MARGINAL EFFECT OF ROAD CONSTRUCTION ON TRAFFIC SPEED: EVIDENCE FROM NEW YORK CITY

A Thesis

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ABSTRACT

Road Construction, which is proposed as a solution to severe congestion, might rise an increase in commuting time and decease in traffic speed due to the poor management or delay in completion. This paper sets up a traffic dataset with 2 million real-time traffic speed data and 13,000 construction record data from 2017 - 2019, to estimate the marginal effect of road construction on traffic speed in New York City and evaluate the efficiency of construction contrast. The main finding is that traffic speed will decrease by 3.47% on average when vehicles are 1km closer to road project. Speed decreases slower when vehicles are further from construction. Besides, long duration and "unplanned" project has greater effect on vehicles speed. The estimated cost of decrease in speed is about $326-451 per hour, which is relatively higher than penalty in construction contrast. Based on this, this paper suggests a bonus for early completion or a higher penalty on late completion should be considered in road construction contrast.

BIOGRAPHICAL SKETCH

Yikuan Ji, growing up in the Guangdong Province of China, has witnessed the sharp economics growth as well as rising issues of environment and society in China. His family background and childhood experience has nurtured his interest in environmental issue and public policy design. Before coming to Cornell, he completed his undergraduate degree at Fudan University in 2018, majoring in public finance.

ACKNOWLEDGEMENTS

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Besides my advisors, my sincere thanks also goes to Dr. Ziye Zhang and Dr.Youming Liu for guiding me from manipulating data to thesis writing. I thank my classmate Wei Li, Weilun Shi for tolerating me explore my scattered ideas. In particular, I thank my friends Bowen Mao and Jiahua(Tiger) Wang for helping me coding Python program for data manipulation. Also I would like to thank Zian You, Liangyu Zhou and other friends, for the joy and energy brought to my life. And thanks to my roommate David Esparza, for his proofreading and editing for my paper work.

Last but not the least, I would like to thank my parents for supporting me spiritually throughout writing this thesis and my life in general. Also thanks to myself, for persisting in my original dream.

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CHAPTER 1

INTRODUCTION

Commuting has become a necessary part of urban daily life. Slow speed and severe traffic congestion could increase commuting time and cause loss of social welfare. That is a typical picture for one of the busiest cities around the world, New York City(NYC) with a population of 8.7 million[1]. According to TomTom Traffic Index [2], people in NYC spent 37% time on commuting averagely than that under the free flow condition, ranking 52th on the list.

Road construction is often proposed as a solution to traffic congestion. However, improper design and schedule of construction or delay in completion might make traffic condition worse during the work period. There are incentives for construction firms to complete the road work on time in the contrast of road projects assigned by NYC government, usually as a penalty of $1000 per day for the late completion. However, I am curious about the efficiency of these road construction contrast and doubt should the cost caused by the construction vary across projects. Therefore, this paper try to estimate the effect of road construction on traffic speed, calculate the cost caused by the road work and evaluate the efficiency of road construction contrasts in NYC. The empirical results could help understanding the institution of traffic system, and give suggestion to urban planning and design.

Literature of traffic congestion and road price could date back to 1950s and 60s (Beckmann, McGuire & Winsten, 1955; Gibbons & Procter, 1954; Walters, 1961; Vickrey, 1963)[3][8][18][17]. These studies mainly focus on applying road pric-

[1] https://www.usapopulation.org/new-york-city-population/

[2] TomTom Traffic Index is based on real-time traffic data from 416 cities across 57 countries in 2019, TomTom Traffic Index 2019

ing to solve traffic congestion. Following studies expand congestion pricing under diverse conditions, such as speed limit(O'DEA, 2001)[11], Hypercongestion(Small & Chu, 2003)[14]. Several recent paper(Font et al., 2014; Pilger et al., 2020; Long et al., 2017; Moretti et al., 2017; Chen et al., 2017; Barati & Shen, 2017)[7][12][9][10][4][2] estimates the effect of construction activities on emission, environment and animals herds, but few on the effect of construction on traffic. Thus this study, to my knowledge, is the first attempt to estimate the cost of road construction on traffic, and compare the cost with incentive for completion of construction.

This paper makes the following contributions to the literature. First, this paper provides a unique database for real-time traffic data in NYC, combined with construction site data. Existing studies are mainly based on theoretical estimate of speed-flow relationship(Vickrey, 1963; O'DEA, 2001; Small, 2012)[17][11][13], the traffic survey data(Devarasetty et al., 2012)[5], or discontinuous data from several certain streets(Dewees, 1979)[6]. Similar to research on Beijing traffic system(Yang, Purevjav & Li, 2020)[19], this paper applies a continuous real-time traffic speed data for the entire NYC from 2017 to 2019, combining with the construction record for NYC to capture the impact of road project.

