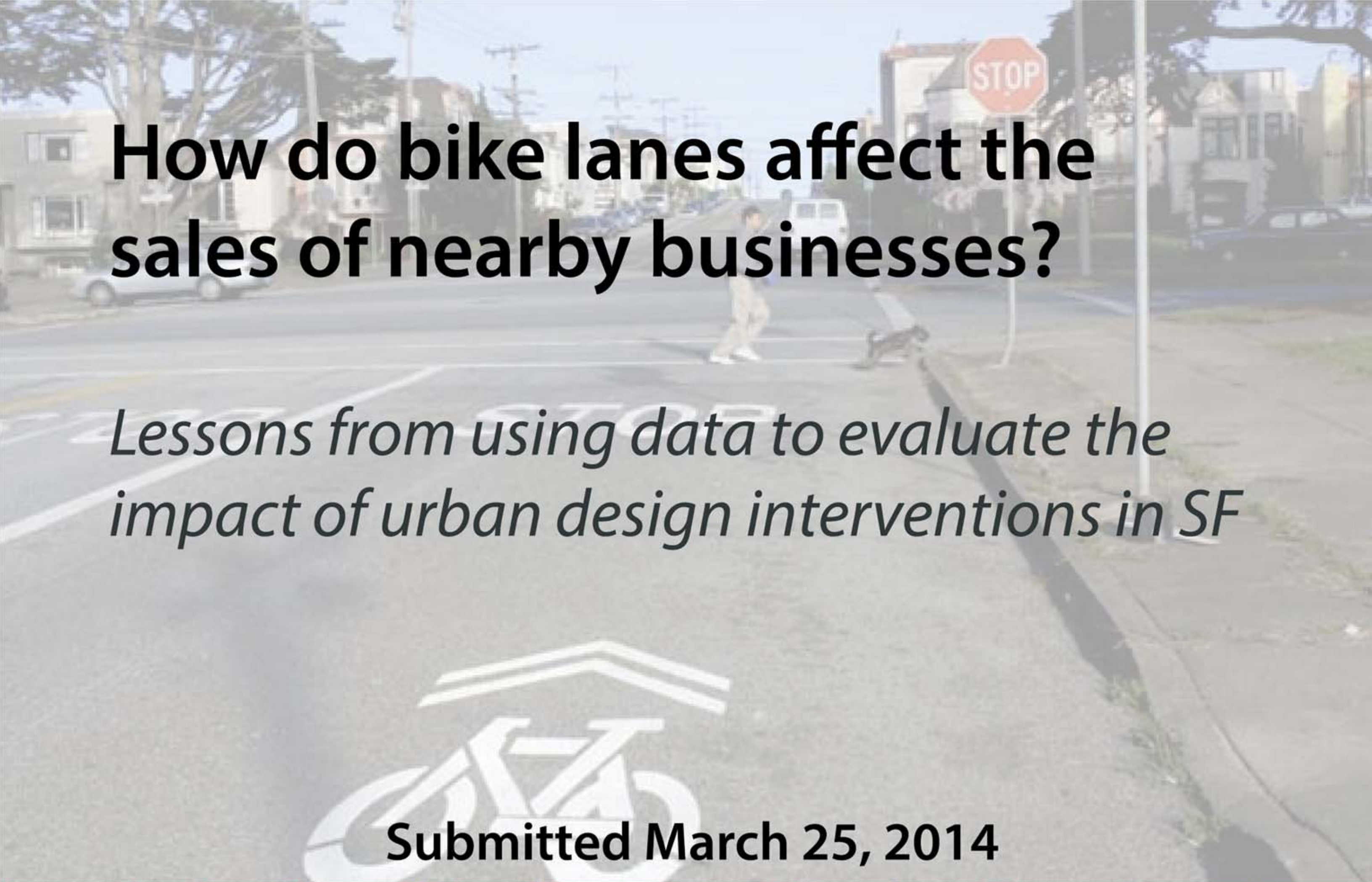


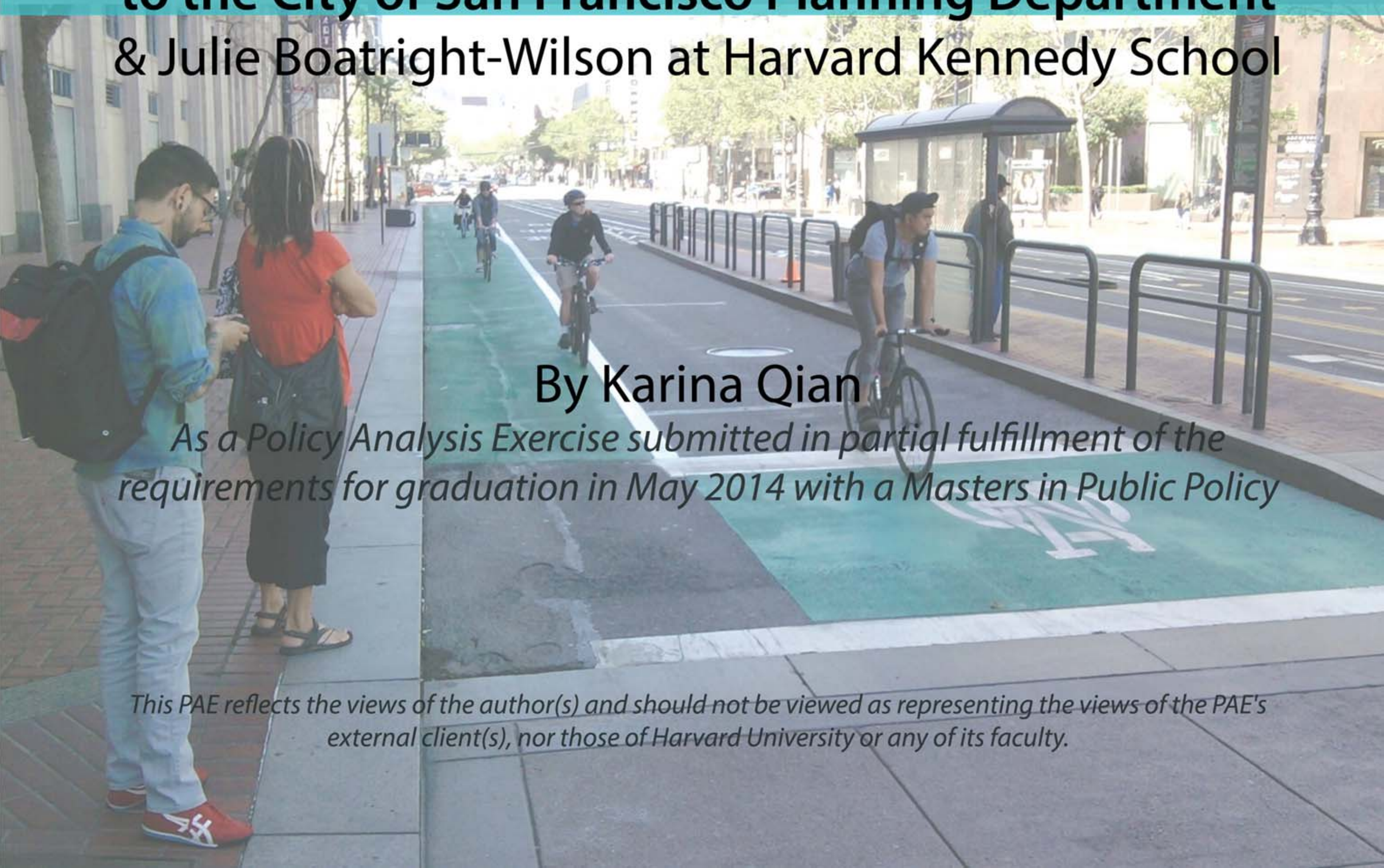
How do bike lanes affect the sales of nearby businesses?

Lessons from using data to evaluate the impact of urban design interventions in SF

Submitted March 25, 2014

to the City of San Francisco Planning Department

& Julie Boatright-Wilson at Harvard Kennedy School



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As a Policy Analysis Exercise submitted in partial fulfillment of the requirements for graduation in May 2014 with a Masters in Public Policy

Executive Summary

A common dilemma faced by city planners is whether street design interventions designed to promote a mode shift to sustainable transit, traffic calming, bicycle and pedestrian safety and greater public access and mobility have negative effects on nearby businesses and the surrounding community.

Some studies, especially recently, have attempted to articulate the effects of bike lanes on businesses using surveys or by comparing retail sales trends on streets before and after the installation of a bike lane. However, none thus far have used robust statistical analysis to evaluate whether the bike lane had any significant effect on business health that can be directly associated with the bike lane, rather than with larger economic forces in the city, variation over time or unmeasured business characteristics.

This study combines spatial and statistical analysis to construct a business-level panel dataset that eliminates these potential confounding effects, and investigates whether bike lane creation in 2010 and 2011 in accordance with the 2005 Bike Lane Plan had any effect on business health. It uses data from 2,211 businesses in San Francisco from 2008 to 2012, including businesses that started out over 4 blocks away but in 2010 and 2011 became within 250 feet (less than a block) of a bike lane (the "treatment group") and those that as of 2012 were still over blocks away (the "control group").

I investigate multiple different specifications and levels of stratified analysis, and find no statistically significant evidence that bike lanes have any negative effect on businesses. In fact, I find that bike lane creation can have a positive, statistically significant association with the percentage increase in sales growth – but that this effect is likely limited to a small subset of the population of businesses.

So while bike lanes don't hurt businesses, they only help certain kinds of businesses – and thereby may indirectly disadvantage others. As a physical construction, bike lanes may be value neutral, but they do not exist in a vaccum and therefore simultaneously reflect the preferences of its most frequent users and impact the life and lanscape of the surrounding community.

These reflected preferences make themselves known in this data. The data shows that bike lane construction is **only associated with a statistically significant increase in the sales volume growth rate for small businesses not owned by minorities, businesses broadly in the leisure and service industries and in neighborhoods that are either highly educated and have an average household size of two or that are (presumably lesser educated) and have an average household size of four.**

In short, bike lanes are associated with and likely facilitate the ongoing demographic and socio-economic changes in San Francisco. This is not to say that bike lanes are should not be constructed or that stopping them will halt gentrification. (Indeed, this study only evaluates the marginal effect of striping bike lanes that were planned in 2005 and have been informally in use for several years before they were formalized.) Bike lanes have always been one of the cheapest forms of transportation available, and are a very effective transit policy insfoar as they reduce traffic and increase cyclist safety.

However, in making these planning decisions the City should consider their roughly quantifable effect on communities and craft integrated intiatives to help ensure that all citizens benefit. For example, if the City plans on striping a bike lane in a majority minority neighborhood with average household size 4 and a mix of minority and not minority-owned small businesses. I would recommend that the City pair this infrastructure development with additional programs. For example, the installation of a bike sharing hub

in the neighborhood, a bicycle education program for local residents and free first-month passes. And for the businesses, promotion of the minority-owned small businesses in particular as part of a cultural 'introduction to the neighborhood' that can be featured at the bike sharing hub, or subsidized bike parking spots near minority-owned businesses.

Soliciting community input has long been integrated into city planning processes, including for transit projects. However, **this study lays out consistent, quantitative guidelines and specific recommendations for evaluating the impact of urban design projects like bike lanes on communities so that they can be more effectively targeted for the net benefit.** It argues that in designing infrastructure improvements like bike lanes, policymakers should also explicitly account for the larger socio-economic and cultural context in that community in order to design more equitable, integrated – and ultimately, sustainable – initiatives.

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I. Introduction

Cyclist unions and local businesses have filled town halls across the country with strenuous debates on whether the particular placement of a bike lane will hurt their sales by taking away parking spaces their customers depend on – or even perhaps facilitate a fundamental change in the neighborhood streetlife.

