Does Airport Access Affect Prices of Various Commercial Properties Differently? A Nonparametric Approach to a Natural Experiment

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Abstract: Airports have become crucial for connecting business travelers with the global economy. The 2009 opening of rail rapid transit in Richmond, BC Canada is a natural experiment that enables us to identify how improved access to Vancouver International Airport may be capitalized into commercial real estate prices. Few known airport access benefits studies focus on commercial property values. In assessing comparative statics, our model implies the rail rapid transit opening leads to higher real estate values when the travel time change is sufficiently large relative to the fixed costs of using the rail line; otherwise the effect is non-positive. Our identification strategy consists of two parts. First we construct a nonparametric Fourier repeat sales price index covering each time period using repeat sales observations from 2005-2012 that are orthogonal to the set of observations that straddle the rail opening date. Second, our natural experiment focuses on how travel time changes affect sales price changes for repeat sales dates straddling the date of the rail line opening, while controlling for neighborhood price changes. Using the nonparametric estimation approach of Locally Weighted Regressions (as in McMillen and Redfearn (2010)) to allow for nonlinear effects, we find significantly positive marginal effects between travel time savings and sale price changes of some commercial properties, while for others this relationship is negative. We also find that on average these marginal effects increase with travel time savings increases, which validates the predictions of our model. Falsification tests indicate our identification strategy is sound.

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Introduction

"The 18th Century really was a waterborne century, the 19th Century a rail century, the 20th Century a highway, car, truck century – and the 21st Century will increasingly be an aviation century, as the globe becomes increasingly connected by air."

-John Kasarda, co-author of *Aerotropolis: The Way We'll Live Next* (quote from National Public Radio Interview on 10/1/2015)[1]

Airports are key assets for metropolitan areas by enabling connectivity to the global economy. Airport access is crucial for business travelers, whose time is especially valuable. While construction costs of alternative travel modes are high (Winston and Maheshiri, 2007), rail rapid transit is one way for business travelers to reach the airport and avoid much of the traffic on route to the airport.

There have been several recent studies on the impacts of airports upon residential housing and land and/or property values, but there has been relatively little known research on the impact of airport proximity on commercial property values incorporating the opening of rail rapid transit as a natural experiment.

The above quote describing how the 21st Century is becoming an "aviation century" in an analogous manner to how the 19th Century was a "rail century", has implications for adapting the monocentric city model as described by O'Sullivan (2009). In that model, cities in the U.S. are assumed to have developed around train stations that are necessary for movement of goods and people. As the U.S. interstate highway system has emerged beginning in the 1950's, many cities have developed into "beltway cities" where the monocentric model morphs into a model where land rents peak close to the highways in addition to in the city center near train stations. More recently, as airports are

[1] http://www.npr.org/sections/parallels/2015/10/01/444749534/a-south-korean-city-designed-for-the-future-takes-on-a-life-of-its-own

becoming major centers for business activity, one might view airports as a central point of economic activity in a new version of the monocentric city model.

Recent research on the concept of airport cities has provided some supporting evidence. For instance, Appold (2015) finds evidence in favor of an aerotropolis argument across 51 U.S. metropolitan areas. Appold and Kasarda (2013) find evidence of the growing stature of airports as central business districts in several U.S. cities. On the other hand, Cidell (2015) finds that arguments for an airport city in the U.S. tend to over-state the potential impacts of an airport.

In our study we focus on a major Canadian airport that is a crucial international gateway, and we motivate our analysis by assuming the airport is a central location for businesses to engage in economic activity by linking to national and international destinations. Our goal is to determine how changes in travel time to the airport affect commercial property values. We motivate our problem by first modifying the Baum-Snow and Kahn (2005) framework, to allow for our situation where there is a rail rapid transit that opens to enable access to an airport (instead of to a central business district). The comparative statics implications of our version of the model are that higher real estate values result from travel time savings occurring after the opening of a rail rapid transit when total travel time savings are sufficiently large. The model also implies lower property values (or no change in property values) for properties in sufficiently close proximity to the airport.

We estimate a nonparametric empirical model that tests for these impacts on commercial property values near a major international airport, using the opening of a rail rapid transit as a natural experiment. Vancouver International Airport (YVR), one of

Canada’s largest airports, is situated in the City of Richmond, British Columbia (BC). A map of the location of Metropolitan Vancouver, BC, Canada, and YVR, is in Figure 1. In August 2009 the Canada Line, a rail rapid transit line opened, connecting the City of Richmond, BC with YVR. As a central gateway to Asia and the remainder of North America, access to YVR for business travelers is crucial, and it could be expected to influence business location decisions. Therefore, the Canada Line opening is a natural experiment that enables us to assess how improved access to YVR is capitalized into commercial real estate prices in Richmond.

In considering the importance of access to this particular airport, some statistics about its prominence are worthy of discussion. In 2012, YVR served 17.6 million enplaned-deplaned passengers of which 9.2 million were domestic passengers and 8.4 million were international passengers. 227,000 tonnes of cargo were enplaned and deplaned at YVR in 2012. Overall, 49% of global Gross Domestic Product (GDP) is accessible by daily, non-stop scheduled air service from YVR. The airport also has the most scheduled flights to China of any airport in North America and considerably more on a per capita basis which reflects Vancouver's and YVR's role as a North American gateway to Asia.[2,3]

A priori, one might expect to see a negative effect of changes in travel time to the airport on commercial property values in the City of Richmond. As is apparent in our theoretical model, the direction of this effect (positive or negative) is expected to depend on whether or not the travel time savings are sufficiently large relative to the fixed costs of rail travel. Both possibilities are generally consistent with some of the findings of Duranton and Turner (2011) that adding public transit in a metropolitan area can have positive, negative, or no significant effects on road usage.

Our identification strategy consists of two components. First, we analyze data on sale prices for commercial properties that experienced repeat sales in Richmond over the period of 2005 to 2012. We focus on the repeat sales observations that straddle the date of the Canada Line opening, in a regression with the repeat sales index as a control, as a natural experiment to test the hypothesis that lower travel time between a particular property and the airport leads to changes in the property's sale prices. We identify the

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[2] In other research (available upon request) that utilizes OLS regressions of the sale price of commercial properties against distance to YVR and a "connectivity index", we find the effect of distance to the airport effect is negative and significant, while the connectivity effect is positive and significant. These results, however, are not obtained through an identification strategy as we implement in the current paper. Also, the connectivity index estimate is identical for all property locations in a given year, and there is little variation in the connectivity index in the various years of our sample (which are the reasons why we do not include connectivity in our repeat sales model specification, in addition to the fact that differencing would lead these invariant connectivity effects to essentially drop out). Therefore, this lack of variation in connectivity over space in a given year and over time implies there is not a major shift in supply (or "supply effect") for air travel, as Bilotkach et al (2012) have described. Thus, the changes in air travel due to opening of the Canada Line can be considered a pure demand side effect if we find that the rail rapid transit opening has a significant effect on commercial property values.

[3] One may argue that another type of "supply effect" that should be considered is the property supply effect, which could be measured by examining property vacancies as in Zabel (2014). While vacancies tend to measure supply in the rental markets of commercial properties, the level of vacancies can nevertheless affect the sale prices of properties. We argue that such supply-side price effects are reflected in the changes in neighborhood price indexes that we include as a control variable in our natural experiment.

repeat sales price index in a manner that is orthogonal to the change in travel time savings by constructing the price index with a different sample of property sales. Specifically, the repeat sales price index is identified based on properties for which both sales occurred before the opening of the Canada Line, and for which both sales occurred after the opening of the Canada Line. In contrast, the impact of travel time savings to the airport is identified using the sample of repeat sales with sale dates that straddle the opening date of the rail line – our natural experiment – while controlling for the neighborhood price index changes. Following the approaches of McMillen and Dumbrow (2001) and Ries and Somerville (2010), we construct a nonparametric Fourier repeat sales price index to obtain a set of "smooth" repeat sales indexes for each of the Richmond Statistics Canada Census Dissemination Areas that have property sales within them during 2005-2012. The nonparametric Fourier approach, as in McMillen (2003), enables us to obtain repeat sales price indexes for each of the dissemination areas for which there are repeat sales, even those with few sales. Across various Locally Weighted Regressions (LWR) specifications, we find that lower travel time between the City of Richmond and the airport as a result of the Canada Line opening led to statistically significant increases in the sale prices of some commercial properties and significantly negative changes in sale prices near other commercial properties.

The remainder of this paper is organized as follows. First, we review the literature on the impacts of proximity to airports and to rail rapid transit on property values. Then we describe the adaptation of the Baum-Snow and Kahn (2005) model to our specific problem, and our empirical modeling approach and identification strategy. Next we provide a brief explanation of the data, followed by an exposition and interpretation of the results. Finally, we discuss the conclusions and implications of these results.