Secondly, this is the first research that studies the relationship of road construction and traffic speed. Just as mentioned, there are literature on the impact of road construction on pollution, emission and animal habitat, or study on traffic speed, but none has studied how road construction affects vehicle speed. Moreover, this paper also studies the effect of different types of road projects, such as long and short projects, planned and unplanned projects, to provide a deep understand and implication for road works.

Third, with the value of time analysis, the empirical results of this paper could improve the efficiency of contract for road construction projects. Bajari et al.(2014)[1] study the bidding process of incomplete contrast of highway paving project and give implication for government procurement. Unlike their study focused on the bidding process, this paper evaluates the cost from decreasing traffic speed and increase in commuting time caused by road construction and compares with the incentive or penalty in the construction contrast. To estimate the cost caused by road work, potential increase of commuting time and value of time are required, which have been fully discussed in existing paper(Small, 2012; Tzedakis, 1980)[13][16].

The rest of the paper is organized as follows. Section 2 provides the background and describes the data. Section 3 discusses the empirical strategy to estimate the effect of construction on traffic speed. Section 4 presents empirical results while Section 5 discusses my findings and its applicant. Section 6 concludes.

CHAPTER 2

DATA

This paper gathers three datasets of New York City on traffic speed, weather and road construction. Together, these three datasets form a hourly panel data for 135 speed sensors in New York City during 2017 to 2019. This enables us to estimate the effect of road construction on traffic speed heterogeneity across subgroups of road or constructions. Details on the datasets are provided below.

2.1 Traffic Speed Data

The original traffic speed data is collected by Traffic Management Center (TMC) of New York City Department of Transportation (NYCDOT). TMC maintains a map of traffic speed detectors throughout NYC. The speed sensors belong to various city and state agencies. This Traffic Speeds Map is available on the DOT's website[1]. The dataset contains real-time traffic information from locations where NYCDOT picks up sensor feeds within the five boroughs(Bronx, Brooklyn, Manhattan, Queens, and Staten Island), mostly on major arterials and highways. Figure A.1 is an example for recorded road section, about 1.5 mile. I pick traffic data from May 2017 to April 2019 and calculate hourly speed by averaging original speed records generated in every five minutes. Totally, there are 135 speed detectors.

Figure A.1 is the box graph of hourly speed. Figure A.2 is the average speed over hour of the day. We could observe that speed data pattern of all sample and

[1] Real Time Traffic Information

weekday sample are similar: there are two rush hour periods during the day. While data pattern for holiday sample and weekend sample are quite different from the former pattern, there are no two rush hour periods but only one lower speed period during 4 to 6 pm. Besides these, speed is relatively higher at night, the highest hourly speed appears nearly at 4 am.

Figure A.3 is average hourly speed for day of week, it is obvious that there are two data patterns for weekday and weekend sample. Figure A.4 is the average speed over day of week. The average speed varies little over the day of week, traffic of Thursday and Friday are relatively slower while faster on weekend. Figure A.5 are graphs over month of year. Traffic in winter months(January, February and December) are relatively faster than other months, while the lowest traffic speed is in June. One possible explanation is that a lower traffic volume on street results in a higher traffic speed when people have the common knowledge of there is snow on the road.

2.2 Weather Data

Weather data is obtained from the National Oceanic and Atmospheric Administration (NOAA). This is hourly city level data, including multiple important weather controls for traffic speed: temperature(°C), atmospheric pressure(hPa), relative humidity(%), wind speed(metersec), wind direction(meteorological degrees), rainfall volume(mm), snowfall volume(mm), and cloudiness(%). Weather variables are necessary to control for drivers' behavior that might be affected by weather conditions. For example, drivers might change their trip plan considering the weather condition, or drivers might be more cautious and drive at a slower speed on a raining/snowing day than a sunny day.

2.3 Road Construction Data

The third dataset is DOT Street Closure data, provided by New York City Department of Transportation[2]. This data identifies locations in the New York City Street Closure map where a street is subject to a full closure, restricting through traffic, for the purpose of conducting construction related activity on a street. Employing GOAT[3] of road and geometrical position data of speed detector, I calculate the minimum distance between the recorded road sections with the nearest construction site on work, allocating each sensor to an active road construction.