This debate was playing out last year in San Francisco, where local business owners and residents have strongly opposed the removal of nearly 170 street parking spaces in fear of a negative impact on their sales amid greater competition for parking.[i] And in New York, business owners had bristled at plans to create a new protected bike lane on Columbus Avenue and continue to oppose plans to create a protected bike lane on Amsterdam Avenue.[ii] There is evidence that these improvements can reduce congestion, improve air quality and cyclist safety and perhaps even lead to healthier communities. The argument can be made that they are effective policies – but whether they are desirable and a net benefit for the community must be balanced with this possibility of negative, economic externalities.

A. Literature Review

Despite the prevalence of discussion in cities, this issue has received little attention from urban economists. Most analysis that exists on this subject has been conducted using surveys and case studies that do not use quantitative data or statistical comparisons that don't prove causality or correlation.

For example, Drennen (2003) studies the impact of bike lanes on businesses through interviews of 27 merchants in the Mission District of San Francisco to conclude that "bike lanes have had a generally positive impact on their business and/or sales." [iii] A similar study in Toronto surveyed the opinions of 61 merchants and 538 patrons and analyzed parking usage data to argue that the creation of bike lanes "will likely increase commercial activity."[iv]

Planners and urban policymakers have recognized the need for more rigorous econometric analysis and, indeed, some practitioners have progressed to utilizing economic data to answer this question. Two recent studies have implemented analyses using "impartial data that is a direct measure of economic activity; accounts before-and-after changes, which occur in a short span of time; and measures impact in a small geographic area."[v]

Rowe (2013) analyses the impact of bike lanes on neighborhood business districts in Seattle by comparing taxable retail sales data for neighborhood business districts in which bike lanes were and were not installed, both before and after the actual bike lane installation to find at least in one neighborhood a "400% increase in taxable retail sales data after a bicycle facility [was] installed."[vi] However, by merely comparing before and after figures Rowe fails to determine whether there is a statistically significant correlation or if that 400% spike in sales index was actually due to the bike lane installation or perhaps merely within the range of normal variation in sales for those areas. He argues that the increase in sales could be driven by the fact that while motorists may spend the most per visit, cyclists visit stores more frequently and therefore spend the most per month.

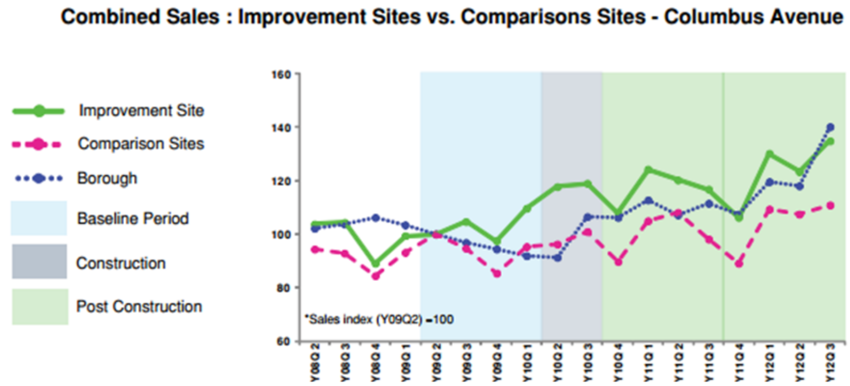

Figure 1. Example before and after retail sales graph from 2013 NYC DOT study.

While pioneering in its use of quantitative data, the 2013 NYC Department of Transportation study “The Economic Benefits of Sustainable Streets” faces similar problems. The study concludes that streets with bike lanes generated increased retail sales in all types of neighborhoods and all types of businesses, including lower-income areas with small mom & pop stores or higher-income areas with high rents. Again, it merely looks at before and after sales tax data for streets where bike lanes were and were not installed. In some cases, they compare sales tax for businesses along the exact length of road onto which bike lanes were striped and compare them to data for businesses on the same road before and after the bike lane starts or on the street down the block without accounting for perhaps spillover effects or, again, differences endogenous to the businesses that might have reacted with the external economic situation to amplify sales volume independent of the bike lane creation.

At their core, these articles argue that bike lanes may not hurt businesses and could actually increase sales. First, it is easier for cyclists to stop by a store they find interesting just because they bike past it, whereas motorists are most likely to just drive to their destination because parking can be so difficult to find and other people in the car may not be similarly inclined. Cyclists by default must be more aware of their surroundings and pay more attention to streets, stores and people than drivers who could be distracted by the radio, a phone call or conversation with others in the car.

Second, installing bike lanes introduces stores to a new population of potential customers – people who don’t own cars and primarily bike. This is especially true in areas that may be under-served by public transit, and therefore hard to access for people who don’t drive.

Third, installing bike lanes may fundamentally change the composition of a neighborhood because new sources and types of population demand are introduced with the creation of bike lanes. People who may never have previously thought to visit a part of the city may go there regularly because it is a more convenient bicycle commute; others may simply bike by as part of an exercise routine, become interested in a shop and therefore integrate activities there into their regular routine. Business owners and residents may also change their patterns accordingly, and increasingly conduct routine activities and errands by bike. People who are moving into a city may also make housing and even commercial rental choices accordingly, especially if they prefer to bike – or, at least in San Francisco, prefer to not own a car. Therefore, there is a long-term argument that bike lanes open up the door for a more fundamental change in the composition and rhythm of a neighborhood in the long-term.

Centrally, this literature all intends to find an empirically accurate answer to this classic development question. Urban policymakers and transportation planners alike recognize that a rigorous, data-driven methodology to document the economic impact of changes in street design on nearby businesses gives us a much more powerful tool for measuring the efficacy of these policies and understanding the full scale of their costs and benefits. Finally, using a full econometric model also allows us to actually integrate basic predictive analytics into cities’ urban design plans to broadly predict and test the impact of specific intervention decisions and therefore better locate street interventions to promote economic development and overall community well-being.

B. Context of this paper

This paper therefore seeks to fill this void by using rigorous econometric techniques to 1) determine whether there is a statistically significant correlation between the creation of bike lanes and the health of nearby businesses and 2) get as close as possible to causation to understand the unique effect of these streetscape interventions.

I focused on the City of San Francisco as a case study for this analysis, since they were open about specific data required to measure business health. However, this choice comes with a couple caveats.

First and most usefully, there was an injunction against the creation of new bike lanes in San Francisco from late June 2006 to August 6, 2010 on the grounds that an environmental review under the California Environmental Quality Act must first be conducted. The City's planning department has always been guided by a multi-year, strategic San Francisco Bicycle Plan. The current plan in place was originally formulated and unanimously approved by the Board of Supervisors on June 7, 2005 but as a result of the injunction did not begin to be implemented until late 2010. No bike lanes were constructed from 2005-2010, with the exception of a handful of intersections that were striped in 2009 with the permission of a court order since they were needed to join disconnected bike lanes and therefore were critical to cyclist safety. This provides us with a useful discontinuity in the sense that though a bike network existed in those years one can assume that any effect of bike lanes constructed previously had smoothed over and already been incorporated into existing sales trends by 2008. Therefore, from 2008-late 2010 there is a fully delineated pre-treatment period where no new "treatments" were applied.

Second, there was a national housing bubble and then a significant economic recession in this time period. For San Francisco, the peak of that bubble was 2007, the trough of that recession was in 2009 and the city has been attempting to recover ever since – though out of all the cities in the US, San Francisco was one of the least affected. However, any analysis must control for these external economic shocks and natural regression to the mean that may have been occurring with economic recovery starting in 2010 – just when the injunction against bike lanes was lifted.

Lastly, San Francisco is undergoing a dramatic demographic and socio-economic change with increasing gentrification in some of the city's older and traditionally higher percentage minority and low income districts like the Mission. This transformation is also being driven by a specific population subset: young, highly educated single or just married white and Asian[vii] tech professionals moving in who are buoyed by the fat paychecks of the tech boom that started in Silicon Valley just south but has been expanding into the City proper. This transformation also manifests uniquely on the street: in boutique, artisanal, local, and organic goods and food stores that sell anything from craft beer to organic, custom-made liquid nitrogen ice cream and Victorian-style corset stores. It has boosted San Francisco to the top of national rankings of income inequality. And arguably, as this paper will show, this transformation is partly being facilitated by bike lanes since bicycles are a common form of transportation utilized by this new population subset. Careful work needs to be taken to disentangle the correlated effect of bike lanes and increased sales for such luxury goods businesses, which may both be driven by these large socio-economic and demographic trends.

II. Research design

A. Data sources

This study uses data on bike lanes and the economic health of businesses in San Francisco. For the bike lane data, I used the San Francisco Metropolitan Transit Agency (SFMTA)'s publicly available ArcGIS shapefile. This file both spatially locates where bike lanes were installed and provides an adjoining database of information on year installed, street name and length of the bike lane, among others. This data is flawed insofar as it does not distinguish between different, specific types of bike lanes (e.g. protected versus sharrows), does not denote when and how many parking spaces have been replaced and in some cases is simply inconsistent in defining whether a new bike lane has actually been installed or whether an old one has simply been re-striped. However, while I will recommend that the City begin collecting these additional variables moving forward, in the interim this is the best data available. And out of the years for which there is data, the City verified that 2010 and 2011 had the most accurate data on the actual creation of bike lanes – partially due to the injunction discussed above.

For economic health data, this study uses both firm-level sales volume data and neighborhood-level sales tax data to approximate economic health both in terms of scale and margins. Specifically, it primarily uses data disaggregated at the firm level on an annual basis across 6 years (from 2008 to 2012) in San Francisco. I use data from Dun & Bradstreet for every business in San Francisco in these years. This data includes a unique DUNSNUMBER (ID) for each business, sales volume data every year and a wealth of other information including line of business, Standard Industry Classification (SIC), number of employees, etc. It has limitations – the sales volume data is self-reported or if unavailable, projected based on sales gained by other, similar businesses in the area. However, it is the best available data recording the economic growth of businesses in the US today and is the data currently used by the City – other than retail sales tax data, which by law cannot be disaggregated at the individual level.

The City of San Francisco generously provided sales tax data for the impact areas, which I use to validate the conclusions reached and help offset flaws in the Dun & Bradstreet data.

Finally, I spatially joined in 2010 Census data to the businesses to give a flavor of what the different surroundings neighborhoods look like. Therefore, each business 'entry' within the final dataset also includes information from the surrounding Census tract. This is all based on the hypothesis that bike lanes may affect stores in, for example, a majority 2-person household neighborhood differently than those in a Census tract averaging 4+ person families.

B. Methodology

Broadly, the methodology has two steps:

1. Using ArcGIS to identify those businesses in San Francisco within 250 feet (the treatment group) and over 2000 feet (the control group) of bike lane construction in 2010 and 2011 and aggregating panel data on their distance to a bike lane and sales volume for the study period;

2. Using statistical analysis to evaluate whether treatment – the construction of a bike lane in the immediate impact area – had a statistically significant impact on business health in terms of sales volume and sales tax.

Figure 2. Treatment and control businesses for bike lane year 2010. Bike lane network before 2010 in dark grey, bike lanes constructed in 2010 in purple and bike lanes constructed in 2011 in orange. 2010 treatment businesses within 250 feet in light purple, control businesses in light gray.

To detect the impact of bike lane construction in San Francisco, I compare the evolution in percent change in sales volume for all businesses within a 250-feet (roughly 1 block) "impact area" around each bike lane to the evolution of percent change in sales volume for businesses located more than 2000-feet (4 blocks) away from any bike lane constructed in either 2010 or 2011.