Literature Review

There are many studies examining the impacts of transportation infrastructure on property values, most of which compare the tradeoffs between enhanced residential property values and greater noise associated with airport (and/or other transportation infrastructure) improvements.[4] Others, such as Duranton and Turner (2011) and Anderson (2014),focus on the relationship between transit and road usage or congestion. Few known previous studies, however, focus on the nexus of commercial property impacts[5,6] from proximity to a specific airport in a specific city near this airport, using the opening of a rail rapid transit to the airport from a nearby city as a natural experiment. No known previous airport studies develop an identification strategy with such a natural experiment.

Much of the early work in this area focuses on hedonic housing price models, and to a much smaller extent, commercial property impacts of airports and/or transit proximity. For instance, Crowley (1973) studies the effect of airports on land values in an area next to Toronto International Airport (Malton). The analysis looks at residential, commercial, industrial and public land prices for both sales and rent in the years 1955 – 1969. Specifically, the study compares the land value changes of the properties near the airport relative to land prices farther away and evaluates the changes in the mix of land

[4] For instance, Tomkins et al (1998) find the benefits of residential location near airports exceed the costs.
[5] This lack of research on commercial property value impacts of airports was pointed out to us by Jan Brueckner.
[6] Since airport noise is less of a concern for commercial property, the focus for commercial property studies is more properly placed on the benefits from proximity to the airport.

uses (industrial vs. commercial vs. residential). The study concludes that residential land values decreased during “shock years” when there were substantial changes but typically rebounded to their initial levels soon thereafter. The author hypothesizes that this initial decrease in price may be caused by a significant population putting their houses up for sale to prematurely to avoid potential noise related issues in the future.

A more recent study of the commercial property improvement impacts of airports is Cohen and Morrison Paul (2007). They assess the impacts on manufacturing property values of airport infrastructure stocks aggregated to the U.S. state-level. They find airport infrastructure improvements in a particular state enhance the commercial property values for the manufacturing sector in that state. A shortcoming of their approach, however, is the level of aggregation of the data at the state level, as well as potential endogeneity of the infrastructure variables.

Cohen and Coughlin (2007) study the relationship between distance to the Atlanta airport and housing prices in the surrounding areas. They find that for every ten percent increase in distance to the airport, housing sale prices fall by approximately 1.5 percent, after controlling for several other factors that might affect sale price. Other recent studies of the impacts of airport proximity on housing prices include McMillen (2004), and Tompkins et al (1998).[7] [8]

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[7] The former study focuses on Chicago home prices, while the latter examines Manchester, England. Both of these studies find that proximity to the airports tends to increase the price of housing.

[8] There are also previous studies that examine aviation networks, which imply that there are benefits from improved networks. Oum, Taylor and Zhang (1993) find that alliances develop that enhance global networks. Fu, Oum and Zhang (2010) find that connectivity can be enhanced by deregulation, which also impacts passenger flows. These findings have implications for the benefits of locating near an airport that has fluctuating connectivity with other airports both domestically and internationally.

There is another literature with a focus on transit's impact on property values. The focus of Baum-Snow and Kahn (2005) is on the use of transit to access the central business district (CBD). We adapt their model below to a situation where there is an airport rather than a CBD. There are also some recent rigorous studies of the impacts of increased public transit on road usage, including Duranton and Turner (2011), who find there is mixed evidence in terms of the direction and significance of these effects; and Anderson (2014). In an earlier literature, Damm (1980) studies the response of property values of single and multiple family houses and retail properties in anticipation of the heavy rail transit system installation in Washington D.C. The structural approach represents buyers' and sellers' behavior. Their second estimation equation uses house prices as the dependent variable. Their study finds that for multi-family properties, the closer the property is to the metro station, the lower the property value but the effect of distance declines rapidly. Retail property is much more sensitive to distance to the metro stations.

Kim and Zhang (2005) assess whether the benefits of the station are the same in other parts of the same metropolitan area, using 731 properties in the metropolitan area of Seoul, South Korea. They assess the question of how and where (in terms of distance) does the transit station impact the land values. One of the paper's conclusions is that the closer the property's location to the station and the denser the surrounding area, the higher the price will be for commercial land values.

Landis et al (1995) examines 5 transit systems in California. The paper compares transit investments, land uses and property values of single family property, commercial property, station area and metropolitan areas. The main research question is whether urban rail transit investments affect nearby property values and land uses. They conclude that it does but the effect is small, is not consistent, and not always in ways that are expected.

Debrezion (2007) measures the impact of railway stations on property values by analyzing several other previously published studies. The paper finds variation in these other studies, in terms of the differences in the impacts on residential and commercial property and the impact's dependence on demographic factors. The analysis concludes that the conclusions drawn by other studies are not uniform and tend to be overestimated.

Clearly there are many studies on the impacts of airport proximity on residential property values, while few known studies have explored the relationship between proximity to an airport and commercial property values, using a rail rapid transit opening as a natural experiment. These are significant contributions of our analysis, which we present in more detail below.

Theoretical Model

We adapt the model introduced by Baum-Snow and Kahn (2005), by allowing for commercial entities (instead of households) with employees who travel to the airport to access global markets in order to make business transactions; and we allow for fixed costs of walking to a rail station, and for an airport city where the goal of businesses is to reach the airport so that they can complete business transactions when they make global and/or domestic air connections. In our version of this model, there are 3 options for travel to the airport -- including drive directly (which we assume is the only transport mode to the airport considered by employees who work at commercial properties before opening of the Canada Line), drive to the train station and then take the train to the airport, or walk to the station and then take the train to the airport.[9] Each business has preferences over the amount of land (denoted by s) and other inputs necessary for its operations (with price u), with a cost function of z(s, u). We assume z is increasing in both s and u. Businesses receive one unit of revenue (w) when employees reach the airport and connect with out-of-town business transactions (or equivalently, when one of their clients is able to make a trip from the airport to the local business location). There is an opportunity cost associated with rail travel due to the need to wait in line for boarding, purchase rail tickets, etc., equal to the per-unit revenue (w) times the fixed amount of time cost (x). We also assume the fixed cost associated with walking to the train station is given by Ω. There are also marginal costs for each form of travel, which are given as the average travel times per kilometer, b_R, b_D, and b_F for rail, driving, and walking, respectively, where we assume (after the rail line opening) $b_R < b_D < b_F$.[10]

The distance from each business location to the airport is given by r, and the angle to the nearest Canada Line stop in Richmond is given by ϕ.[11] To elaborate on the theory, consider a circle with radius r and centered at the origin (which is the location of the airport), as in Figure 2. The x-axis is assumed to be the route of the rail line to the airport (although this can be easily generalized for any linear route to the airport). So for a property that is r kilometers away from the airport (that is, somewhere on the arc of the circle), that property is the furthest possible distance on the arc from the rail line when

[9] Due to the relatively slow speed of most local bus service, we assume that business travelers do not consider bus service as a viable option to reach the train station or the airport. Subsequent to the construction of the Canada Line rail service to the airport, virtually all bus service between Richmond, BC and the airport has been discontinued.
[10] Given an anecdotal comparison of rail and automobile travel times in Richmond, this is a realistic assumption.
[11] This aspect of the model closely follows that of Baum-Snow and Kahn (2005), although our focus is on distance from businesses to the airport as the central point, opposed to their focus on distance from households to the central business district of a city.

the angle is 90 degrees. But for a property located distance r from the airport that is exactly at the rail line (that is, on the x-axis), the angle from the rail line is zero degrees. From any point on the circle, the travel distance to reach the rail line is given by the distance from the x-axis in the vertical direction, or $r \times \sin(\phi)$, and the travel distance on the rail line to the airport is given by the distance to the origin in the horizontal direction, or $r \times \cos(\phi)$.

There is a fixed cost (A) associated with a firm having or using a car (or a worker using a car). We also assume the fixed cost (Ω) associated with walking to the rail station could include the need to purchase comfortable walking shoes, and boots and/or an umbrella for stormy days. A firm must choose the travel mode to the airport for workers that minimizes travel costs among the three choices described above. We describe this travel cost minimization problem below as the choice of commuting option among the three possibilities (drive to rail station then take the train to the airport; drive directly to the airport; and walk to the rail station and then take the train to the airport) that minimizes total commuting costs:

$$\text{Min } \{ [A + w(x + r\, b_D (\sin\phi) + r\, b_R (\cos\phi))],\ [A + wr\, b_D],$$

$$[\Omega + w(x + r\, b_F (\sin\phi) + [1-1/\gamma]r\, b_R (\cos\phi))] \}.$$

For our empirical analysis, it is helpful to determine how our model predicts changes in travel time to the airport, due to the rail line opening, are capitalized into property values. Since there are relatively few repeat sales observations available in our data set for vacant land (and few observations that break down the property values into land versus improvements), examining land values in an empirical model is not a feasible approach to follow. Since land values represent location values, while structures should be reproducible at the same construction costs anywhere in the city (Cohen, Coughlin, and Clapp, forthcoming), we expect each total property value (land and improvements) in the relatively small geographic area of Richmond, BC to be highly correlated with land values.[12]

In order to form expectations of how opening the rail line affects property values, it is helpful to consider the general implications of bid-rent theory in urban economics. The "Leftover Principle" (O'Sullivan, 2009) states that all remaining revenues after non-land expenses are used for land, which implies a bid-rent (or zero-profits) function expressing land rent (Ψ) as a function of distance to the airport (r), the price of other inputs, and land area, given w and the marginal travel costs. For simplicity, we assume that properties are very close to the rail line, so that the angle (ϕ) from the rail line is essentially zero degrees for a property r kilometers away from the airport. Therefore, $\sin(\phi) = 0$, and $\cos(\phi) = 1$, and the distance travelled on the rail line (that is, on the x-axis) is 1 times r.