Table B.1 shows the average speed and observation numbers among different distance group, while Figure A.6 presents the distribution of distance. Most observations fall within the 5km distance group, especially in 0-1km and 1-2km distance group, while there is fewest observations with a distance exceeds 5km to a construction site. The average vehicle speed increases simultaneously with the increase in distance to a road construction.

After averaging log(speed) over distance, I generate scatter graph between average log(speed) and distance, and a linear fitted line with 95% Confident Interval (Figure A.7). Observations gather within 5km distance groups. There is a positive relationship between distance and log(speed), which meets our expectation: traffic will become slower when it is near the construction site and faster

[2] DOT Street Closure data

[3] The Department of City Planning Geographic Online Address Translator (GOAT)

when it is away from construction. Figure A.8 is the quadratic fitted value curve for log(speed) and distance, which states that the traffic speed starts to decrease when distance to the nearest construction exceeds 10km. Thus a negative coefficient for square term of distance is expected. After applying "binscatter" method by Michael Stepner(2013)[15], Figure A.9 presents a fairly similar pattern with Figure A.7.

At the end of this chapter, the summary statistics is provided for all variables used in this paper in Table B.2.

CHAPTER 3

EMPIRICAL STRATEGY

3.1 Fixed Effect models

Specify the following baseline model of traffic speed based on the results from last chapter as:

$$
\begin{aligned}
Log(Speed_{it}) = \alpha + \beta_1 Distance_{it} + \beta_2 Distance_{it}^2 + \gamma Weather_t + Month_t + Hour_t \\
+ Week_t + Holiday_t + Road_i + \varepsilon_{it}
\end{aligned}
\tag{3.1}
$$

where $Log(Speed_{it})$ is the natural logarithm for average speed (mile per hour) of a vehicle on road i at time t; $Distance_{it}$ is the minimum distance between the road i with the nearest construction site on work at time t; $Distance_{it}^2$ is the square term of distance; $Weather_t$ is a vector of hourly Weather variables including temperature(°C), atmospheric pressure(hPa), relative humidity(%), wind speed(m/s), wind direction(meteorological degrees), rainfall volume, snowfall volume and cloudiness(%); ε_{it} is the unobserved, time-varying and road-specified variables, such as the events, traffic accidents.

In this baseline model, a set of time fixed effects($Month_t$, $Hour_t$, $Week_t$, $Holiday_t$) and road fixed effects have been included. These time fixed effects control unobserved temporal shocks to traffic speed during month of the year, hour of the day, day of the week, and federal holidays, such as the rush hour period in weekdays, after-school hour, the parade in some holiday. The road fixed effect controls the time-invariant, road-specified attributes that affects traffic speed, such as the location of road(nearness to school, subway or bus station, shopping mall, parking area, business district, hospital) and road attributes(number of lanes, one-way or two-ways, speed limit, traffic light, stop sign, sidewalk, bike lane, parking, pedestrian crossing and etc.).

Additionally, I assume that the marginal effect of road project on traffic varies across the distance (vehicles that is very close to construction will be affected stronger than vehicles far from construction). Then I generate six distance groups(0-1km, 1-2km, 2-3km, 3-4km, 4-5km, ≥ 5km), and interact these dummy variable groups with $Distance_{it}$ to get variable $Dist_{nit}$ and rewrite the baseline model as:

$$\begin{aligned} Log(Speed_{it}) = \alpha + \Sigma_1^6 \beta_n Dist_{nit} + \gamma Weather_t + Month_t + Hour_t \\ + Week_t + Holiday_t + Road_i + \varepsilon_{it} \end{aligned} \tag{3.2}$$

where $Dist_{nit}$ represents the distance between the road i with the nearest construction site on work at time t within distance group n. In fact, I separate $Distance_{it}$ into six $Dist_{nit}$ to capture specified effects of construction on vehicle speed that may vary across the distance. For instance, traffic condition of road that is far away (such as 10km away from site) may not be affected by road construction.

Besides, I apply both stricter fixed effects models (fixed effect of road section and hour of the sample) and interaction of fixed effect (road section with month of sample). Employing hour-of-sample fixed effect to replace a set of fixed effects($Month_t, Hour_t, Week_t, Holiday_t$) is at the aim to control variation in traffic speed within every hour of the sample. For example, the variation in the after-school hour at the day before summer vacation begins should be different from other schooldays hours. Moreover, $Weather_t$ and fixed effects of ($Month_t$, $Hour_t$, $Week_t$, $Holiday_t$) are captured by hour-of-sample fixed effect, as well as other time-related unobserved factors. For latter, I want to capture the temporal road-specified differences, such as the difference of traffic condition in usual days and that in school vacation period for a road passing through school area, or the difference of traffic volume during the work hour and that in the evening for a street near to a business district.