I use panel data fixed-effects estimators to control for the presence of unmeasured characteristics unique to each individual firm in our dataset. I selected a 1 block impact area since most other studies only looked at the immediate block surrounding an installed bike lane, and because one might expect the largest effect on those businesses immediately adjacent to a bike lane. I selected a control area over 2000 feet away because in nearly all studies of transit or public housing impact the largest impact area taken is 2000 feet.[viii] I discarded all businesses that were in the 250-foot impact area throughout the study period, limiting the treatment group to businesses that were over 2000 feet away before the treatment year and came within 250 feet as a result of treatment. I constrained the control group to businesses that stayed over 2000 feet away from a bike lane throughout the study period. Therefore, the study should capture the greatest contrast in terms of businesses most and least affected by the creation of a bike lane. Instead of using pure sales volume data, I used the year-on-year percent change

Figure 3. Zoomed in view of treatment businesses in 2010 near the Embarcadero.

in sales volume because volume can vary widely across industries (e.g. grocery stores operate at much higher volume than car dealerships) so I could more comparably analyze economic health across businesses. The sample period is restricted to 2008-2012 to ensure that we have a relatively balanced amount of pre- and post- treatment data given the treatment years of 2010 and 2011.

I dropped businesses with missing sales volume data in the exact year of treatment and if there was no 2012 sales volume data for businesses that were 'treated' in 2012. This way, I ensured that there would be at least one pre-, post- and during treatment data point for each businesses. The final dataset is an unbalanced panel with a total of 2,211 unique businesses in San Francisco for which we have an average of 4.3 years' sales volume data each.

Of these, 260 are the treatment group and 1,951 are in the control group. The treatment group is relatively small because many of the businesses that fall within 250 feet of a bike lane constructed in 2010 and 2011 were already within 250 feet of the existing bike network. These are the few who were substantially affected by the treatment, going from a distance of over 2000 feet from a bike lane to within 250 feet in a year's time – see Table 1 for details.

Table 1
Average distance to a bike lane (feet), by year for treatment and control businesses

	(1) Entire sample	(2) Treatment	(3) Treatment Year 201(	(4) Treatment Year 2011	(5) Control
2008	3347.37	3432.08	4402.86	2708.88	3449.41
2009	3294.12	3349.88	4402.86	2484.11	3287.09
2010	2526.04	1006.15	129.87	1898.81	2694.66
2011	2085.18	126.40	124.31	127.97	2346.61
2012	1412.32	119.93	124.31	116.68	1668.23
Number of businesses in the sample	2,211	260	111	149	1,951

I used fixed effects estimators to study the impact of bike lanes on the treatment and control areas of the study. The basic regression specification is

$$salesgrowth_{bt} = \propto (treatment_b \; x \; post_t) + f_t + \eta_b + \varepsilon_{bt} \qquad (1)$$

where $salesgrowth_{bt}$ is the percent growth in sales in business *b* and year *t*, $treatment_b \; x \; post_t$ is a dummy variable that takes value one if the business *b* is located in the impact area of a bike lane and the year of the observation, *t*, is after the treatment (a bike lane) has been applied. Therefore, it takes value one if the business is within the impact area that is hypothesized to experience a change in sales growth as a result of the adjacent construction of a bike lane and the time period is after that installation has been completed. The variable f_t represents the time effect resulting from the shared experience of the external shocks to the San Francisco economy due to the national recession and the concurrent, expanding tech bubble. It uses year dummies to capture the overall business trends in the San Francisco economy in the study period. η_b represents individual firm effects, or time-invariant business-specific characteristics for each building *b*, which are potentially correlated with the direction and magnitude of the treatment effect. For example, η_b would attempt to capture the effect if, say, an ice cream store in the treatment area were started by a prominent member of the cyclist union and this ownership connection had a statistically significant correlation with an increase in ice cream sales after the installation of a bike lane. Finally, ε_{bt} represents business-specific temporary shocks. In all these estimators, observations are benchmarked against previous sales in order to ensure that percent growth is comparable across all different businesses.

This study assumes that, in the absence of bike lane construction, treatment and control areas would have experienced similar sales trends. The variable $\propto$ represents the impact bike lane construction had on sales for businesses in San Francisco. If the bike lane construction hurt sales, then $\propto$ should be negative. If bike lane construction helped sales, then $\propto$ should be positive. If $\propto$ is statistically significant, the effect was outside the normal variation in that firm's sales volume when controlling for time, firm and external economic effects – and therefore is likely directly associated with bike lane construction.

C. Potential sources of bias

Observational statistical results always must be qualified. The value of $\propto$ does not necessarily directly identify the magnitude of this effect since there are multiple sources of potential bias.

First, these bike lanes were striped as part of the 2005 Bike Lane Plan. Yet according to the San Francisco Cyclists' Union, they were part of an already existing, informal bike network that was already being utilized by cyclists as far back as the early 2000s. The most critical and perhaps only change in 2010 and 2011 in terms of treatment was the actual striping of the bike lane and in some areas, construction of protected areas, green lines and sharrows meant to highlight its function. To some extent, impact areas had already been exposed to an early version of the treatment – and since no bike lanes were created from 2005-2010, accustomed to their effects. However, one might anticipate that such an effect would increase the bike safety of those routes, and therefore increase their use. As such, this bias would only enhance the statistical power of our tests for the null hypothesis since we would only pick up on the potentially marginal effects of striping an already in-use informal bike lane.

Second, the question itself is premised on an endogenous bias – businesses often lobby against the adjacent placement of bike lanes, perhaps correctly because their sales might be affected. Insofar as businesses have some say in where bike lanes are placed, there is a bias toward a positive effect. One could argue that businesses that could truly be hurt by bike lanes will vehemently oppose them or move away. Thus, only businesses near bike lanes would be ones that do not anticipate a negative effect on their sales. Such endogenous bias would wholly invalidate our results. However, two factors offset this bias. First, these bike lanes already informally existed. Second, the bike lanes constructed in 2010 and 2011 after the injunction was lifted did not deviate from the 2005 multi-year strategic plan adopted by the Board of Supervisors. Therefore, starting from 2005, businesses had little say in bike lane placement – especially since the injunction was lifted without any fundamental change to the original plan. And arguably, businesses had little say even before if cyclists were already using these routes informally. Businesses that would truly be hurt by bike lanes would have either already gone out of businesses, adjusted accordingly or even moved away in the 5 years between the filing of the injunction and its lifting – and perhaps even before once people began biking informally on those streets.

Another source of bias is the potential substitution effect between treatment and control areas after bike lanes were installed. The comparison of these groups encompasses two potential effects of bike lanes: positive or negative effects on the sales growth of businesses in the impact area and, assuming that consumers still demand these goods, the corollary negative or positive effects on businesses outside the impact area with no bike lanes. This tests the theory that if I can no longer park to buy ice cream at this store due to the installation of a bike lane, I will instead choose to go to an alternative ice cream shop without bike lanes in order to satisfy my sweet tooth. This bias would accentuate the power of the statistical tests by amplifying the difference in sales growth in treatment and control areas.

D. Additional levels of analysis

i. Dose-response designs

Finally, in order to further validate the results, I employ three additional levels of analysis. First, I use a dose-response design in which a business' exposure to the impact of bike lanes is generated as the distance as a continuous variable to the nearest bike lane:

$$salesgrowth_{bt} = \propto (distance\ to\ nearest\ bike\ lane_b) + f_t + \eta_b + \varepsilon_{bt} \qquad (2)$$

Here, $distance\ to\ nearest\ bike\ lane_b$ is the distance between business *b* and the closest bike lane in the entire SF bike lane network that year. Through this analysis, it is possible to see evaluate whether it is not just placement within a specific impact area that has an impact on sales but if the effect of bike lanes varies directly and continuously over distance. This allows us to test whether a business 1500 feet away from a bike lane might experience a different effect from a similar business that is 2000 feet away.

Next, I use a dose-response design in which I analyze the potential for an unique effect of businesses' exposure to bike lanes created in 2010 and 2011 under the 2005 Bike Plan.

$$salesgrowth_{bt} = \propto (distance\ to\ nearest\ bike\ lane_b\ x\ post_t) + f_t + \eta_b + \varepsilon_{bt} \qquad (3)$$

Exposure to bike lanes in 2010 and 2011 is constructed as the interaction between the post-treatment dummy $post_t$ and distance to the closest treatment bike lane ($distance\ to\ nearest\ bike\ lane_b$) for each business *b*. This model evaluates whether businesses in the post-treatment years experience a differential effect based on absolute proximity to the newly-updated bike network.

Finally, I test the below model, which includes both the treatment variable and the first dose-response design to see whether there is a statistically significant effect to both being within the impact area and more generally in greater proximity to a bike lane.

$$salesgrowth_{bt} = \propto \left(distance\ to\ nearest\ bike\ lane_b + (treatment_b\ x\ post_t)\right) + f_t + \eta_b + \varepsilon_{bt} \qquad (4)$$

ii. Stratified analysis

Figure 4. Treatment and control businesses for bike lane year 2010, by classification as a small business. Dark purple and dark gray are treatment and control small businesses, respectively. Light purple and light gray are treatment and control 'large' businesses.

Second, I use stratified analysis to see if the effect of bike lanes differs across three levels of business differentiation –

1. **Business characteristics** – registration as a small and/or minority-owned business, and years in operation

2. **Business classification** – by North American Industry Classification System (NASIC) industry (e.g. trade versus professional services) and Dun & Bradstreet Line of Business Classification (e.g. grocery stores versus eating and drinking places)

3. **Neighborhood characteristics** – including demographic (average household size) and socioeconomic (education level)

Bike lanes may have a different effect on restaurants versus, say, consulting firms; small businesses may be more susceptible to impact than larger ones (a common argument in town halls) and businesses in neighborhoods full of singles or young professionals may also experience different results than those in neighborhoods with large families. The final dataset thus includes the following additional variables:

Business Characteristics	**YEARSINBIZ**	Number of years the business has been in operation
	SMALLBIZ	Officially registered as a small business
	MINORITYBIZ	Officially registered as a minority-owned business
NAISC Industry Classification	**MAJORINDUSTRY**	NAISC code
Dun & Bradstreet Line of Business Classification	**GROCERY**	A grocery store, corner store, etc.
	EATINGDRINK	A resturant, bar, café, etc.
	EXERCISE	Gym, yoga or dance studio, etc.
	COMPUTER	Technology services or products
	SERVICES	Management consulting, design, marketing, architecture, financial advising firms, etc.
	FILM	Movie theaters, production agencies, etc.
	CIVIC	Churches, foundations, associations and clubs
NEIGHBORHOOD CHARACTERISTICS	**HOUSEHOLDS**	Average household size rounded to the nearest integer, by 2010 Census tract
	HSGRADSQ	Quintile of percent of adults (25+) with high school education or more, by 2010 Census tract

iii. Sales tax analysis

Finally, I supplement the Dun & Bradstreet sales volume analysis with impact area-level data on quarterly retail sales tax paid to the City as another, more accurate but less precise measure of business health in order to further substantiate our results. Here the specification is similar:

$$increaseinsalestax_{bt} = \propto (treatment_b \; x \; post_t) + f_t + \eta_b + \varepsilon_{bt} \qquad (5)$$