This implies 3 separate bid-rent functions, and the choice of transport mode to the airport is given by the envelope of the bid-rent functions:

$$\Psi_{F,R} = -wrb_R/s + (w-wx-\Omega-z)/s \quad (1')$$

$$\Psi_{D,R} = -wrb_R/s + (w-wx-A-z)/s \quad (2')$$

$$\Psi_D = -wrb_D/s + (w-A-z)/s \quad (3')$$

[12] We note it is likely that an increase in land values should lead to an increase in the sale price of a property, but acknowledge that there may not be a one-to-one correspondence between land value changes and overall property value changes in the City of Richmond, BC. This potential disparity may be reflected in some of the empirical estimation results (in which the dependent variable is commercial property sale prices, opposed to land values).

First, we describe some comparative statics that generate a hypothesis on how the opening of the Canada Line is expected to affect land values.[13] Note that by subtracting (3') from (1'), we obtain the difference in land values before and after opening of the Canada Line:

$\Psi_{F,R} - \Psi_D = wr(b_D - b_R)/s + (A - wx - \Omega)/s$, and

$$\Delta\Psi/\Delta rb = (\Psi_{F,R} - \Psi_D)/(rb_D - rb_R) = w/s + (A - wx - \Omega)/[s(rb_D - rb_R)] \quad .$$

This implies that $\Delta\Psi/\Delta rb > 0$ when $r(b_D - b_R) > (\Omega/w) - (A/w) + x$.

Before the opening of the rail line, rb_R (travel time by rail) is very large because the travel speed by rail (given as $1/b_R$) is zero (since rail travel is not possible). After the opening of the rail line, b_R decreases to the inverse of the actual speed of the Canada Line. Therefore, holding r and b_D constant for a particular property, $\Delta rb = r(b_D - b_R)$ is expected to be positive when the rail rapid transit opens because b_R falls when the rail line opens.

We can think of (Ω/w) as the fixed time cost of walking to the rail station, (A/w) as the fixed time cost of owning or using a car, and x as the fixed time cost of using rail. So if there is a relatively high payoff (w) from reaching the airport, it is more likely that $\Delta\Psi/\Delta rb > 0$. If there is a low fixed cost for using rail (i.e., if x is small), then it is more

[13] Unless $A \leq \Omega$, no firms will have their workers drive to the rail station; i.e., the bid-rent curve (2') always lies completely below (1') as long as $A > \Omega$ and firms locate on or very close to the rail line. The comparative statics results below are robust to the scenario where $A \leq \Omega$. In the empirical estimations we impose no a priori restrictions on the relative magnitudes of A and Ω, so that it is possible for workers to drive or walk to the rail station.

likely that $\Delta\Psi/\Delta rb > 0$. As $r(b_D-b_R)$ becomes large (that is, if a property is located far from the airport and/or if the travel time savings from rail are large), then it is also more likely that $\Delta\Psi/\Delta rb > 0$.

Similarly, if $A<\Omega$ and if people drive to the rail station, we have:

$$\Psi_{D,R} - \Psi_D = wr(b_D-b_R)/s - wx/s \text{ , and}$$

$$\Delta\Psi/\Delta rb = (\Psi_{D,R} - \Psi_D)/(rb_D-rb_R) = w/s - wx/[s(rb_D-rb_R)] \quad .$$

In this scenario, if there is a low fixed cost of using rail (i.e., if x is small), it is more likely that $\Delta\Psi/\Delta rb > 0$. Once again, when r is large or if the travel time savings from opening the rail line is large, then as $r(b_D-b_R)$ (travel time savings) rise due to the opening of the Canada Line, leading to higher property values between the period when everyone drove to the airport (before the rail opening) and subsequently when people drive to the train station and then take the train to the airport.[14]

In the next section we explain our identification strategy for testing the comparative statics of how changes in travel times affect commercial real estate prices.

Identification Strategy

Our identification strategy in estimating the effect of improved access to the airport on commercial property values is to examine how travel time savings impact property values. There are two identification issues for us to address. First, we consider

[14] The direction (but not the magnitude) of this relationship is the same when we calculate $[(\Psi_{F,R} - \Psi_D)/ (rb_D-rb_R)]/ \Psi_D$, i.e., when the difference in land values is expressed in natural logarithms.

the potential simultaneity of location decisions and property values by analyzing the natural experiment of rail rapid transit opening. Another potential identification issue is the possibility of shocks to the repeat sales price index being correlated with travel time savings. To address this issue we adapt a methodology similar to the split-sample Case and Shiller (1989) approach, and the Reis and Somerville (2010) approach, the latter of whom study school quality and rezoning in Vancouver. As the latter application is based on residential properties, their starting point is a traditional hedonic model with the log of sale price as the dependent variable, and independent variables including the neighborhood price index at a particular time, the property characteristics, the average neighborhood test scores, and other neighborhood characteristics. They also follow the Bailey, Muth, and Nourse (1963) repeat sales methodology by including a residual term that includes a neighborhood price component and an iid component. Taking the two sales of any particular property, and differencing these in the model, the property characteristics and “other” neighborhood characteristics terms drop out. This leaves the log of the sale price ratio as the dependent variable, and explanatory variables for the neighborhood price changes between the two sale dates, and the difference in neighborhood school test scores (as well as a new error term that only includes iid components). Their identification strategy is to construct their repeat sales price index based on properties with both sales either before or after the rezoning. Then in estimating their model, they focus on the impacts of changes in test scores for repeat sales of properties that straddle the date of the rezoning, while controlling for the repeat sales price index. They construct a parametric version of a Fourier repeat sales index at the neighborhood level, which they use as the control in their regression of the log of the sale price ratio of each of the two sales against the difference in average school test scores for properties that changed school districts as a result of the rezoning (and the neighborhood repeat sales price index as an additional control). Their relatively large sample size of home sales enables them to include the parametric version of the “smooth” Fourier repeat sales index as an explanatory variable.

We begin with an empirical model that is analogous to a hedonic housing model, except our problem is for commercial properties so it is somewhat different. Specifically, our model is in the form:

$$\text{Log}(P_{nit}) = \theta C_{ni,t} + X\,\zeta + \varepsilon_{nit} \qquad (4)$$

where $\varepsilon_{nit} = \alpha_{i,t} + \upsilon_{nit}$, $\upsilon_{nit} \sim \text{iid}(0, \sigma^2)$; P_{nit} is the actual sale price of property n in time t (which is located in neighborhood i, defined as the Census dissemination area); $C_{ni,t}$ (with parameter θ) is the travel time from property n to the airport at time t (equal to r×b, where r is distance to the airport and b is hours per kilometer travelled, as defined earlier in the theoretical model); $\alpha_{i,t}$ represents a commercial property price index in dissemination area i at time t; X (with parameter vector, ζ) is a matrix of observations for physical characteristics of the commercial property (such as the “effective” year of construction and a dummy for whether or not the property is zoned for Class 5). X includes a column of 1’s as an intercept term as one of the variables in the characteristics matrix. The subscript i denotes the Census dissemination area.

A potential criticism of the repeat sales approach is that the quality of properties may change over time. An advantage of the data set we have obtained from BC Assessment is they include an “effective construction date” variable, which adjusts the construction date for any changes in quality. Moreover, among all of the repeat sales properties in our sample, this effective date is the same for both sales observations, implying no significant quality changes for these properties in the time period of 2005-2012. Also, all of the 2059 property sales in this period only include “qualified” or arms-length sales, so there is no concern with any “zero” sales prices.

While the construction plans for the portion of the Canada Line connecting Richmond and YVR were announced in May 2000, the exact travel time for the trip from each station to the airport (and whether or not it would still be faster to drive to the airport) was not known by potential riders until service actually began in August 2009. Therefore, the appropriate “event” for this natural experiment is the opening of service on the Canada Line between Richmond and YVR.[15]

Assuming the travel time to the airport may be different before and after the opening of the rail rapid transit, as well as differencing equation (1) for the two periods of a given property’s repeat sale that straddle the opening of the rail line, yields:

$$\mathrm{Log}(P_{ni,t+j} / P_{nit}) = \alpha_{i,t+j} - \alpha_{i,t} + \theta(C_{ni,t+j} - C_{ni,t}) + \upsilon_{ni,t+j} - \upsilon_{nit} \qquad (4')$$

where $\upsilon_{nit} \sim \mathrm{iid}(0, \sigma^2)$, and $C_{ni,t+j}$ represents travel time to the airport from commercial property n at time t, including time to reach the nearest station and the time to ride the train to the airport; and $C_{ni,t}$ is the driving time from commercial property n to the airport. The term $\alpha_{i,t+j} - \alpha_{i,t}$ represents the difference in the neighborhood-level commercial property price index between the two time periods.