3.2 Heterogeneity

In case of heterogeneity, I apply two approaches that separate the sample into subgroups based on different variables. The first approach is using duration to test the coefficients across different duration sub-samples. Among construction projects, the duration of construction varies from several hours to months. Different type of construction may have diverse data pattern. The duration in this paper is time between the start and completed time of the projects, not the total time that construction is on work. In the other words, I cannot judge whether a certain project is under construction. Instead, I could make a reasonable assumption that projects with shorter duration should be the small works, such as pavement striping or tiny road repair, which always block one lane of the road. Then construction with longer duration, such as 3 months, should be those giant work, which could sometimes blocked the whole section. In this case, I could treat duration as a measurement of project size.

The second approach is applying the data pattern in the start date of construction. Exploring the road project data, a special data pattern for the start time of construction project could be found. The start time of some projects are in the pattern as "09/08/2017 00:00:00", well-organized as the start of a day, while other projects start at a random moment such as "09/08/2017 15:48:36". I treat the first group as "planned", the second group as "unplanned" and expect there should be variation across these two subgroups.

CHAPTER 4

EMPIRICAL RESULTS

4.1 All Sample Results

Table B.3 presents empirical results of Model (3.1) and (3.2), including weather controlling variables, holiday dummy variable and fixed effects of road section, hour of day, day of week and month of sample. In Column(1), the coefficients of distance and distance square term are insignificant but their signs meet with my expectation in scatter-plot. After separating distance into six groups, the coefficients of two distance groups (1-2km and 2-3km) in Column(2) become significant positive, while the coefficients of other distance groups are insignificant. Weather controlling variables are significant in two columns, the holiday dummy variable as well.

Then I apply both stricter fixed effects models (fixed effect of road section and hour-of-sample) and interaction fixed effect (fixed effect of road section with month-of-sample). Results become better (Table B.4). The coefficient of distance square term is significant negative, which meets our expectation in Figure 2.8. When the vehicle is close to the construction, traffic speed will decrease with a higher rate, while the value of this rate decreases as the vehicle drives further from construction. Results in Column(2) tell a specific story. The coefficients for five distance groups(within 5km to the construction site) are significant positive. For example, the traffic speed will decrease by 4.23% if it moves 1km near to the construction site for observation within distance group 1-2km away from construction. These coefficients for distance group, which could be interpreted as the marginal effects of distance to construction site on speed, decrease as the observation getting further away from the construction site, and approach to zero where the distance between speed sensor and construction site is nearly 10km. This indicates that the effect of road construction on speed is diminishing as the distance between speed recorder and construction increases. On the other hand, the coefficients for distance group that is more than 10km from construction shows insignificance. One potential explanation could be addressed as that the effect of construction on traffic speed for vehicles far away from construction is weak, where other factors may have stronger effect on speed.

Based on the results of Column(1), I predict the change in traffic speed with the distance to construction site, shown in Figure A.10. When vehicle is driving away from construction site, the traffic speed will increase, but will begin to decrease when distance exceeds around 7km. However, the results for models including interaction fixed effects (Column (3) and (4) in Table B.4) are insignificant and the value of coefficients are quite different from that in Column (1) and (2), which could be addressed as I failed in captured temporal road-specific fixed effect.

4.2 Approach I: Long and short projects

First, I treat road works whose duration is longer than one week as "long" projects, while those duration is shorter than one week will be treated as "short" projects. Figure A.11 shows the scatterplot for these two groups. The observations from "short" projects sample fall within the distance 0-8km, while observations from long project sample fall in all distance groups. Table B.5 presents the empirical results from two sub-samples. Coefficients in the long project sample(Column (1) & (2)) are significant, fairly similar to that of all sample(Table B.4). Results from short project are, however, insignificant. This is coincided with our assumption, longer projects, which are also large tasks, has more significant effect on speed than those instant and tiny projects.