III. Data analysis

A. Main results

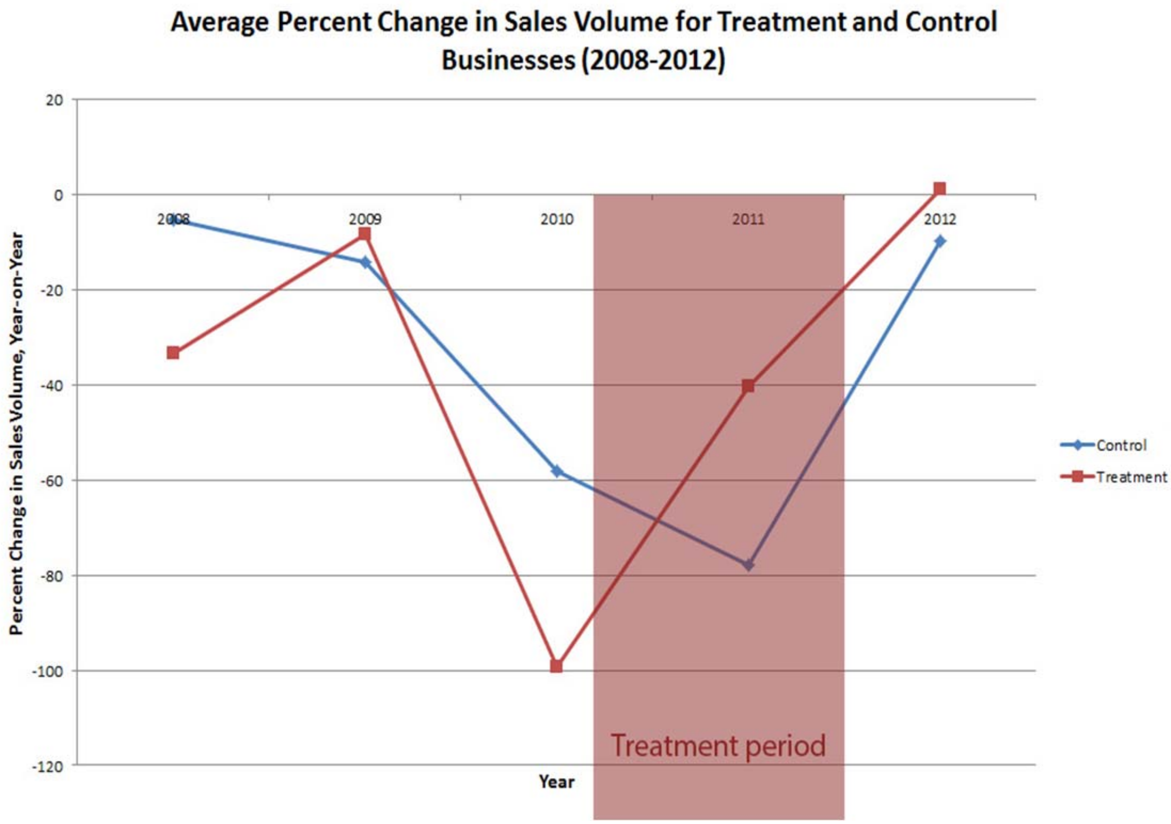

Figure 5. Average percent change in sales volume (year-on-year) in treatment and control areas. Treatment period (bike lanes constructed in 2010 and 2011) highlighted in red.

Figure 5 shows average annual percent increase in sales volume for businesses in all treatment and control areas from 2008 to 2012. This plot of the two sales series data reveals that while businesses in the two groups experienced different patterns of growth before 2009 they were both affected by the 2009 recession and only fully recovered to reach previous rates in 2012. And while there may have always been a difference in sales growth between the two groups even before 2010, sales growth rates during the treatment period and after suggest that perhaps bike lanes may have had a significant effect on the ability of treatment businesses to recover. Treatment businesses' sales fall harder in 2010, but recover quickly in 2011 to end above average sales growth for the control group in 2012. Control businesses' sales continue to fall in 2011 to their lowest but quickly recover to reach 2008 levels in 2012.

That the two groups appear to always have experienced different patterns in sales growth suggests they might include a different mix of businesses that naturally grow at different rates and were distinctly affected by external economic shocks like the recession. The difference in business composition between the samples is a complicating, but not insurmountable, factor. Stratifying comparison of businesses in the groups by characteristics such as industry controls for at least these external factors and allows for more robust conclusions. For example, comparing service businesses in the treatment area only with service businesses in the control group to ensure parity.

On its face, the overall pattern of the sales series in Figure 5 suggests that there may be real weight to the hypothesis that bike lanes may have an unique, statistically significant effect on business health. At the very least, there seems to be no *prima facie* reason to believe that bike lanes hurt business sales.

Table 2 reports descriptive statistics for the entire dataset. 11.76% of the businesses in the total sample are located in the treatment areas. This number is relatively small because many of the businesses that fall within 250 feet of a bike lane constructed in 2010 and 2011 were already within 250 feet of the existing bike network. These are the few who were substantially affected by the treatment, going from a distance of over 2000 feet from a bike lane to within 250 feet in a year's time – see Table 1 for details.

Relative to businesses in the control group, businesses in the treatment group are significantly newer. There are fewer registered small businesses in the treatment group but more minority-owned businesses. In the treatment group, there are fewer manufacturing, trade, public administration, and service businesses but more education & healthcare, entertainment & food businesses. The surrounding neighborhoods are also different – treatment businesses are in neighborhoods with more high school graduates, a greater number of average people per household and in different supervisor districts. These are all statistically significant differences between the samples that must be accounted for within the regression itself or in the stratified analysis to ensure apples to apples comparison.

Table 2

Descriptive statistics - means and standard deviations (treatment and control businesses in San Francisco)

	(1) Entire sample	(2) Treatment	(3) Control	(4) Diff. (2) - (3) (s.e.)
Business characteristics				
Years in business	9.49	8.54	9.62	1.067**
	[12.08]	[13.34]	[11.89]	(0.365)
Registered small business (percent of total sample)	92.69%	88.33%	93.28%	0.050**
				(0.008)
Registered minority business (percent of total sample)	4.56%	5.96%	4.37%	-0.016**
				(0.006)
NASIC industry classification				
Manufacturing	8.73%	5.51%	9.16%	0.037**
				(0.01)
Trade	3.05%	3.97%	2.92%	-0.010**
				(0.005)
Information, management	2.80%	3.08%	2.76%	-0.003
				(0.005)
Education, healthcare	3.65%	7.21%	3.16%	-0.040**
				(0.006)
Entertainment, accomodation and food	12.79%	20.91%	11.69%	-0.091**
				(0.01)
Other (including agriculture and construction)	7.56%	4.62%	7.96%	0.034**
				(0.008)
Public administration	61.43%	54.70%	62.35%	0.079**
				(0.015)
Dun & Bradstreet line of business classification				
Grocery	0.73%	0.64%	0.75%	0.001
				(0.003)
Eating & drinking places	3.25%	6.12%	2.86%	-0.033**
				(0.005)
Exercise	0.42%	0.32%	0.43%	0.001
				(0.002)
Computer	2.31%	1.85%	2.37%	0.005
				(0.005)
Services	41.55%	32.21%	42.82%	0.106**
				(0.015)
Film	0.95%	0.73%	0.98%	0.003
				(0.003)
Civic	2.65%	3.23%	2.58%	-0.007
				(0.005)
Neighborhood characteristics				
Households	2.64	2.47	2.66	0.184**
	[0.56]	[0.44]	[0.57]	(0.017)
High school graduates	87.10%	89.36%	86.79%	-2.566**
	[10.89%]	[6.74%]	[11.30%]	(0.328)
Supervisor district	7.12	6.73	7.17	0.438**
	[2.42]	[2.46]	[2.41]	(0.073)
Percent increase in sales (year-on-year):				
2008	-8.54%	-33.39%	-5.23%	25.160**
	[75.40%]	[193.44%]	[37.08%]	(5.733)
2009	-13.44%	-8.36%	-14.09%	-5.749
	[203.04%]	[43.65%]	[215.07%]	(14.919)
2010	-62.11%	-99.40	-57.97%	41.433
	[465.44%]	[715.00%]	[428.95%]	(33.377)
2011	-73.56%	-40.40%	-77.90%	-37.500
	[815.97%]	[242.52%]	[863.22%]	(54.452)
2012	-7.88%	-1.20%	-9.67%	-10.868
	[263.46%]	[29.97%]	[287.99%]	(17.918)
Number of businesses in the sample	2,211	260	1,951	

Finally, descriptive statistics for the average percent change in sales volume data show a statistically significant difference between the two groups in 2008. Starting in 2009, this stops being statistically significant even though it continues to vary fairly wildly from year to year. This suggests that both groups were experiencing dramatic variations in percent change in sales volume, likely as a result of the external economic shocks. However, the return in 2012 to a small magnitude difference with relatively low standard error suggests both groups were recovering financially.

Table 3
Bike lanes and change in sales volume for businesses in San Francisco (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	(2)	(3)	(4)
treatment x post	31.16** (14.85)			
distance to nearest bike lane		-0.0098* (0.0053)		
distance to nearest bike lane x post			-0.0023 (0.0136)	
treatment x post & distance				23.43 (15.08)
R-squared	0.0038	0.0037	0.0037	0.0037
Number of observations in the sample	9,410	9,410	9,410	9,410

In order to quantify and probe the statistical significance of the differences observed in change in sales volume in treatment and control areas, fixed-effects models are used to control for the effects of unmeasured business-specific characteristics as well as the effects unique to each year. Table 3 reports the estimates for the basic specifications in Eqs. (1) to (4) as well as clustered standard errors at the business level. Column (1) reports that year-on-year percent change in sales volume for businesses that were within 250 feet of a bike lane constructed in 2010 or 2011 were 31 percentage points higher than for businesses that were over 4 blocks away from those bike lanes. The coefficient of the interaction term $treatment_b \ x \ post_t$ indicates that bike lanes had a statistically significant positive impact at the 5% level on sales growth for businesses in the immediate proximity, even when controlling for the effect of time and individual business characteristics.

Note the R-squared is low in comparison to other studies, but in contrast to such studies I am not evaluating the predictive capacity of the covariate in question. I am not arguing bike lanes are a significant factor in determining business sales – that would be a stretch by any means. I am merely exploring whether bike lanes *have any effect* on business sales and, if so, what that effect looks like.

In columns (2) to (4) of Table 3, alternative models for understanding the effect of bike lanes on businesses are explored. Column (2) shows that distance to the bike network as a whole had a statistically significant at the 10% level on sales growth for businesses. It reports that, after controlling for other business and time characteristics, every additional foot in distance from a bike lane is associated with a 0.01 percentage point decrease in percentage change in sales growth, on average.

Column (3) explores another formulation – whether the construction of bike lanes in 2010 and 2011 had an additional marginal effect on businesses – and offers no statistically significant evidence to that effect. Neither is there evidence in column (4) evidence to a credible joint effect of both being within the impact area and in greater proximity to a bike lane. This result also suggests that the validity of model (2) – and thereby the overall effect of bike lane proximity – is concentrated on businesses in the impact area. Otherwise, the statistical significance of both distance and treatment would not be diluted in (4).

In general, Table 3 indicates bike lanes are associated with a statistically significant increase in percent change in sales growth for businesses within 250 feet of bike lanes constructed in 2010 and 2011 and that there is an inverse association between distance to a bike lane and change in sales growth. These results suggest bike lanes positively affect on change in sales volume for businesses in San Francisco. It is also important to note there is no evidence thus far of bike lanes having a negative effect on businesses.

However, Table 2 showed significant differences between the control and treatment populations. Therefore, it is necessary to explore whether these differences are actually driving the statistical significance observed above by using stratified analysis to compare businesses of similar types.