One potential concern is that property-level shocks in estimating α could be correlated with $C_{ni,t}$, and thus biasing θ. Case and Shiller (1989) suggest a split-sample approach to address such concerns. In this spirit, we employ a similar approach suggested

[15] This information is based on discussions we had with individuals at the Vancouver Airport Authority.

by Reis and Somerville (2010), as we discuss above, by focusing on the sample of repeat sales for which both property sales are before the opening of the rail line, and for which both property sales are after the opening of the rail line, in estimating α. Then we use a different sample - the sample of repeat sales with dates that straddle the opening date of the rail line - in estimating equation (4'). Specifically, our identification strategy in this regression is to construct a nonparametric Fourier repeat sales price index using properties with both repeat sales before (as well as properties with both repeat sales after) the opening of the Canada Line. This approach also enables us to construct a repeat sales index that is independent of the effects of the opening of the Canada Line. Then, in order to analyze the natural experiment that enables us to identify θ, we use these repeat sales price indexes for the Census dissemination areas in the City of Richmond as a control, and include as a second regressor the difference in travel times at each of the two sale dates for the properties that straddle the opening date of the Canada Line. Since we estimate a nonparametric version of the Fourier repeat sales index, as in McMillen (2003), we are able to obtain a repeat sales price index for each Census dissemination area at each point in time (i.e., day) over the period 2005-2012, even for those dissemination areas with few sales.

The Fourier repeat sales price index is introduced by McMillen and Dombrow (2001), who obtain the parametric version of the Fourier repeat sales estimator by first estimating the following equation:

$$\mathrm{Log}(P_{n,t+j} / P_{nt}) = \phi_1(z_{t+j} - z_t) + \phi_2(z^2_{t+j} - z^2_t) + \sum_\rho (\lambda_\rho (\sin(\rho z_{t+j}) - \sin(\rho z_t)) + \delta_\rho(\cos(\rho z_{t+j}) - \cos(\rho z_t))) + u_{n,t+j} - u_{nt} \qquad (5),$$

where ρ is the number of lags, $z_t = 2\pi T_t / \max(T)$, and T_t represents the numerical day in the sample at time t.[16] After using least squares regressions to estimate the parameters ϕ_1 , ϕ_2, λ_ρ, and δ_ρ, one would then calculate the fitted value of the following equation at various time points to obtain the price index:

$$\alpha_t = \hat{\phi}_1 (z_t) + \hat{\phi}_2 (z^2{}_t) + \sum_\rho (\hat{\lambda}_\rho (\sin(\rho z_t) + \hat{\delta}_\rho (\cos(\rho z_t))) \qquad (5'),$$

The lag length (ρ) is determined through minimization of the Schwarz information criterion (SIC).

Due to the relative sparsity of data across each time period in each Census dissemination area in our sample, we use nonparametric estimation techniques to develop a Fourier repeat sales index (as in McMillen, 2003) for each Census dissemination area at each point in time. We accomplish this by using Locally Weighted Regressions (LWR), as in McMillen (2003). Specifically, LWR is a nonparametric estimation procedure that is essentially a form of weighted least squares, and the estimator is obtained as follows:

$$\hat{\beta}_{i,LWR} = (\textstyle\sum_j w_i x_{ij} x_{ij}')^{-1} (\sum_j w_{ij} x_{ij} y_{ij}), \qquad (6)$$

where $y_{ij} \equiv \mathrm{Log}(P_{ik,t+j} / P_{it})$,

$x_{ij} \equiv [(z_{t+j} - z_t), (z^2{}_{t+j} - z^2{}_t), (\sin(z_{t+j}) - \sin(z_t), (\cos(z_{t+j}) - \cos(z_t)]$ (assuming ρ=1),[17]

and w_i is the kernel weights, which denotes how "important" each observation is in relation to the centroid. We use the Gaussian kernel, denoted by $w_i = \exp(-d_{in}/h)$, where h is the bandwidth,[18] i is the target point (i.e., the centroid of dissemination area i), n is

[16] As McMillen and Dombrow (2001) note, this essentially lines up the dates in the sample, in our case starting at January 1, 2005 as T=1, January 2, 2005 as T=2, etc., and rescales the time variable on the interval between 0 and 2π.
[17] x_i should be adapted accordingly for the situation where $\rho>1$. In our application we have determined that $\rho=1$ minimizes the SIC.
[18] McMillen and Redfearn (2010) note that the results are generally invariant from the choice of the kernel; however there is often more sensitivity to the bandwidth. As described below, we follow the approach of

the property for which there is a repeat sales that has both sales either before or after the Canada Line opening, and d_{in} is the Euclidean distance between the centroid i and property n location.

After obtaining the estimator $\hat{\beta}_{i,LWR} \equiv (\hat{\phi}_{1,i,LWR}, \hat{\phi}_{2,i,LWR}, \hat{\lambda}_{\rho,i,LWR}, \hat{\delta}_{\rho,i,LWR})'$, the nonparametric Fourier repeat sales price index can be calculated for every Census dissemination area centroid (i) and time period t+j (i.e., each day between 1/1/2005 and 12/31/2012), by varying T in the vector x_{ij}, as follows:

$$\alpha_{i,t+j} = x_{ij}' \hat{\beta}_{i,LWR} \tag{7}$$

where the subscript i denotes Census dissemination area i.

After obtaining $\alpha_{i,t+j} - \alpha_{i,t}$ with the estimates in (4), we estimate the independent effects on changes in sale prices of proximity to YVR and the repeat sales price index for a particular dissemination area, with a revised version of (4') as follows (using the same identification strategy as implemented for (4')):

$$\text{Log}(P_{ni,t+j} / P_{nit}) = \eta[\alpha_{i,t+j} - \alpha_{i,t}] + \theta(C_{ni,t+j} - C_{ni,t}) + \upsilon_{ni,t+j} - \upsilon_{nit} \tag{4''}$$

A potential limitation of using OLS to estimate this model is that the comparative statics of our theoretical model imply there is likely to be heterogeneity across various locations in the effects of opening the Canada Line on commercial property values, depending on the travel time savings for each location. One way to allow for this variation is with LWR, as in McMillen and Redfearn (2010), which we also use to

McMillen and Redfearn (2010) and consider two different bandwidth choices. Specifically, we use the two alternative bandwidths of h=0.5 and h=1.0. But the h=0.5 model leads to singularity problems due to the relatively small number of observations that receive substantial weight, so in the results presented below we focus on the Fourier price index estimates from the h=1.0 model. In our application, the optimal lag length is ρ=1, as determined by the Schwartz Information Criterion (SIC).

estimate the price index above, but now separate estimates for the parameters η and δ are computed for various target points (n). In this analysis, the target points are the locations of the repeat sales (opposed to the centroids of the Census Dissemination Areas that were the target points for the price index estimation). The estimation equation becomes:

$$\mathrm{Log}(P_{nc,t+j} / P_{nct}) = \eta_n[\alpha_{i,t+j} - \alpha_{i,t}] + \theta_n(C_{ni,t+j} - C_{ni,t}) + \upsilon_{ni,t+j} - \upsilon_{nit} \qquad (4''')$$

In the results section below, the varying signs and magnitude of the LWR estimates for η_n and θ_n demonstrate that there are nonlinearlities in the relationships, which can mask the true effects of changes in travel time on commercial property values when we estimate equation (4') by OLS. This is justification for estimating separate equations for individual observations, since we find evidence that there are different parameter estimates for the travel time savings across the sample.

Data

The data and variables are as follows. Our dependent variable is the sale price of commercial properties near the airport. Our commercial property sales data are obtained from the BC Assessment Authority roll years 2005-2012, for the full set of 2,059 "qualified" commercial property transactions in Richmond, BC, the host city of the airport. The definition of "commercial" property is based on BC Assessment's Class 05 and 06 properties. Class 05 is defined as "Light Industry", which includes extracting, processing, manufacturing or transporting, storage of products. Class 06 consists of other "commercial" properties, including restaurants, retail, hotels, offices, and others. In the repeat sales sample, approximately 95% of the properties are Class 06 while approximately 5% are Class 05.[19] Thus, one of our explanatory variables is whether or not a property is classified as Class 06.

Our other control variables include the "effective" construction year[20] (the average of which is 1995), which adjusts the actual construction date for any known improvements; and the drive time from the property to YVR.[21]

Finally, we also use fixed effects estimation for the OLS version of (4) to control for the location in each of 49 Census Dissemination Areas of each of the 2,059 commercial property (class 05 and 06) transactions in Richmond, BC, 694 of which comprise repeat sales. These Census Dissemination Areas are determined by Statistics Canada, with each consisting of approximately 400 to 700 people.