Noticed that small sample size of short projects may arise problem with degree of freedom, I continued separate our data into four sub-groups and conduct the fixed effect model again. Results present in Table B.6. Coefficients for groups(1 week to 1 month) and group(longer than 2 months) shows significance. Focused on Column (3) & (4), I are surprised by the fact that the effect of road construction on speed is higher than that in all sample. Traffic speed drops 31.6% when vehicles are within 1km to the construction whose duration is between 1 week to 1 month, compared to the number is 7.9% in Table B.4. This could also be interpreted by the former assumption. Drivers might be more likely to notice those projects lasting for months and schedule their routes to avoid these sites beforehand. While tiny work last less than one week has relatively slightly effect on traffic. Projects with duration between one week and one month, are larger tasks than one-week small work, but smaller than those giant projects conducting for months. Residents in NYC might fail to notice these construction and brake suddenly with a glimpse of the sign ”Under Construction”, which also give a living explanation of the 31.6% decrease in traffic speed within 1km to constriction.

4.3 Approach II: Planned and unplanned projects

Figure A.12 shows the scatterplots for both planned and unplanned projects groups. The variations of unplanned projects is slightly larger than planned projects. Table B.7 presents the empirical results from two sub-samples. For planned projects, the coefficient of distance is significant positive in Column (1), meeting with our expectation. However the coefficient for distance square term is insignificant, meaning there is no quadratic relationship between speed and distance in planned project sample. In Column (2), only the coefficients of distance group 2-3km, 3-4km and 4-5km are significantly positive.

I interpret this as drivers have knowledge about those planned projects beforehand, thus they will avoid to drive too near the road work, resulting in the insignificance of coefficient for distance groups near construction. For unplanned projects, coefficients for distance and square term are both significant in Column (3), showing there is quadratic relationship between speed and distance. Unplanned projects usually start without posting any notice beforehand, causing drivers have no information about these road tasks and drive close to these projects. Unplanned projects could also be conducted on heavy traffic road or during rush hour for an unexpected reason, leading many vehicles are so near to construction that traffic speed gets slower.

Then I combine duration groups with planned(or unplanned) attribution and re-run the fixed effect models (Table B.8). Results are fairly similar with Table B.6 & B.7. Projects with duration between 1 week to 1 month have significantly effect on traffic speed, while unplanned group possesses larger absolute value of effect.

CHAPTER 5

DISCUSSION

Now we should move to the economics analysis of road construction projects. The information of these road projects could be found in the NYC Citywide Administrative Service database, including announcement, schedule, bidding history and contrast. DOT assigns a construction project with an estimate total cost, then several firms bid for this project and the one with lowest price wins. Inside the project contrast, there are "Date for substantial completion" [1] and "Liquidated damages"[2], which are the key terms I want to compare with our empirical results.

Here is the rough estimate of the cost of construction on commuters. According to the American Community Survey(ACE, 2018)[3], there are totally 1,060,311 people in NYC that drive a car, truck, or van to commute(alone or carpooled), and the estimated travel time to work is 41.2 minutes(one-way). Based on the relationship below, I could estimate the increase in commute time:

$$\begin{aligned} Distance &= Travel\ speed \times Commute\ time \\ \Delta Commute\ time &= \frac{1}{1 - \Delta Travel\ speed} - 1 \end{aligned} \tag{5.1}$$

I then use the distribution of our sample to measure the average distance to the construction for vehicles in NYC. Based on the result from Table B.2, the average

[1] Defined as the Contractor shall substantially complete the Work in the number of Days indicated, such as 730 days.

[2] Defined as: If the Contractor fails to substantially complete the Work within the time fixed for substantial completion plus authorized time extensions or if the Contractor, in the sole determination of the Commissioner, has abandoned the Work, the Contractor shall pay to the City the amount indicated. This payment could be either "Amount vary as per Contract terms" or assigned by government (e.g. $1000 for each Day beyond the completion date of a specific work order and $20,000 per month if the contractor fails to install the Minimum Quantity)

[3] American Community Survey

distance is 2.52km. Applying result in Column(2) of Table B.4, traffic speed will decrease by 3.47%. According to Eq.5.1, travel time for NYC residents increases by 3.59%, i.e. nearly increases by 1.48 minutes. The mean individual income for NYC residents is $74,834, while the medium individual income is $50,825, reported in ACE(2018). Converting to hourly wage[4], the mean hourly wage is $35.98, while the medium is $24.44. Based on the Traffic Volume Counts(2014-2018)[5], the average hourly traffic volume for individual road section is 542 vehicles. Together, we could have the rough estimated impact of construction on traffic is $326 - 451 per hour.