B. Stratified analysis

In this section, I conduct stratified analysis to compare businesses with similar characteristics in order to strengthen the difference-in-difference analysis. In doing so, I utilize the two regression models validated previously throughout – columns (1) and (2).

i. Business characteristics

First, I stratify analysis according to the three fundamental business characteristics highlighted in the last section – years in business and whether it is a registered small or minority business. The theory here is that perhaps older businesses may be more established and therefore be at least risk of variation in their revenue stream. On the other hand, newer businesses may be more agile and able to adapt, and also have a younger clientele that is more aligned with the population of people who bike and of those who are moving into San Francisco.

Small businesses are more perhaps more vulnerable to fluctuation in their revenue stream because they operate at a relatively reduced scale in comparison to big box stores. In fact, many of the businesses that oppose bike lane construction nationally are small businesses that fear losing customers, needing to reduce staff, relocate or simply go out of business. However, big box stores like supermarkets or stores like Target may therefore by definition be more susceptible insofar as their clientele is probably more likely to want to buy a lot and need to travel by car to transport all of their purchases back home.

Another common argument is that many of these small businesses are minority-owned and that bike lanes therefore disproportionately impact – and hurt – minority-dominated neighborhoods. There is an ongoing debate about whether bike lanes promote gentrification with one woman in a traditionally African-American neighborhood of Austin stating, "When the bikes came in, the blacks went out."[ix] At the same time, in New York there is demand by poor and minority communities for bike lanes.[x]

Table 4
Regressions using data for businesses with specific characteristics only (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	*R squared*	*# observations*	(2)
Business characteristics				
(a) Years in business (quintiles)				
1	45.46 (29.79)	*0.0062*	*2150*	0.012 (0.010)
2	2.73 (14.70)	*0.0033*	*2058*	-0.028* (0.015)
3	24.74 (60.65)	*0.0013*	*1622*	0.009 (0.018)
4	54.25 (58.84)	*0.0055*	*1649*	-0.005 (0.014)
5	57.09 (65.70)	*0.0111*	*1931*	-0.046* (0.024)
(b) Registered small business				
Yes	35.46** (13.66)	*0.0034*	*8696*	-0.008* (0.005)
No	-33.07 (81.19)	*0.0143*	*714*	-0.039 (0.048)
(c) Registered minority business				
Yes	21.92 (37.79)	*0.0036*	*460*	-0.0137 (0.0153)
No	31.13** (15.61)	*0.0348*	*8950*	-0.0099 * (0.0055)

1. Does the age of a business affect degree of bike lane impact?

Table 4 reports the estimated coefficients for the two validated fixed effects models above using only data for businesses with the specific, outlined characteristics. For years in business, I split businesses up into five equal categories with the average age of businesses in quintile 2 at 5 years and in 5 at 28 years. Row section (a) shows that the coefficient on the interaction between the treatment and post dummies in column (1) is never significant but that increased distance to the bike network as a continuous variable has a weakly statistically significant association with decreased sales for businesses in the 2nd and 5th quintile of age. It appears therefore that the effect is fairly spread out between old and new businesses and that perhaps both theories discussed above are possible and not mutually exclusive.

Figure 6 appears to help explain some of the variation in sales, with much older businesses in quintile 5 experiencing the most extreme dip in sales in 2010 out of all other ages of

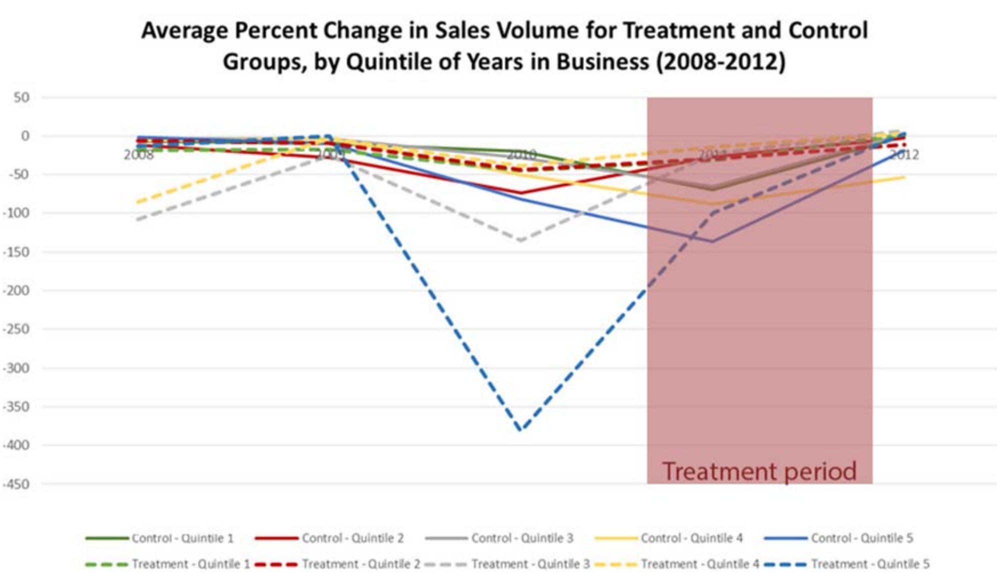

Figure 6. Average percent change in sales volume (year-on-year) in treatment and control areas, by quintile of number of years in business. Treatment period highlighted in red.

businesses. Both control and treatment groups in quintile 2 (highlighted in red) track fairly closely to one another throughout the entire study period, with the treatment group starting out slightly higher in 2008 and marginally lower in 2012. Starting in 2009, there is a significant difference between the treatment and control groups in quintile 5 with the treatment group plummeting in 2010 and control group not reaching its trough until 2011. The pattern in quintile 5 mirrors trends for the general population in Figure 5. This suggests the effect of distance as a continuous variable is much weaker, and likely varies significantly further along additional characteristics not currently under examination. Moving forward, this study will focus on interpreting the post treatment interaction effects only.

2. What about if it is a small business?

Row section (b) shows that coefficients on both the post treatment interaction term and distance term are statistically significant – but only for small businesses. They also have the same directionality as found previously – an increase in the interaction term to 1, which means the business is in the impact area after the treatment period, is associated with an increase in the percentage growth in sales volume by 35.46 points. Every increase in the distance to the nearest bike lane term of 1 foot is associated with a decrease in percentage sales growth by 0.008 points. This result is consistent with the working hypothesis that bike lanes have a positive impact on sales – but refines it, specifying this effect is limited to small businesses. It also corresponds with real-world arguments that small businesses are disproportionately affected by bike lane construction – but shows that, statistically, they increase average sales growth rate.

3. A minority-owned business?

Table 4 row section (c) shows that coefficients on both the post treatment interaction term and distance term are statistically significant – but only for businesses that are not minority-owned. They also have the same magnitude as found previously – an increase in the interaction term to 1, which means the business is in the impact area after the treatment period, is associated with an increase in the percentage growth in sales volume by 31.13 points. Every increase in the distance to the nearest bike lane term of 1 foot is associated with a decrease in percentage sales growth by 0.0099 points. This result is consistent with the hypothesis – only refining it, specifying this effect is limited to businesses that are not minority-owned.

It also disputes, at least in San Francisco, the real-world arguments that minority-owned businesses are disproportionately affected by bike lane construction – but shows that, statistically, they experience no significant effect. However, it is unlikely that these real-world arguments are entirely false since business owners avidly profess them based on their real experience. It is perhaps possible then, that minority businesses suffer *in comparison* given that non-minority businesses appear to benefit by as much as an additional 31 percentage point increase in sales volume growth. Minority-owned businesses may then, as a result, experience the effects articulated previously: needing to reduce staff, relocate or simply go bankrupt because they cannot compete with similar, white-owned businesses nearby. This could also conceivably drive up commercial and residential rents in the neighborhood as patronage of specific, white-owned stores increases and attracts similar businesses, different businesses with similar clientele and even those clients to reside nearby.

4. What about minority-owned small businesses?

However, 96% of minority-owned businesses in the sample are small businesses. Regression analysis shows that small businesses that are not minority owned have a post treatment interaction coefficient of 35.78 percentage points that is highly statistically significant at the 5% level. However, small businesses that are minority owned do not experience a statistically significant effect.

Therefore, bike lane installation is only associated with an increase in percent sales growth for treatment small businesses that are not minority-owned.

ii. Business industries

1. How does the bike lane effect vary according to NAICS code?

First, I stratify analysis according to two different business industry typologies – the North American Industry Classification System Code (NAICS) and Dun & Bradstreet Line of Business classifications. NAICS is the standard categorization of business establishments used by all Federal statistical agencies, and adopted in 1997 by the Office of Management and Budget (OMB), to collect, analyze and publish statistical data on the US business economy. Broadly, the major NAICS categories are[xi]:

1. Agriculture, forestry, fishing and hunting
2. Mining, utilities and construction
3. Manufacturing - residential and nonresidential construction, plumbing, electrical work, etc.
4. Wholesale trade; retail trade; transportation and warehousing
5. Information; finance and insurance; real estate rental and leasing; professional, scientific and technical services; management of companies and enterprises; administrative and support and waste management and remediation services
6. Educational services; health care and social assistance
7. Arts, entertainment and recreation; accommodation and food services
8. Other services (except Public Administration)
9. Public Administration

Table 5
Bike lanes and change in sales volume for different types of businesses in SF (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	*R squared*	*# observations*
NAISC industry classification			
Manufacturing	-2.11 (22.00)	*0.0045*	*840*
Trade	187.64 (192.08)	*0.0173*	*306*
Information, management	15.80 (20.67)	*0.0811*	*268*
Education, healthcare	30.72 (28.60)	*0.0156*	*350*
Entertainment, accomodation and food	70.23** (34.11)	*0.0104*	*1275*
Other (including agriculture and construction)	-13.89 (11.19)	*0.0182*	*742*
Public administration	11.32 (19.03)	*0.0033*	*5616*

Table 5 shows that, across industries, the coefficient on the post treatment interaction term is only statistically significant for entertainment, accommodation and food businesses. An increase in the interaction term to 1 is associated with an increase in the percentage growth in sales by 70.23 points.

This result is consistent with the hypothesis, but specifies this effect is concentrated in this particular industry that arguably experiences greater demand elasticity than others. If you need to see a doctor or math tutoring, then you will go and take whatever mode of transportation makes the most sense to you. Transit won't influence necessarily which doctor or tutor you see and how often. But it might influence how often you consume entertainment, accommodation and food. One might imagine that a leisure biker who is tired on a hot day might stop by an ice cream store to grab a scoop before heading on his way. A young professional might hop on her bike to the yoga studio in the Mission, especially if she is particularly health-conscious and exercise-inclined. In this sense, bike lanes may be particularly good for businesses insofar as they might generate new sales in sectors that are demand sensitive and therefore where customers – especially young, self-conscious tech professionals flush with cash – can be induced to buy more. This is not merely a substitution effect away from businesses not near bike lanes, but stronger demand and a greater income stream for those nearby.

There is a possible substitution effect. If you have to drive to one yoga studio and find parking nearby when there is another, equally preferable studio that you could just bike to you might choose that instead – especially if you are health-inclined. Other businesses in this category include restaurants, flower, interior design, clothing and coffee shops, tailors, hardware shops, markets, data companies, and adventure travel companies.