A map of the 2059 Richmond property sales between 2005 and 2012, color coded by the nearest Canada Line station, is shown in Figure 3. Descriptive statistics of the data are presented in Table 1. For the sample of 694 repeat sales, the average driving distance to YVR is 8.2 kilometers, and the average drive time to YVR is 0.205 hours.

Results

First we present the OLS results of equation (4), in Table 2. We also estimate a version of (4) including fixed effects in Table 3. In these specifications, α is embedded in the residuals, but we control for general price levels through a year of sale control variable. In both Table 2 and Table 3, we find that the sign on the drive time to YVR

[19] Note that the sum of the shares of Class 05 and Class 06 are greater than 1, due to there being some properties that are zoned for both uses.

[20] It is noteworthy that in our sample of repeat sales, the effective construction year is the same for both sales in all of the repeat sales pairs.

[21] We estimate the repeat sales model with a drive time to the rail station assumption which is based on interpolated values of drive time in Richmond for each year of sale, given estimates of drive time in Richmond for the years 2005 (43.2 km/hour) and 2011 (40.4 km/hour). The drive times from each repeat sales property address to YVR are based on mapquest.com queries.

variable is positive and significant in the OLS and OLS with fixed effects models. These travel time coefficients are equal to approximately 0.08, implying that for a one minute increase in the travel time to YVR, there is an approximately 8 percent increase in the sale price of commercial properties. While we would have anticipated that lower travel time to YVR increases commercial property values, this counterintuitive direction (and a somewhat large magnitude) may be due to the fact that these OLS estimates do not address the possible simultaneity due to businesses preferring to locate close to the airport. Ignoring this concern is likely leading to biased parameter estimates, which explains the counterintuitive sign on the drive time variable. Our identification strategies in estimating models (4'') and (4''') are remedies for this concern.

After estimating the nonparametric Fourier price index for each Census dissemination area, we then estimate the model in equation (4''). Initially, we estimate this model in (4'') by OLS. In this specification, the fixed effects, the intercept, and the other variables in X are not included because they drop out when differencing equation (4) as we move to equation (4''). The coefficient on the change in travel time savings in Table 4 is approximately -0.04 and is statistically insignificant. This result may be arising because with OLS estimation, we are constraining the model to reflect a linear relationship between travel time savings and sale price changes.

To allow for a more general relationship, we estimate equation (4''') using LWR, by varying the bandwidth from h=0.5, 0.75, and 1.0.[22] It is noteworthy that we also attempt to vary the bandwidth for the Fourier price index, but lowering it to h=0.5 results

[22] If the true relationship had been linear, we would find all coefficients equal to each other in the LWR specification. As we demonstrate below, the nonlinear specification results in many observations with statistically significant parameter estimates for the change in travel time variable.

in singularity in the LWR of many observations' equations in model (4'''), so we present results for the Fourier bandwidth equal to 1.0 while varying the bandwidths for the LWR of model (4'''). For the model where the LWR h=1.0, 164 out of 167 coefficients on the price index are statistically significant. Table 5a demonstrates that there are 131 coefficients that are between 0 and 10, while the standard errors on many of these imply they are not significantly different from 1.0 (which is reassuring because one might expect changes in neighborhood prices should translate into changes in individual property prices in approximately a one-to-one ratio). There are also a handful of outliers for this price index coefficient. Table 5b shows the LWR coefficients estimates for the Canada Line opening variable. The coefficient range is between -0.8 and +0.6, with 109 negative coefficients and 58 positive coefficients. There are 113 statistically significant coefficients (θ_n) for the Canada Line variable.

As we move to a higher bandwidth (h=0.75) for the LWR model, the results in tables 6a and 6b demonstrate that there are 143 out of 167 coefficients for the price index that fall between 0 and 8, with the remaining coefficients as outliers. Once again, 164 out of 167 of the coefficients on the price index are significant. For the Canada Line opening coefficient , all observations' parameter estimates for the LWR model are between -0.5 and +0.2, with 112 negative coefficients and 55 positive coefficients. There are 119 statistically significant coefficients (θ_n) for the Canada Line variable.

When we allow the LWR bandwidth to be higher (h=1.0), there are 148 of the price index coefficients that fall between 0 and 8, with 149 observations that have statistically significant coefficients in Table 7a. All of the Canada Line coefficients (θ_n)

in Table 7b are between -0.4 and +0.1, with 150 that are statistically significant, with 45 that are positive while 122 are negative.

Given these results, there are a few noteworthy trends. First, it is clear that for some properties, travel time savings from the Canada Line opening lead to higher property values, while for others property values fall. Also, as we increase the bandwidth, there are more significant coefficients (θ_n) on the Canada Line variable. At the same time, when the bandwidth increases we observe a slight decrease in the number of significant coefficients on the price index. A higher bandwidth, which flattens the probability distribution for the kernel weights, gives greater weight to more distant observations. Since the Fourier price indexes are calculated for each Census dissemination area, broadening the bandwidth gives greater weight to more distant observations that are probably not influenced by a particular dissemination area's price index, which may be a reason for the greater number of insignificant observations for the price index in equation (4'''). At the same time, the wider bandwidth gives greater explanatory power to the Canada Line variable by including more observations, which is expected to lead to a greater number of observations with statistically significant coefficients for the Canada Line variable.

We perform some additional exploratory analyses in order to gain some insight into the potential drivers of the variation in the signs of the effects of changes in travel times on commercial property values. First, our theoretical model implies that properties with sufficiently high "payoffs" from airport travel are likely to have positive coefficients for θ. We utilized the City of Richmond business license database for the year 2012 (which is the only year that we were able to obtain), in order to compare the types of businesses that are located at the properties for which we have repeat sales data with the sign of θ for those properties. For the most part, there were no clear patterns in these data. There may be several potential explanations for this lack of evidence. First, many of the properties are leased by businesses that do not own the properties, and if they were to vacate the property it is possible that businesses in different industries may relocate there. In other words, in at least some cases there is a potential disconnect between the owner (who may not occupy the building but who receives any benefits from price appreciation) and a tenant (who could be engaged in economic activity in a variety of different industries).

A perhaps more fruitful focus for an explanation of the signs of θ is on the travel time change variable. In an exploratory analysis to gain some understanding on the magnitude of potential nonlinearities in the relationship between travel time savings and the marginal effect on property values of travel time savings, we regress the t-statistic for θ_n on a constant and the change in travel time, $r(b_D\text{-}b_R)$, to determine whether properties that experience higher travel time savings after the opening of the rail line also had higher marginal effects of time savings on sale price changes (as predicted by our theoretical model). The results of these OLS regressions (for h=0.50, 0.75, and 1.0) are presented in Tables 8a, 8b, and 8c.[23] In two of these three regressions, the coefficient on the travel time savings is positive and significant, while the regression with h=0.50 has an insignificant coefficient. This implies some evidence that on average, when the

[23] As described above in the results section, most of the price index coefficient estimates (η_n) in the range of 0 to 8 are not statistically different from 1.0, implying a one-to-one movement between neighborhood house price changes and these individual properties' price changes. Therefore, we focus on this sample in our analysis of the relationship between the marginal effects (θ_n) and travel time changes.

bandwidth is reasonably large (h=0.75 and h=1.0), properties with higher travel time savings have higher marginal effects of travel time savings on property price changes.

Falsification Tests

Finally, to demonstrate the effectiveness of our identification strategies, we perform a set of "falsification tests", similar to one of the falsification tests of Reis and Somerville (2010). Specifically, we estimate the following model:

$$Log(P_{ni,t+j} / P_{nit}) = \eta_n[\alpha_{i,t+j} - \alpha_{i,t}] + \xi_n(C_{ni,t+j} - C_{ni,t}) + D\times\theta_n(C_{ni,t+j} - C_{ni,t}) + \upsilon_{ni,t+j} - \upsilon_{nit} \quad (8)$$

In this version of the model, the term $(C_{ni,t+j} - C_{ni,t})$ refers to changes in travel time for repeat sale observation pairs for property n in dissemination area i when both sales occurred before the opening of the rail line, and when both sales straddle the opening date of the rail line. $D\times\theta_n(C_{ni,t+j} - C_{ni,t})$ refers to the effect for sales with dates that straddle the opening date (since D is a dummy variable taking a value of 1 when sales straddle the opening date, and zero otherwise). We would expect $\xi_n = 0$ when both sales are from the pre-opening period (i.e., when D=0), since the Canada Line had not opened yet in this sample period. The coefficient ξ_n is considered a "placebo effect" in the sense that it should equal zero if travel time savings are uncorrelated with unobserved neighborhood price changes. In other words, we expect θ_n to be nonzero if the opening of the Canada Line had an impact on property prices. But since ξ_n is the effect on prices when both sales occurred before the opening of the Canada Line (i.e., before the event), if $\xi_n \neq 0$ when D=0 this is evidence of the presence of spurious correlation. This could imply there is bias arising due to correlation between $\upsilon_{ni,t+j} - \upsilon_{nit}$ and $(C_{ni,t+j} - C_{ni,t})$, from unobserved price trends, and/or from reverse causality. If our identification strategy has been successful, we would expect $\xi_n = 0$ and $\theta_n \neq 0$. To perform this falsification test, we estimate (8) by LWR, and then perform a set of F-tests on each of ξ_n and θ_n, as in McMillen and Redfearn (2010), to ascertain whether each variable in equation (8) significantly adds explanatory power to the model. We find strong evidence supporting the validity of our identification strategy for the sale price effects of changes in travel time savings from the Canada Line opening.

