate of agglomeration benefits and assume that, on average, workers in a Census Tract benefit by that margin through higher incomes. This is equivalent to assuming that the benefits to firms are capitalized in higher wages or profits retained locally. DFT (2005) produced industry-specific agglomeration benefits that vary widely. They calculated the benefits by the sector they worked in, but aggregated to an economy-wide measure. Such firm-level or industry-specific data is not readily available in Canada.

I do not calculate the economic benefit of increased labour market participation as I did in Dachis (2013) or other economic benefits that DFT (2005) investigates. Both studies found that these are small amounts compared to agglomeration effects and the effect of increased commute time on job access.

For the second economic benefit of increased travel range, I estimate the economic benefits for each Census Tract in the Vancouver CMA as the product of:

- the average wage premium that people receive if they commute an additional kilometer;
- an estimate of how much commute length will increase on average in Metro Vancouver as a result of investment plans;
- the current employment income of people in each Census Tract; and
- the number of people over the age of 15 with a job in each Census Tract.

The basic premise of the benefit (as I discuss in Dachis 2013, based on Venables 2007) is that people live in one of two areas: an urban area and a periphery. In the urban area, residents have high paying jobs but incur commuting and housing costs in order to live in the city. The housing costs urban residents pay decline as they live further from the urban core – where all urban jobs are located – whereas their commuting cost increases in proportion to the distance they travel.

A second group of workers live and work outside the urban area in the periphery, where all jobs are lower paying than in the urban area but there are very low housing or commuting costs. Workers then sort themselves between urban and non-urban areas up to the point in which a worker will earn the same real wage including commuting and housing costs.

What would happen if the cost of commuting fell because of transportation infrastructure? People within the existing urban area would see their commuting costs fall and people previously living and working outside the urban area would start commuting to the urban core. These new commuters now benefit from higher wages by switching to a high-wage job inside the urban area although they must now pay higher commuting and housing costs. If incomes in the city increased, in aggregate, with overall urban population, then the wages of both existing urban area-dwellers and new commuters would increase.

A numerical example helps explain this model: A worker residing and working in the periphery earns \$120 a day after tax (\$200 before tax). She has an alternative opportunity: to work in an urban area for \$144 a day after tax (\$240 before tax). However, if the additional monetary commuting costs of reaching the new job are \$12 and inconvenience costs (such as tolerating crowds) and time value are an extra \$14 a day, she would value the urban area job at \$118 a day (144 – 26), and prefer her current job. If a transport improvement reduced her commuting costs by \$4 a day (an increase in her productivity at her job in the urban area would have the same result), what is the gain to her income and welfare? If she took the job in the city, her real wage would increase by \$16 by earning \$24 more per day but paying only \$8 in commuting costs. If the commute takes the same amount of time or is the same level of inconvenience, which she values at \$14, her welfare gain is \$2 per day, meaning she will be better off by taking the urban area job, but only slightly. Her increase in income is \$40 because of the increase in pre-tax salary. A road toll (or transit improvement) that increased the commuting cost by, say, \$2 from the original scenario, but reduced the time cost or inconvenience value of her commute by \$6, would have the same net result of an increase in her welfare and income.

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