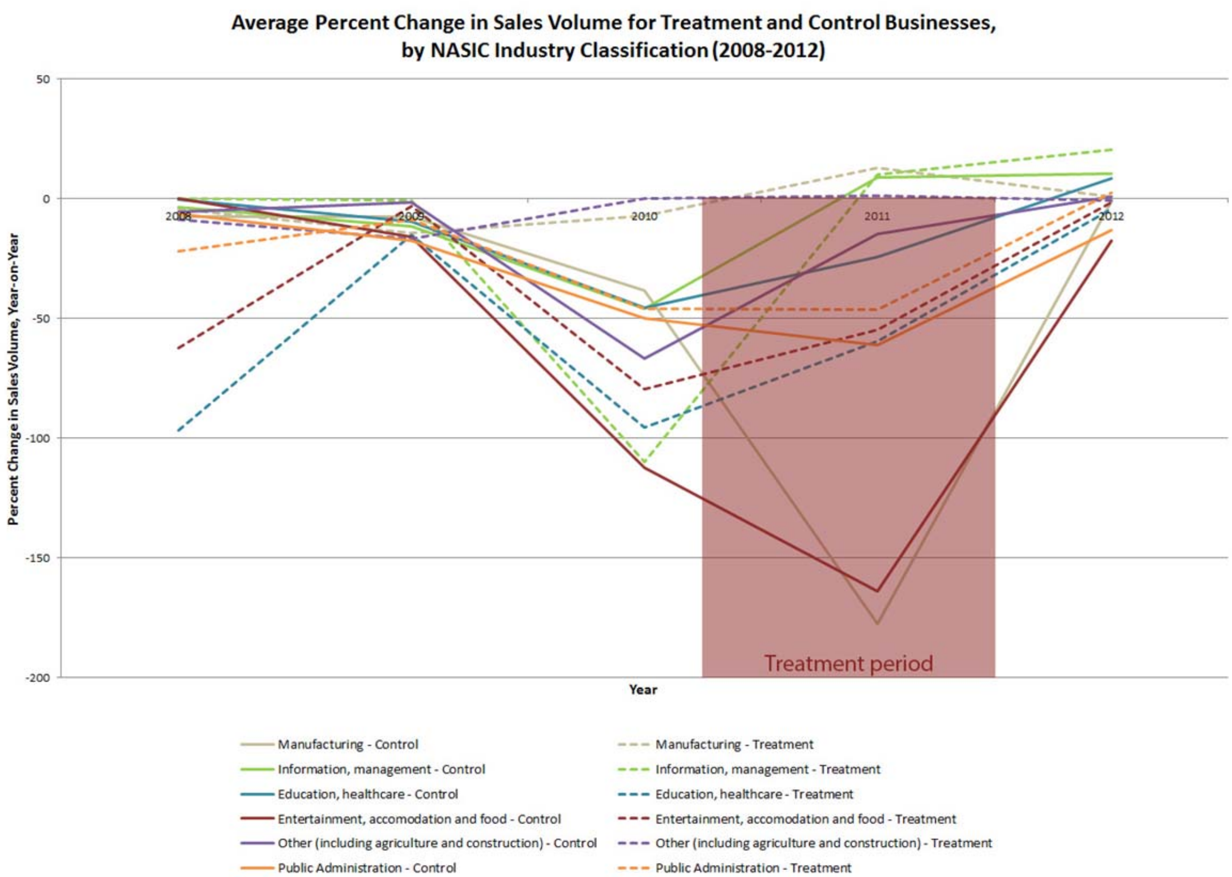

Figure 7. Average percent change in sales volume (year-on-year) in treatment and control areas for businesses according to key NAICS classifications. Treatment period highlighted in red.

Figure 9 shows the average percent change in sales volume for businesses according to NAICS classifications. The entertainment, accommodation and food industry is shown in red and while treatment businesses start lower than control, the situation reverses in 2009 and the gap becomes dramatically wider in the treatment period. Other industries, like manufacturing, also experience differences between the treatment and control groups but do not experience a statistically significant effect as a result of bike lane installation. This highlights the flaws in the methodology employed by previous studies that merely look at sales index and how that changes over time. It can appear that there is an even very significant change in sales growth that coincides with the treatment period but statistically is not even correlated with the actual treatment. A methodology that takes care to look at multiple levels of alternative causation – from the year, the firm and business and neighborhood characteristics – is more accurate, even though it probably still fails to capture some alternate causation.

2. What about variation according to Dun & Bradstreet Line of Business?

However, the NAICS major industry designations are a national categorization that is extremely broad and masks a lot of variation. Based on the NAICS analysis, I used Line of Business data from the Dun & Bradstreet dataset to investigate the following types of businesses:[xii]

- Grocery – supermarkets, local mercados, etc.
- Eating + Drinking Places – including specialty beer, coffee, retail bakeries and chocolate stores
- Exercise – physical fitness, dance and yoga studios
- Computer – data processing, computer programming, computers and software, etc.
- Services – all kinds of services, including business, legal, transportation, day care, architectural, public relations, building maintenance, adjustment and collection, etc.
- Film – movie theaters, production studios, etc.
- Civic and Religious – civic, social and religious organizations like churches, associations, etc.

Table 6
Bike lanes and change in sales volume for different types of businesses in San Francisco (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	*R squared*	*# observations*
Dun & Bradstreet line of business classification			
Grocery	34.67 (42.14)	*0.0203*	*74*
Eating & drinking places	-27.77 (27.67)	*0.0342*	*326*
Exercise	622.36** (18.42)	*0.0380*	*89*
Computer	178.94 (202.48)	*0.0234*	*235*
Services	70.23** (34.11)	*0.0039*	*3642*
Film	27.03 (39.06)	*0.0302*	*89*
Civic	10.39 (85.27)	*0.0166*	*259*

Table 6 shows that, across line of business categorization, the coefficient on the post treatment interaction term is only statistically significant for exercise and service businesses. They also have the same direction as found previously – an increase in the interaction term to 1 is associated with an increase in the percentage growth in sales volume by a stunning 622.36 percentage points for exercise stores and 70.23 percentage points for service businesses.

This result is consistent, but specifies that the bike lane effect is concentrated in these particular lines of business. Surprisingly, food businesses do not have a statistically significant association – although perhaps manually breaking down eating & drinking places further into restaurants and specialty food (e.g. chocolate, ice cream, coffee) stores might yield different results. Computer companies also do not have statistically significance, which is meaningful insofar as one would certainly expect an increase in the sales growth of these businesses due to the booming tech sector in SF the last few years. Neither film nor civic organizations (primarily, churches) are statistically significant.

However, exercise businesses experience a statistically significant effect of very high magnitude – which makes sense given the scenario imagined previously. A health-conscious ballet dancer or yoga student is probably more likely to bike than drive – especially if they are going to exercise. The clientele of these organizations is primed to prefer more physically strenuous forms of transit and, therefore, is more likely to patronize exercise stores that are accessible via bike lanes. Anecdotally, anyone who has been to the Yoga to the People studio in the Mission knows how much the staff and building management stress students cannot bring their bikes into the building without losing them.

More interesting is services, which if only looking at businesses within the relevant NAISC code includes tailors, alcohol and child abuse services, gas stations, etc. Outside of the NAISC code, the category includes daycares, law firms, music services, technology services, insurance agencies, and many consulting and design firms, among others. Here there is also a pretty significant jump in sales growth percentage in association with bike lanes. The argument here is more nuanced, since there has likely been a huge jump in the health of these industries due to the tech boom. All of these businesses arguably provide auxiliary services to the new population of tech entrepreneurs migrating to the City.

One could argue that, because many of these new residents prefer biking, they also prefer to get their services from stores that are bike accessible. The CEO of an up-and-coming Y Combinator start-up may need user experience design services, and may choose one to go to a shop he's biked past previously and may choose not to go to one that is only accessible by car simply because he doesn't own a car and doesn't want something stuffy but rather, new and trendy. This is because the time effects holds for variation experienced by all businesses in each year of the study period, however probably doesn't fully capture all the effects of the socio-economic and demographic changes that have been slowly happening in San Francisco for at least the last half decade. It makes sense, then, that the R-squared term for this regression is low even in comparison to others in this series given the comparatively large number of observations and dramatic amount of variation even within this group.

iii. Neighborhood characteristics

The final level of stratified analysis I will conduct is around the type of neighborhoods businesses in. One point of differentiation is the average household size.[xiii] The theory is that businesses in neighborhoods that are majority single and married professionals with no children may experience different effects than business in neighborhoods with majority married families with one or two children. Neighborhoods with average household size three likely include a mix of single and married households with varying numbers of children, so likely tend toward a little younger than average household size 4 neighborhoods but still more age- and household type diverse.

Finally, the last factor analyzed is the percent of high school graduates in the neighborhood. The original Census data has full percentages from 0-100% for Census tracts in 2010; to simply the stratified analysis I have split the data into quintiles. The hypothesis here is that this measure of the level of education can act as a proxy for the socio-economic status of a neighborhood. From there, the connection to economic health is fairly clear – wealthier households have greater spending power, and at least in the Bay Area are quite inclined to bike. *The Economist* has dubbed competitive cycling "the new golf"[xiv] and noted how often business networking and even recruiting occurs on cycles. Therefore, we can expect bike lanes in wealthier areas to potentially have a greater impact than those in poor neighborhoods since the lanes will be more frequently used by people with more purchasing power. In the words of Corinne Winter, president of the Silicon Valley Bicycle Coalition, "People who are ambitious in business and innovation are very likely to also want to climb up a steep hill on a bike as fast as they can. There's a correlation between being physically driven as well as professionally successful."[xv]

At the same time, bicycles are also traditionally a cheap form of transportation in comparison to cars and perhaps even public transit.

1. How does bike lane impact vary according to average household size?

Table 7 shows that, across neighborhoods of different average household size, the coefficient on the post treatment interaction term is statistically significant for household size 2 and 4. They also have the same direction as found previously – an increase in the interaction term to 1 is associated with an increase in the percentage growth in sales volume by 49.83 percentage points for household size 2 and 122.70 percentage points for household size 4. This result is consistent with the hypothesis that bike lanes have a positive impact – but only in neighborhoods of these average household sizes.

Table 7

Bike lanes and change in sales volume for businesses in different neighborhoods in SF (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	*R squared*	*# observations*	(2)
Neighborhood characteristics				
Households				
2	49.83* (29.77)	*0.0031*	*3807*	-0.023* (0.013)
3	17.44 (17.43)	*0.0049*	*4796*	-0.007 ().005)
4	122.70* (72.02)	*0.0187*	*807*	-0.003 (0.027)

Married families with average 2 children (4 person households), may, perhaps use bike lanes in a different proportion than single and married professionals with no children because they may be more likely to need cars to run basic errands like buying food, going out to restaurants, etc. due to the quantity of materials they need to buy and people they must transport. We can expect that they may be less likely to use bikes for errands and, to some extent, commuting since that can be tied with picking up and dropping off children in the later years. They may also use bikes in a different fashion for leisure – to take the children out for play in the proximate area (unless the hills make it too difficult) and perhaps to buy an ice cream in the summer. Leisure biking would be more spatially restricted and child-friendly.

The magnitude of increase in the sales volume growth rate is very high, perhaps given these households' high rate of consumption. An average 4 person household means there must be a fair number of households on the even higher range of that spectrum with more than 2 children, or living with extended family. Higher household sizes are usually correlated with lower income. Therefore, even within neighborhoods that average 4 people there may be two effects observed – well-off families that use bike lanes as a form of recreation and professional networking, and lower-income families that use it as a means of transit.