Specifically, to reinforce our identification strategy for the neighborhood price indexes, we first re-estimate equation (5') with a sample of repeat sales that is non-overlapping with the sample used in estimation equation (8), to obtain new estimates of $[\alpha_{i,t+j} - \alpha_{i,t}]$. Then we estimate equation (8) using this change in the neighborhood price index, and the orthogonal sample for $(C_{ni,t+j} - C_{ni,t})$ - the sample of repeat sales with both sales occurring before the rail opening, and the sample where the sales straddle the rail opening date. We calculate the F-statistics for ξ_n and θ_n using a bandwidth of h=1 for the Fourier price index, and vary the bandwidth for the LWR estimation of equation (8) in the range of h=1, h=0.75, and h=0.5. These F-statistics results are in Table 9. In all cases, the F-statistic for ξ_n implies this parameter is highly insignificant (with P-values ranging from 0.2455 to 0.3108 with these bandwidths), while the F-statistic for θ_n implies a high degree of significance for θ_n (with P-values ranging from 0.0047 to 0.0082). These falsification test results reaffirm the validity of our identification strategy for the effect of travel time savings from the rail line opening on commercial property sale prices.

Conclusions

We examine the impacts of Vancouver International Airport on commercial property sales prices in the City of Richmond, BC, Canada, over the period 2005-2012.

Our identification strategies enable us to demonstrate that some properties have higher value after the Canada Line opening while others face lower values, after controlling for the evolution of neighborhood prices. We confirm the validity of our identification strategies with falsification testing. While it might seem puzzling that greater travel time to the airport can lead to increases or decreases in commercial property values, this result is predicted by our theoretical model.

There are major potential policy implications from our analysis. If the commercial property owners in Richmond can expect their property values to rise as access to the airport improves, this may result in higher assessments of these properties. Depending on how the property tax rates are set by Richmond, the higher assessments could lead to greater tax revenues. Regardless of the impacts on local property tax revenues, it is clear that Vancouver International Airport has a significant impact on the businesses in the local community.

Our results reinforce the notion that access to an airport can be crucial for business travelers. The "Aerotroplis" notion that is anticipated to prevail in the 21st Century can be modelled theoretically with a version of the monocentric city model, as well as empirically through our identification strategies. While Vancouver International Airport is a major large hub, there are other larger hubs in North America that may lead to a curiosity of whether these effects on commercial property values are stronger in those other locations. There are also potential benefits of airport access to other individuals (i.e,. non-business travelers) that could justify a residential property analysis of improved airport access in future work.

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Figure 1: Vancouver International Airport's Location in Richmond, BC Canada

YVR

Figure 2: Model of Rail Line and Airport in an Airport-Centric City

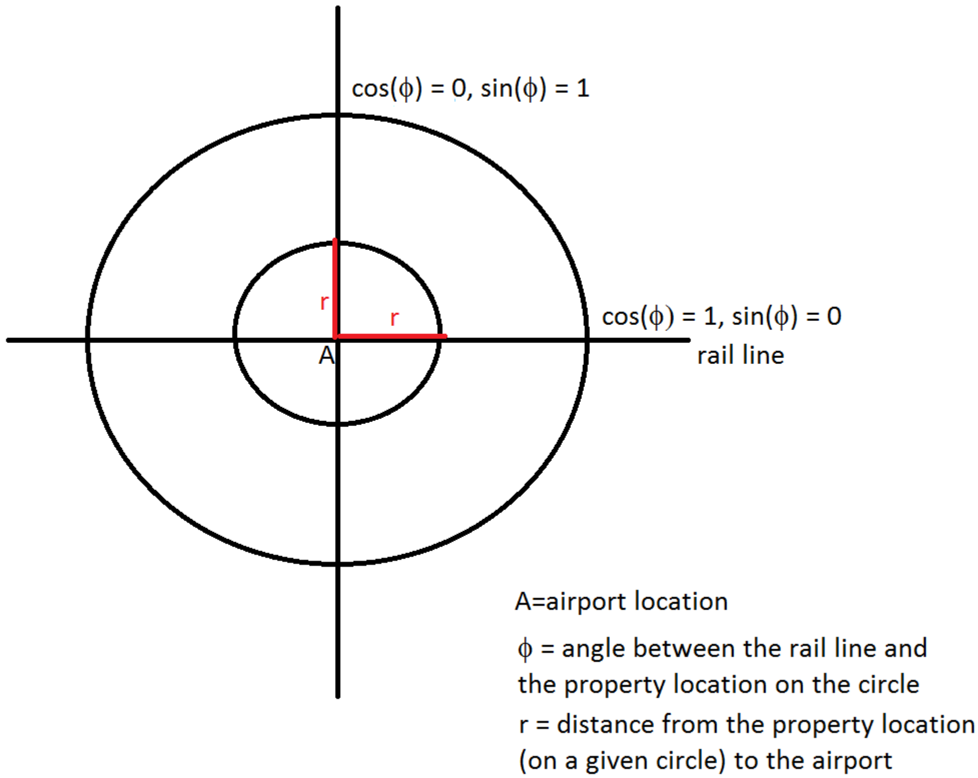

Figure 3 – Locations of all 2059 "Qualified" Richmond BC Commercial Property Sales, Color-Coded by Nearest Canada Line Station, 2005-2012

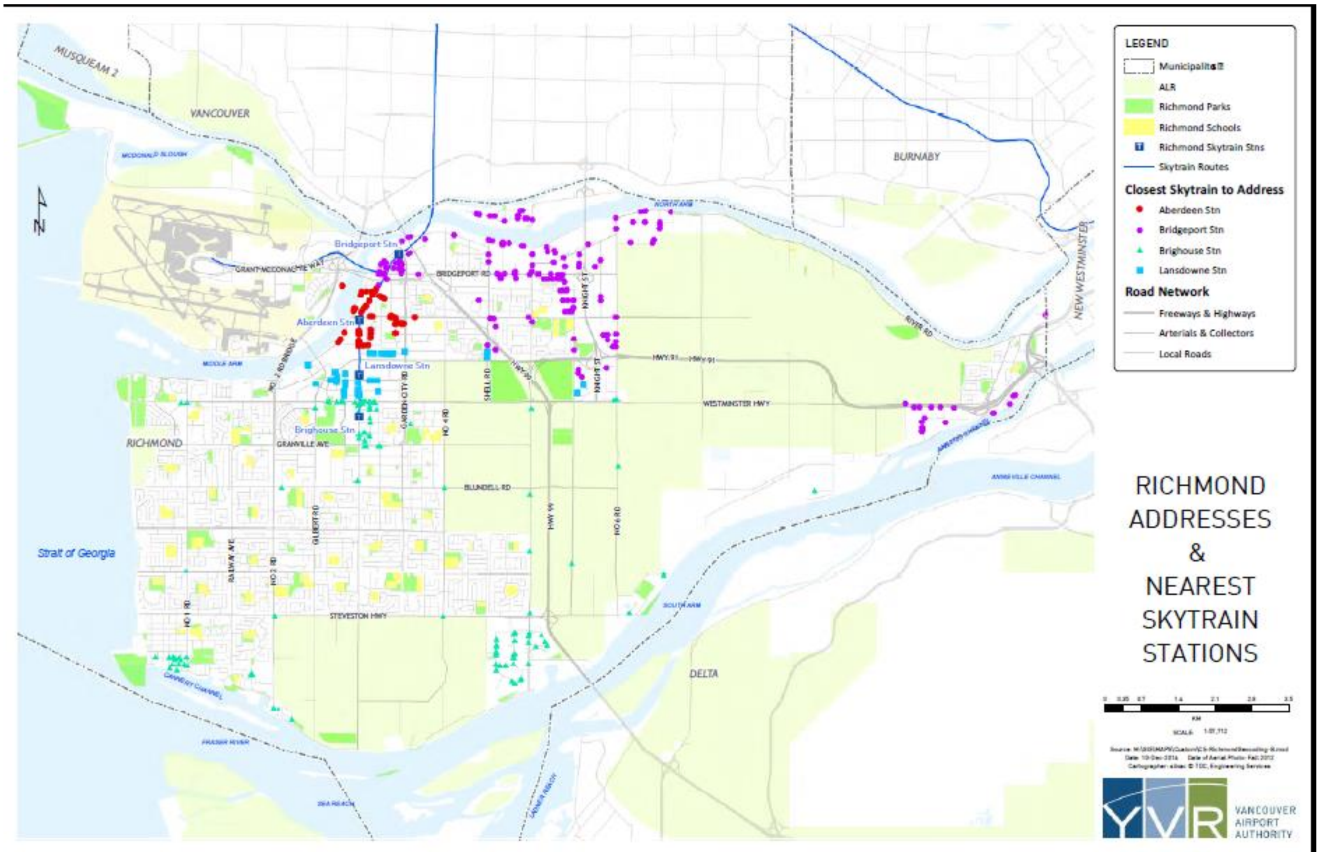

Table 1 – Descriptive Statistics – Repeat Sales Observations, Richmond, BC Canada, 2005-2012