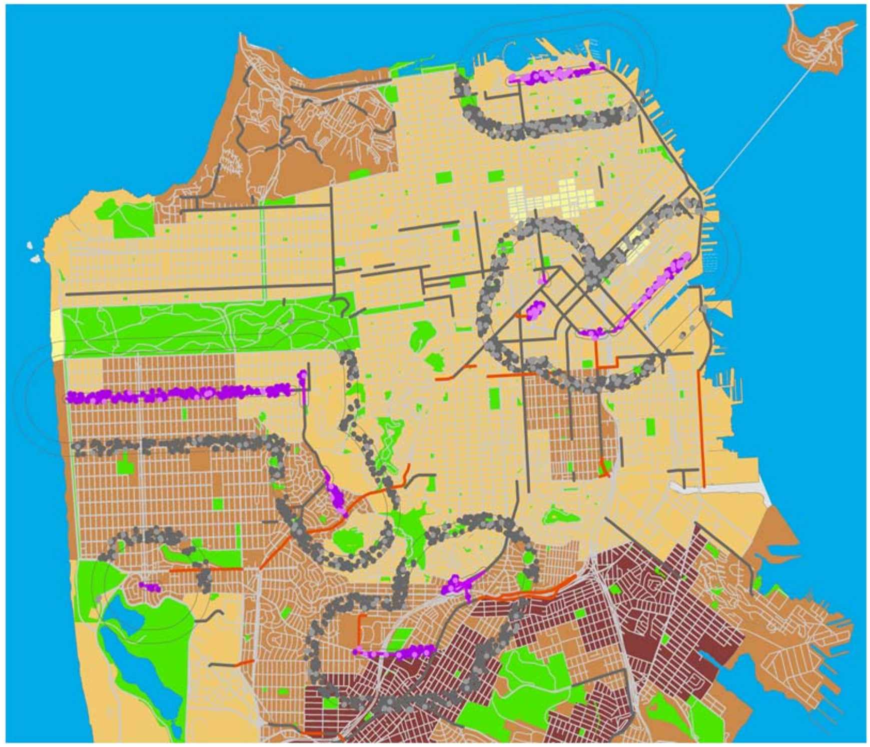

Figure 8. Map of San Francisco, with 2010 bike lanes in purple, 2011 in red. Only 2010 treatment businesses shown. Census tracts colored according to (rounded) average household size where a darker color means a greater average household number. 1 is pale yellow. 2 is light beige, 3 is brown; 4 is dark brown.

Single and married professionals with no children are arguably more likely to commute to work and to rely on bikes as their sole, personally-owned method of transportation as opposed to cars. They have fewer requirements; they may be able to bike back and forth with the amount of food they'd need for a week (especially if they eat out or at work often). They likely have more free time for exercise, specialty store shopping and may be more willing to bike longer and more strenuous distances to do so.

2. *How does bike lane impact vary according to % high school graduates?*

Table 8 shows that, across neighborhoods with different levels of education (as represented as % high school graduates living in that Census tract), the coefficient on the post treatment interaction term is statistically significant for the top two quintiles. Together, these two quintiles have a range from 90.98% to 99.38% and therefore represent the highest educated neighborhoods in the city. They have the same

Table 8

Bike lanes and change in sales volume for businesses in different neighborhoods in SF (fixed-effects estimates with robust clustered standard errors, 2008-2012)

	(1)	*R squared*	*# observations*
High school graduates			
1	13.31 (19.25)	*0.007*	*1960*
2	-144.99 123.74)	*0.0108*	*319*
3	19.64 (18.53)	*0.0054*	*2677*
4	80.24* (45.69)	*0.0031*	*1732*
5	26.84** (11.33)	*0.0084*	*2722*

direction as before – an increase in the interaction term is associated with an increase in percentage growth in sales volume by 80.24 percentage points for quintile 4 and 26.84 percentage points for 5.

This result is consistent – but again specifies that perhaps primary for businesses in well-educated areas that are probably patronized by their well-educated and, presumably, wealthy residents. This suggests both that many bikers are likely well-educated and that they frequent stores in similar neighborhoods that are likely more expensive and more niche due to higher rents and different tastes.

The first theory is borne out by other studies – according to a 2008 US National Sporting Goods Association survey, a higher percentage of bicyclists are college graduates compared to the total population. 30% of bicyclists live in households earning over $100K and bikers have a median household income $10K higher than the US average – including both frequent and infrequent cyclists.[xvi]

Mapping out these highly educated regions of San Francisco affirms the association between neighborhood education levels and socio-economic status in the Bay. See below side-by-side comparison of education levels and rental prices in San Francisco – even given a 4 year gap in data.

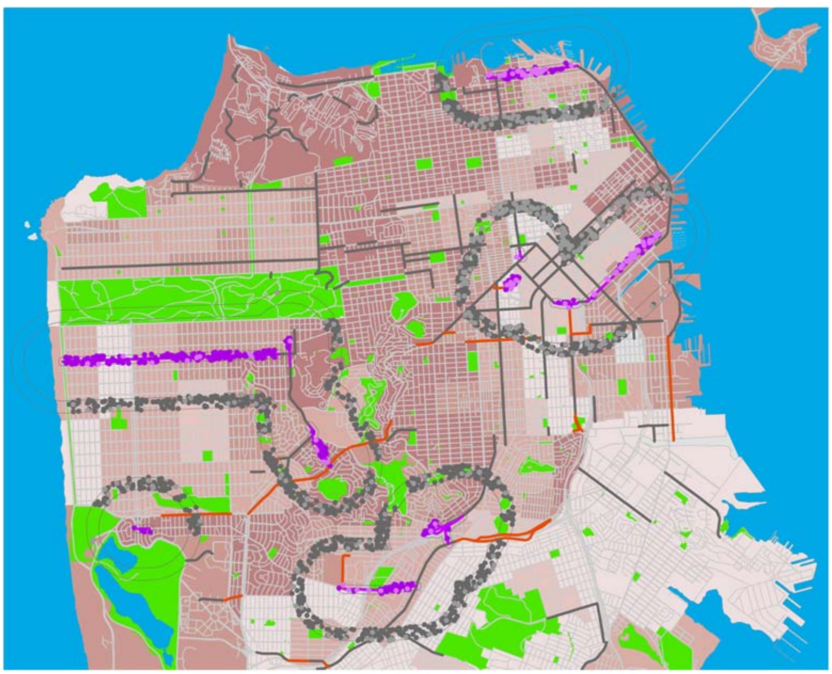

Figure 9. Map of San Francisco: 2010 bike lanes in purple, 2011 in red. Only 2010 treatment businesses shown. 2010 Census tracts colored by quintile of percent high school graduates. Darker color means higher percentile.

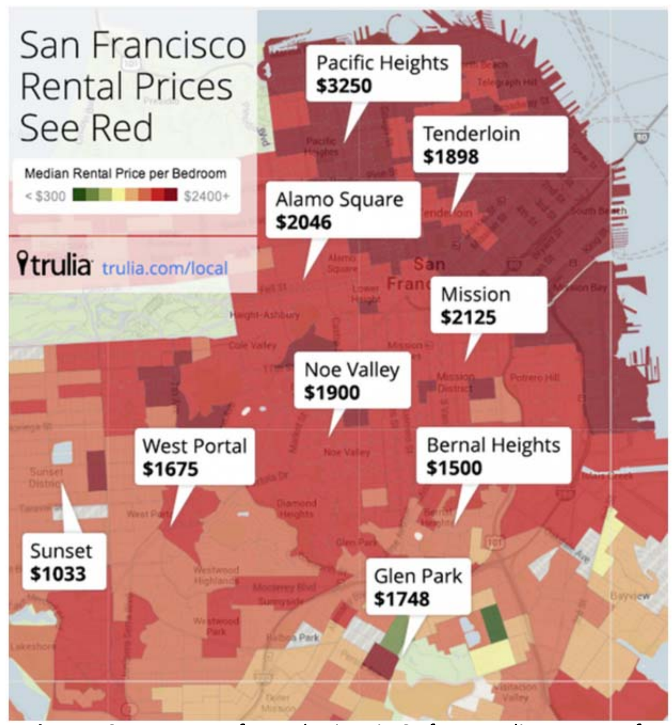

Figure 10. Heatmap of rental prices in SF from Trulia.com, as of late January 2014.

3. Is there a relationship between education level and household size?

Overlaying household size and education level data results in the map below shows that by and large areas that are highly educated average 2 person households. Regressing the two factors reveals a highly statistically significant negative correlation between average household size and education quintile.

Stratifying analysis only for businesses in highly educated, 2-person household areas yields post treatment coefficient of 74.65 that is statistically significant at the 10% level. There are insufficient observations to understand businesses in highly educated, 4-person household areas. However, regression analysis of 4-person household areas that are in the lower 3 high school graduate quintiles results in a treatment coefficient of 43.36 that is highly statistically significant at the 5% level. This suggests that average household size has a bigger effect than education level.

Therefore, the data suggests that there are two distinctly different neighborhoods where bike lanes have an effect on business health: highly educated areas with average 2-person households and (presumably less educated) areas with average 4-person households.

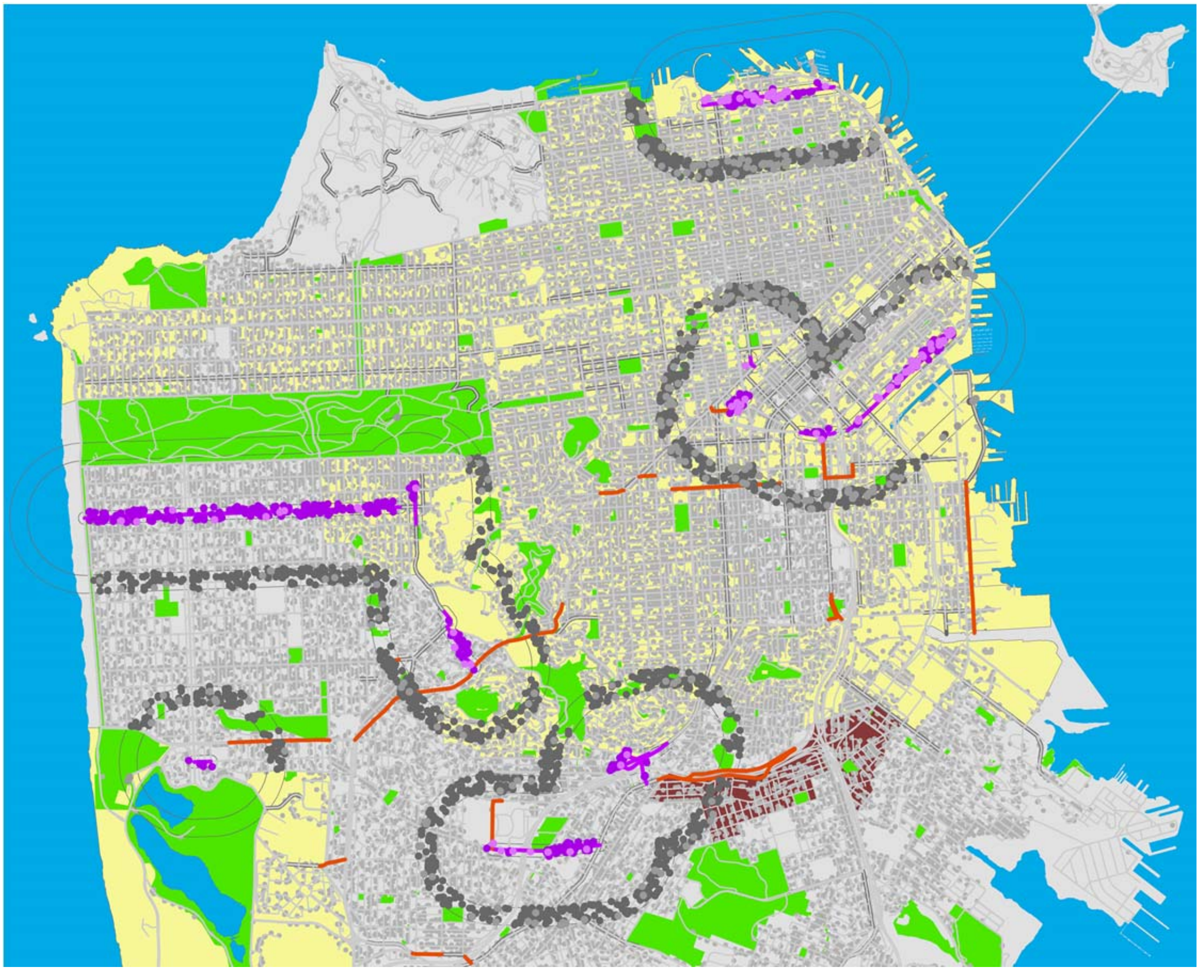

Figure 11. Map of San Francisco: 2010 bike lanes in purple, 2011 in red. Only 2010 treatment businesses shown. Yellow and dark brown represent Census tracts that are both in the top two quintiles of percent high school graduates and average either 2 or 4 people per household, respectively.

C. Sales tax analysis

Fixed effects regressions on impact area level sales tax data showed that bike lane construction in 2010 and 2011 had no statistically significant effect on aggregate retail tax collected in the neighborhood. An additional difference-in-difference specification was therefore not necessary. This suggests further that bike lane construction is positively associated with an increase in the sales volume growth rate for only a specific subset of businesses, rather than all businesses or even all businesses within a neighborhood.

IV. Conclusion

A. What the data shows

The main results of this study suggest that bike lanes can have a statistically significant effect on businesses. This effect appears to always be positive in increasing the percentage growth in sales volume, even when confounding effects from unmeasured business-specific attributes and common shocks to the San Francisco economy in the study period are eliminated.

However, stratified analysis suggests that only certain businesses benefit from this effect:

- **Small businesses that are not minority owned**
- **Leisure and service businesses** (NAISC code 7: entertainment, accomodation and food and Dun & Bradstreet service and exercise lines of business)
- Businesses that are located in **highly educated neighborhoods with average 2-person households** or (presumably less educated) **neighborhoods with average 4-person households**

Stacking these specificiations together shows a statistically significant post treatment effect for some combinations, including small, non-minority-owned small businesses in both types of neighborhoods and which are listed as NAISC code 7 or service firms. This, along with the sales tax analysis, further suggests that the positive association of bike lane construction with the sales volume growth rate is likely limited to a small subset of the entire population of businesses.

B. What the data means

While bike lanes don't appear to hurt businesses, they only help certain kinds of businesses – and thereby may indirectly disadvantage others. Bike lanes could thus be a factor in facilitating long-term changes in certain neighborhoods – for example, in promoting the sales of small, non-minority-owned businesses compared to immigrant-owned businesses and service firms and perhaps specialty food stores instead of simple grocery stores and supermarkets. This is especially unsettling in a city like San Francisco, which is already undergoing a significant demographic and socioeconomic transition that includes major population shifts along specific minority and socioeconomic lines.

Like traditional roads for cars, bike lanes are a neutral physical construction but with only three primary uses: transit, leisure and exercise. People can commute to work or run small errands on bikes, as well as engage in strenuous physical exercise, leisurely explore the city or even socialize and network professionally. While driving on a regular street can hardly be considered exercise, roads share the transit and leisure functions – and additionally operate as the infrastructural backbone for the transport of resources from place to place. The critical importance of roads in facilitating the transport of goods is arguably a key democratizing function – infrastructure lowers the costs of goods across the board. Both luxury and basic goods are, by and large, transported on land via roads. However, since there are multiple transit, leisure and exercise options bike lanes as infrastructure are more reflective of the preferences of its most frequent users. The sharows and protected lanes are not in and out of themselves biased, but the people who use them may be – and not in any malicious way, but out of pure human personal preference. These reflected preferences make themselves known in this data.

This study uses quantitative evidence to tell a fundamentally human story. Infrastructure may be value neutral, but it does not exist in a vaccum and both reflects the preferences of its most frequent users and impacts the life and lanscape of the surrounding community.

Soliciting community input is already integrated into city planning processes, but often rely on town hall meetings or community surveys with varied methodologies and results. Such work is incredibly meaningful, given the literature on the importance of choice to public health. At the same time, the variability and lack of robustness of these studies means that up to this point planners and communities alike may not be clear about the precise impact of these policies.

This study has laid out an additional, data-driven methodology and specific recommendations for evaluating and understanding the impact of urban design projects like bike lanes on communities. It is far from incontrovertible – the next section will summarize the battery of additional analyses that could and should be done. Now that the data exists, government should seek to use it in ways that helps better understand the impact of its policies and more effectively target them to improve livelihoods. In designing infrastructure improvements like bike lanes, policymakers should also account for the larger socio-economic and cultural context in that community in order to design more equitable, integrated – and ultimately, sustainable – initiatives.

V. Recommendations

A. Collect more and better data

There is always more data and more tests you can run. In this instance, more granular – specifically, business-level sales tax data – would greatly enrich this dataset and account for several flaws. Since this data would come from the Controller's office, it would be relatively incontrovertible in comparison to the self-submitted data and estimates from Dun & Bradstreet. Additionally, it would help account for the fact that some businesses operate on high margins rather than high volumes and therefore percent change in sales growth rate is perhaps not the best metric for these. The preliminary analysis I was able to do with impact area-level sales tax data was helpful in validating some hypotheses – primarily, that bike lanes have an associated effect with only a small subset of businessess rather than all businesses or the entire neighborhood. Nevertheless, it is still a good complement to the existing analysis.

More accurate bike lane data would also strengthen this study. The shapefile I used is the most recent authoratative version from the SFMTA. As stated previously, it fails to differentiate between specific types of bike lanes (e.g. protected versus sharrows), doesn't denote when and how many parking spaces have been replaced and in some cases is inconsistent in defining whether a new bike lane has actually been installed or whether an old one has simply been re-striped. Insofar as these are different types of streetscape interventions they constitute distinct treatments that may have variable effects and thus must be tested separately. I recommend that the City begin collecting these additional variables moving forward in order to improve the validity of this analysis.

Businesses that have either lobbied for or against bike lanes should also be removed from the analysis or treated separately because this may have endogenous effects. This is less of a problem for bike lanes currently being constructed under the 2005 plan, but will be a problem if this methodology continues to be used moving forward.

Other factors were considered but omitted from this study because they were not statistically significant. These include slope, bike stores, furniture stores, whether a business was woman-owned, etc. Additional factors were examined and sometimes statistically significant but omitted because they overly complicated the analysis due to excessive noise or inaccuracy, including percent low income in the neighborhood, number of employees, etc. I would recommend that future studies attempt to standardize and include these variables in the analysis to see if they indeed have effects. More thorough segmentation and analysis of Dun & Bradstreet Line of Business verticals would also be useful to tease out differences between different types of businesses.

Finally, I recommend applying this sort of data-driven methodology to improve the impact evaluation and location targeting of other policies with a spatial component. Early analysis of the effect of parklets showed no association with a change in business health once a difference-in-difference model was adopted to control for year and external common shock effects. The effects may compound or slowly emerge after time, so regular analysis is worthwhile. Other policies that could be similarly analyzed include not just street design interventions but even localized economic development programs.

B. Integrate transit policy with larger community initiatives

The most critical recommendation this study makes is that transit and city planners should broaden their focus beyond the most efficient way to get people from point A to point B. Given that these policies are situated within a community and reflect specific user preferences, planners and communities should take a holistic approach that accounts for the policies' impact on everything from public health (e.g. food access and nutrition, air quality and asthma) to economic impact and the broader commercial life and diversity of the neighborhood.

The data shows that bike lanes are associated with greater sales growth for small businesses. Cyclists seem to prefer shopping in smaller stores, likely because they get in and out faster and they aren't interested in buying a large amount if items. However, more worrisome is that this effect is canceled out for minority small business owners. This suggests that if planners and residents of minority communities call for bike lanes, they should also consider the impact that might have on the commercial life of their neighborhoods and design additional business incentive programs for minority-owned shops. Similarly, if bike lanes are associated with greater sales growth for primarily leisure and service type businesses then planners and communities should consider whether promoting these industry verticals is really the best fit. This is particularly true in instances where residents of those communities may not need or be able to afford interior design and consulting services or artisanal craft beer gardens. Finally, planners, policymakers and communities should also think critically about the communities where bike lanes are to be built since these effects are most significant in particular neighborhoods.

Essentially, bike lanes are associated with and likely facilitate the ongoing demographic and socio-economic changes in San Francisco. This is not to say that bike lanes are should not be constructed or that stopping them will halt gentrification. (Indeed, this study only evaluates the marginal effect of striping bike lanes that were planned in 2005 and have been informally in use for several years before they were formalized.) Bike lanes have always been one of the cheapest forms of transportation available, and are a very effective transit policy insfoar as they reduce traffic and increase cyclist safety.

Rather, in making these planning decisions the City should consider their roughly quantifable effect on communities and craft integrated intiatives to help ensure that all citizens benefit. For example, if the City plans on striping a bike lane in a majority minority neighborhood with average household size 4 and a mix of minority and not minority-owned small businesses. I would recommend that the City pair this infrastructure development with additional programs. For example, the installation of a bike sharing hub in the neighborhood, a bicycle education program for local residents and free first-month passes. And for the businesses, promotion of the minority-owned small businesses in particular as part of a cultural 'introduction to the neighborhood' that can be featured at the bike sharing hub, or subsidized bike parking spots near minority-owned businesses.

Take the Better Market Street project, where the city is currently looking at placing a bike lane either on Market or Mission Street. A rough sample of businesses along the relevant sections of Mission (between South Van Ness and the Embarcadero) and Market (Octavia and Embarcadero) and tabulation of the key significant indicators highlighted in this study yields the following table.

	Mission		Market	
# small businesses	1102	74.06%	4025	75.02%
# minority-owned businesses	59	3.97%	183	3.41%
# NAISC code 7 businesses	177	11.90%	609	11.35%
# D&B Service or Exercise businesses	926 + 7	62.70%	2031 + 15	38.14%
Neighborhood type	Highly educated, average household size 2		Highly educated, average household size 2	

Even this cursory analysis shows that the percentage of small and minority-owned businesses in this area are roughly comparable – which makes sense since these streets are one block away from each other in the downtown area. However, Market Street has nearly twice as many service or exercise businesses and therefore the merchants on that street might benefit more from the construction of a bike lane. This economic analysis should be paired with other types of social analysis – effect on public health, crime, etc. – as well as traditional transit analysis of impact on traffic and pedestrian and cyclist safety in making a final decision about bike lane installation.

At the same time, the losses of the minority-owned businesses owners should also be carefully mitigated to ensure that the project is as inclusive as possible. Other cities including Denver, Boston and Washington, D.C. have explored strategies for increasing low-income participation in bike share programs including subsidized membership.[xvii] It has also been explored as a strategy for improving public health outcomes in Minnesota, though merely installing kiosks in low-income areas was insufficient to increase residents' physical activity. As a result of the study, however, Nice Ride Minnesota began exploring strategies to meet the needs of low-income individuals: "1) extending trip time limits from 30 minutes to 45 minutes and 2) installing more stations at destinations for recreational riding (eg, lakes and parks)" as well as "prepaid debit cards for low-income individuals who sign up using free subscriptions."[xviii]

Few of these community engagements have thus far been successful, and increase bicycle ridership in low-income, minority neighborhoods continues to be a challenge. However, this study recommends that city and transit planning authorities, the bicycle coalition and local communities should always consider bike lane construction in conjunction with such initiatives. Not to make infrastructure development more difficult with more hard and fast regulation – but to better understand and account for its true effects to promote sustainable, inclusive and healthy communities.

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[xi] Given lack of observations I collapsed NAICS categories 1 and 2 with code 8 "Other services" in order to ensure the integrity of regression analysis.

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[xiii] Rounded to the nearest integer to simplify analysis.

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