	ACTUAL_SALE_ PRICE	CLASS5	CLASS6	DRIVE_DIST_YVR_ KM_FINAL	DRIVE_TIME_TO _YVR_FINAL	EFFECTIVE YEAR BUILT	SALE_YEAR
Mean	619674.6	0.047550	0.958213	8.208646	0.205495	1995.744	2008.045
Median	260000.0	0.000000	1.000000	7.000000	0.200000	1997.000	2008.000
Maximum	33000000	1.000000	1.000000	19.20000	0.333333	2010.000	2012.000
Minimum	1.000000	0.000000	0.000000	0.000000	0.000000	1952.000	2005.000
Std. Dev.	2119164.	0.212967	0.200246	2.941127	0.050398	7.517017	2.273384
Skewness	11.44386	4.252085	-4.579808	1.121841	0.122371	-1.200808	0.309098
Kurtosis	162.9019	19.08023	21.97464	3.781764	2.599427	6.695163	1.807107
Jarque-Bera	754507.2	9568.369	12837.14	163.2421	6.371998	561.6192	52.19919
Probability	0.000000	0.000000	0.000000	0.000000	0.041337	0.000000	0.000000
Sum	4.30E+08	33.00000	665.0000	5696.800	142.6133	1385046.	1393583.
Sum Sq. Dev.	3.11E+15	31.43084	27.78818	5994.608	1.760219	39158.35	3581.615
Observations	694	694	694	694	694	694	694

Table 2 – OLS for repeat sales, Richmond, BC Canada, 2005-2012

Dependent Variable: LOG(ACTUAL_SALE_PRICE)
Method: Least Squares

Included observations: 694

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	27.68661	40.62112	0.681582	0.4957
60*DRIVE_TIME_TO_YVR_FINAL	0.081950	0.014952	5.480692	0.0000
CLASS6	-0.038324	0.229379	-0.167076	0.8674
EFFECTIVE YEAR BUILT	-0.000119	1.68E-05	-7.086941	0.0000
SALE_YEAR	0.035132	0.019798	1.774554	0.0764

R-squared	0.099536	Mean dependent var	12.43326
Adjusted R-squared	0.094308	S.D. dependent var	1.227262
S.E. of regression	1.167959	Akaike info criterion	3.155571
Sum squared resid	939.8841	Schwarz criterion	3.188298
Log likelihood	-1089.983	Hannan-Quinn criter.	3.168227
F-statistic	19.04023	Durbin-Watson stat	0.916041
Prob(F-statistic)	0.000000		

Table 3 – OLS with Census Dissemination Area (DA) Fixed Effects, Repeat Sales

Dependent Variable: LOG(ACTUAL_SALE_PRICE)
Method: Least Squares (with Census Dissemination Area Fixed Effects)

Included observations: 694

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-4.938210	39.60955	-0.124672	0.9008
60*DRIVE_TIME_TO_YVR_FINAL	0.082674	0.036850	2.243512	0.0252
CLASS6	-0.128362	0.226991	-0.565496	0.5719
EFFECTIVE YEAR BUILT	-0.000112	1.83E-05	-6.127022	0.0000
SALE_YEAR	0.049376	0.019097	2.585478	0.0099
DA2	-0.705653	0.794493	-0.888180	0.3748
DA3	-1.057465	0.174029	-6.076365	0.0000
DA7	-0.730638	0.863035	-0.846592	0.3975
DA9	0.911267	0.820336	1.110845	0.2670
DA10	-1.775138	0.682084	-2.602522	0.0095
DA16	-0.638082	0.250580	-2.546418	0.0111
DA19	1.570062	0.891377	1.761390	0.0786
DA20	0.474469	0.835749	0.567717	0.5704
DA24	1.772217	0.478099	3.706795	0.0002
DA25	-1.502548	0.493851	-3.042513	0.0024
DA26	-0.940547	0.499696	-1.882240	0.0602
DA29	-1.219776	0.275102	-4.433910	0.0000
DA31	-1.063146	0.283781	-3.746357	0.0002
DA33	-1.125972	0.454658	-2.476526	0.0135
DA35	-0.706655	0.297289	-2.376996	0.0177
DA37	-0.585333	0.829213	-0.705890	0.4805
DA40	-1.049151	0.307039	-3.416993	0.0007
DA41	-1.100559	0.281932	-3.903632	0.0001
DA43	-0.609664	0.833086	-0.731814	0.4645
DA44	-0.565766	0.714582	-0.791745	0.4288
DA47	-0.875560	0.343698	-2.547468	0.0111

R-squared	0.224355	Mean dependent var	12.43326
Adjusted R-squared	0.195326	S.D. dependent var	1.227262
S.E. of regression	1.100898	Akaike info criterion	3.066874
Sum squared resid	809.6008	Schwarz criterion	3.237053
Log likelihood	-1038.205	Hannan-Quinn criter.	3.132685
F-statistic	7.728742	Durbin-Watson stat	1.025568
Prob(F-statistic)	0.000000		

*Note: DA dummies are included for DA's that have at least one repeat sales pair

Table 4 – OLS, Differenced Results for Repeat Sales, Including Change in Fourier Repeat Sales Price Index as a Control

Dependent Variable: $\text{Log}(P_{ni,t+j} / P_{nit})$
Method: Least Squares
Included observations: 167
White heteroskedasticity-consistent standard errors & covariance

Variable	Coefficient	Std. Error	t-Statistic	Prob.
$[\alpha_{i,t+j} - \alpha_{i,t}]$	0.110264	0.063131	1.746597	0.0826
$(C_{ni,t+j} - C_{ni,t})$	-0.039958	0.033590	-1.189587	0.2359

R-squared	0.002063	Mean dependent var	0.149021
Adjusted R-squared	-0.003986	S.D. dependent var	1.045659
S.E. of regression	1.047741	Akaike info criterion	2.943053
Sum squared resid	181.1306	Schwarz criterion	2.980395
Log likelihood	-243.7450	Hannan-Quinn criter.	2.958209
Durbin-Watson stat	2.085872		

Note: Included observations are the repeat sales with dates that "straddle" the opening date of the Canada Line

Tables 5a and 5b – LWR Estimates (h=0.50) with Controls for Fourier Price Index (h=1.0) (η_n) and Difference in Travel Times Before and After the Canada Line Opening (θ_n)

Dependent Variable: $Log(P_{ni,t+j} / P_{nit})$

Table 5a: Descriptive Statistics for η_n, h=0.5

Categorized by values of η_n
Included observations: 167 after adjustments

η_n	Mean	Max	Min.	Std. Dev.	Obs.
[-10, -5)	-7.397172	-7.068105	-7.726239	0.465371	2
[-5, 0)	-0.561561	-0.034603	-1.335603	0.684790	3
[0, 5)	0.873546	4.823422	0.000000	1.137615	120
[5, 10)	7.785317	9.250112	5.275766	1.695312	11
[10, 15)	11.88631	14.26384	10.12440	1.297835	19
[15, 20)	19.98289	19.98289	19.98289	NA	1
[20, 25)	21.68758	23.17227	20.01475	1.450085	7
[90, 95)	92.28593	92.28593	92.28593	NA	1
[525, 530)	527.6229	527.6229	527.6229	NA	1
[845, 850)	847.8840	847.8840	847.8840	NA	1
[3015, 3020)	3018.288	3018.288	3018.288	NA	1
All	30.28564	3018.288	-7.726239	245.0740	167

***164 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Table 5b: Descriptive Statistics for θ_n, h=0.5

Categorized by values of θ_n
Included observations: 167 after adjustments

θ_n	Mean	Max	Min.	Std. Dev.	Obs.
[-0.8, -0.6)	-0.608853	-0.601137	-0.617261	0.008084	3
[-0.6, -0.4)	-0.508431	-0.404461	-0.587474	0.053752	15
[-0.4, -0.2)	-0.245386	-0.211072	-0.290872	0.036907	5
[-0.2, 0)	-0.039745	-0.000332	-0.164682	0.031554	86
[0, 0.2)	0.038636	0.169347	0.000000	0.049626	56
[0.2, 0.4)	0.257308	0.257308	0.257308	NA	1
[0.4, 0.6)	0.409583	0.409583	0.409583	NA	1
All	-0.067470	0.409583	-0.617261	0.177839	167

***113 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Note: Included observations are those that “straddle” the opening date of the Canada Line

Tables 6a and 6b – LWR Estimates (h=0.75) with Controls for Fourier Price Index (h=1.0) (η_n) and Difference in Travel Times Before and After the Canada Line Opening (θ_n)

Dependent Variable: $\text{Log}(P_{ni,t+j} / P_{nit})$

Table 6a: Descriptive Statistics for η_n, h=0.75
Categorized by values of η_n

Included observations: 167 after adjustments

η_n	Mean	Max	Min.	Std. Dev.	Obs.
[-4, -2)	-2.991337	-2.991337	-2.991337	NA	1
[0, 2)	0.429694	1.863542	0.008600	0.602247	113
[2, 4)	3.309740	3.987975	2.571204	0.500481	10
[4, 6)	5.265506	5.902491	4.295768	0.676293	8
[6, 8)	7.460965	7.959441	6.630902	0.379746	12
[8, 10)	8.746905	9.874509	8.025239	0.784218	7
[10, 12)	11.04226	11.98622	10.34218	0.697803	4
[12, 14)	12.69750	13.62154	12.09856	0.558897	8
[76, 78)	76.12285	76.12285	76.12285	NA	1
[544, 546)	544.9912	544.9912	544.9912	NA	1
[826, 828)	827.2128	827.2128	827.2128	NA	1
[1518, 1520)	1518.804	1518.804	1518.804	NA	1
All	20.26602	1518.804	-2.991337	139.4625	167

*** 164 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Table 6b: Descriptive Statistics for θ_n, h=0.75
Categorized by values of θ_n

Included observations: 167 after adjustments

θ_n	Mean	Max	Min.	Std. Dev.	Obs.
[-0.5, -0.4)	-0.436277	-0.400531	-0.484040	0.031954	8
[-0.4, -0.3)	-0.365744	-0.308231	-0.399438	0.032511	11
[-0.3, -0.2)	-0.230529	-0.208561	-0.262930	0.027185	5
[-0.2, -0.1)	-0.144733	-0.108383	-0.197892	0.047063	3
[-0.1, 0)	-0.044684	-0.001731	-0.099624	0.025545	85
[0, 0.1)	0.027175	0.097423	0.003433	0.015556	53
[0.1, 0.2)	0.144133	0.171446	0.116820	0.038626	2
All	-0.066885	0.171446	-0.484040	0.132629	167

*** 119 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Note: Included observations are those that "straddle" the opening date of the Canada Line

Tables 7a and 7b – LWR Estimates (h=1.0) with Controls for Fourier Price Index (h=1.0) (η_n) and Difference in Travel Times Before and After the Canada Line Opening (θ_n)

Dependent Variable: $Log(P_{ni,t+j} / P_{nit})$

Table 7a: Descriptive Statistics for η_n, h=1.0
Categorized by values of η_n
Included observations: 167 after adjustments

η_n	Mean	Max	Min.	Std. Dev.	Obs.
[-22, -21)	-21.69835	-21.69835	-21.69835	NA	1
[-2, -1)	-1.812456	-1.812456	-1.812456	NA	1
[0, 1)	0.133878	0.995347	0.010829	0.183413	95
[1, 2)	1.458350	1.888966	1.034444	0.329877	21
[2, 3)	2.512039	2.882883	2.116654	0.204976	13
[3, 4)	3.228808	3.671265	3.025604	0.298129	4
[4, 5)	4.592086	4.625518	4.576061	0.022687	4
[5, 6)	5.609995	5.896358	5.207208	0.199049	11
[10, 11)	10.83270	10.98330	10.75541	0.130431	3
[11, 12)	11.59362	11.96428	11.13534	0.396046	4
[12, 13)	12.37348	12.81861	12.01389	0.350798	6
[13, 14)	13.19337	13.19337	13.19337	NA	1
[253, 254)	253.5694	253.5694	253.5694	NA	1
[552, 553)	552.7660	552.7660	552.7660	NA	1
[695, 696)	695.5926	695.5926	695.5926	NA	1
All	10.86059	695.5926	-21.69835	71.01093	167

***149 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Table 7b: Descriptive Statistics for θ_n, h=1.0
Categorized by values of θ_n
Included observations: 167 after adjustments

θ_n	Mean	Max	Min.	Std. Dev.	Obs.
[-0.4, -0.35)	-0.365056	-0.352077	-0.388066	0.011035	11
[-0.35, -0.3)	-0.346052	-0.346052	-0.346052	NA	1
[-0.3, -0.25)	-0.291132	-0.290219	-0.292079	0.000760	4
[-0.25, -0.2)	-0.224024	-0.220083	-0.227965	0.005574	2
[-0.2, -0.15)	-0.178711	-0.150178	-0.197625	0.020159	4
[-0.15, -0.1)	-0.128960	-0.100153	-0.147526	0.022077	5
[-0.1, -0.05)	-0.076865	-0.050687	-0.092788	0.012633	24
[-0.05, 0)	-0.037873	-0.001127	-0.049557	0.009439	71
[0, 0.05)	0.027654	0.047796	0.011703	0.010018	40
[0.05, 0.1)	0.067856	0.094671	0.055896	0.015650	5
All	-0.062408	0.094671	-0.388066	0.107042	167

**150 observations have statistically significant coefficients (5% level, two-tailed), based on the magnitude of the t-statistic for each observation (computed based on standard errors of each coefficient estimate)

Note: Included observations are those that "straddle" the opening date of the Canada Line

Tables 8a, 8b, 8c: OLS Regressions of t-statistics for θ_n (marginal effect of time savings from rail rapid transit) vs. $C_{ni,t+j} - C_{ni,t}$ (change in travel time when rail rapid transit opens)
Note: Included observations are those that "straddle" the opening date of the Canada Line

Table 8a: Dependent Variable: T-STATISTIC for θ_n (h=0.5)
Method: Least Squares
Sample: 1 167 IF η_n <8 AND η_n >0
Included observations: 123

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	0.602523	2.281571	0.264083	0.7922
$(C_{ni,t+j} - C_{ni,t})$	-0.324316	1.018181	-0.318524	0.7506

R-squared	0.000838	Mean dependent var	0.803160
Adjusted R-squared	-0.007420	S.D. dependent var	24.23068
S.E. of regression	24.32041	Akaike info criterion	9.236635
Sum squared resid	71569.37	Schwarz criterion	9.282362
Log likelihood	-566.0531	Hannan-Quinn criter.	9.255210
F-statistic	0.101458	Durbin-Watson stat	1.512749
Prob(F-statistic)	0.750636		

Table 8b: Dependent Variable: T-STATISTIC for θ_n (h=0.75)
Method: Least Squares
Sample: 1 167 IF η_n <8 AND η_n >0
Included observations: 143

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-2.123818	0.531475	-3.996080	0.0001
$(C_{ni,t+j} - C_{ni,t})$	0.723460	0.231172	3.129524	0.0021

R-squared	0.064949	Mean dependent var	-2.326861
Adjusted R-squared	0.058317	S.D. dependent var	6.500375
S.E. of regression	6.307986	Akaike info criterion	6.535397
Sum squared resid	5610.486	Schwarz criterion	6.576836
Log likelihood	-465.2809	Hannan-Quinn criter.	6.552236
F-statistic	9.793922	Durbin-Watson stat	0.894583
Prob(F-statistic)	0.002128		

Table 8c: Dependent Variable: T-STATISTIC for θ_n (h=1.0)
Method: Least Squares
Sample: 1 167 IF η_n <8 AND η_n >0
Included observations: 148

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	-2.180784	0.322881	-6.754135	0.0000
$(C_{ni,t+j} - C_{ni,t})$	0.828356	0.139247	5.948811	0.0000

R-squared	0.195097	Mean dependent var	-2.327917
Adjusted R-squared	0.189584	S.D. dependent var	4.350526
S.E. of regression	3.916479	Akaike info criterion	5.581684
Sum squared resid	2239.466	Schwarz criterion	5.622187
Log likelihood	-411.0446	Hannan-Quinn criter.	5.598141
F-statistic	35.38835	Durbin-Watson stat	0.632932
Prob(F-statistic)	0.000000		

Table 9: Falsification Tests: F-Statistics for Locally Weighted Regressions (equation (8))

Dependent Variable: $\mathrm{Log}(P_{ni,t+j} / P_{nit})$

	Parameter	F-Stat	P-Value
	η_n	1.5939	0.2077
h=1.0	ξ_n	1.3535	0.2455
n=328	$D\times\theta_n$	7.0855	0.0082
	η_n	1.8574	0.1739
h=0.75	ξ_n	1.1582	0.2826
n=328	$D\times\theta_n$	8.0879	0.0047
	η_n	2.0807	0.1501
h=0.50	ξ_n	1.0304	0.3108
n=328	$D\times\theta_n$	7.6418	0.0060

Note: The observations considered are those for which both repeat sales occur before the opening of the rail rapid transit, and the observations for which the dates of a pair of repeat sales straddle the opening of the rail rapid transit line. D is a dummy variable that takes the value of 1 when the dates of a pair of repeat sales straddle the opening of the rail rapid transit line, and 0 otherwise.