Applying the same equation and logic, the estimated cost for different types of construction could be calculated. For road projects with duration between one week to one month, the estimated increase in commuting time is 13.41%, and the cost is $1219.76 - 1795.71 per hour. For construction with duration longer than two months, the estimated increase in commuting time is 2.67% and the cost is $242.86 - 357.53 per hour.

This evaluation could also be applied to planned and unplanned projects. For planned construction, the estimated increase in commuting time is 3.49%, the cost is $317.45 - 467.34 per hour. While for unplanned contrition, the commuting time will increase by 4.07% and the cost caused by construction is $370.20 - 545.01 per hour.

All estimations of the cost caused by the road construction are relatively higher than the penalty amount of late completion in the contrasts, and we could observe that the cost varies across the type of projects. Therefore, the penalty should be decided based on the nature of construction, as well other project

[4]Supposed people work 40 hours per week and there are 52 weeks in a year.
[5]Traffic Volume Counts (2014-2018)

attributes and factors.

Even if the calculation is loose, our results reveal the fact that these contrasts do not place a strong incentive for construction firms to complete the projects on time. A bonus for completion of construction before the due date or a higher penalty for late completion might be a better option for construction contrast. Additionally, posting notice or announcement of the road construction could help relive the impact of road work on traffic speed, based on the results for planned and unplanned groups.

CHAPTER 6

CONCLUSION

This paper estimates the effect of road construction on traffic speed using the unique data file on traffic speed and construction projects in NYC from 2017 to 2019. Linking traffic speed sensor data with construction project history with the geographic information, the data allows me to allocate the effect of each construction to the nearest speed sensor.

I find that there is a 3.47% decrease in traffic speed on average when vehicles are 1km closer to road work. Specified, the decrease in speed is 7.93% for traffic that is within 1km to construction, 4.23% for 1-2km, 3.47% to 2-3km, 2.14% to 3-4km and 1.34% to 4-5km. This diminishing trend in marginal effects of construction on speed present the fact that road work places relatively obvious impact on traffic and this impact is more significant when vehicles are driving ahead to construction. Out of my expectation, the empirical results reveal that temporal road-specified difference is failed to be captured but fixed effect of road section and hour of the sample are captured separately.

Besides, this paper also estimates the impact of diverse types of road works on traffic. Empirical results of duration sub-groups address the fact that the magnitude and significance of impact on traffic are difference across duration. Briefly, projects with longer working periods have more significant impact on traffic. Specified, the effect of road constructions with duration between one week to one month is the significantly highest. Traffic speed drops 31.6% for vehicles within 1km to those projects, while the marginal effect is 7.9% in all sample results. Based on the assumption about duration and size of project, this paper provides a reasonable explanation and appeals that these types of construction should be place more emphasis, such as put up the notice of construction earlier or place a higher penalty on the delay in completion of these projects. I also look at the difference between observations in "planned" and "unplanned" groups. Results show that the impact of unplanned construction on traffic speed is higher and more significant than planned work, which also make suggestion to road project contrast.

This paper also evaluates the efficiency of incentive in road construction contrasts. Based on the information from ACE and Traffic Volume Counts dataset, I provide a rough estimated impact of road construction on society: road work will increase commuters' travel time by 1.48 minutes, and this will arise a social cost of $326 - 451 per hour. Moreover, the cost for different types of projects vary, and the maximum cost could reach $1795.71 per hour for the road work with duration between one week to one month. Compared with several project contrasts, in which the penalty[1] of delay in completion is commonly $ 1000 a day, the impact of construction on traffic speed is obviously higher. Thus a bonus for completion before the due date or a higher penalty for late completion are suggested. Penalty should be assigned depend on the nature, duration, and other attributes of the projects but not a same amount for all projects.

Finally, I conclude with some caveats and plans for future research. First, the distance data employed in this paper is the minimum distance between a speed sensor and the nearest road construction, which is based on a strong assumption that only the nearest construction has impact on that street section. However not only the nearest construction influences traffic speed, other road works also place impact traffic in reality, since the traffic system of a city is a network. Thus network effect and multiple distance data should be involved in future study.

[1]In construction contrast, it usually written as "Liquidated damages"

Second, the lack of traffic flow volume data results in the failure of applying road price framework to estimate the marginal cost and social welfare change in road pricing schemes. My original research purpose is to give suggestion to congestion pricing policy in NYC, which could be conducted in future research with Traffic Volume Counts Data from NYCDOT. Moreover, event study, identification of endogeneity and other advance research designs should be included to help understand how construction impact traffic of the whole city and how to set up an efficiency project contrast.

APPENDIX A

APPENDIX I: FIGURES

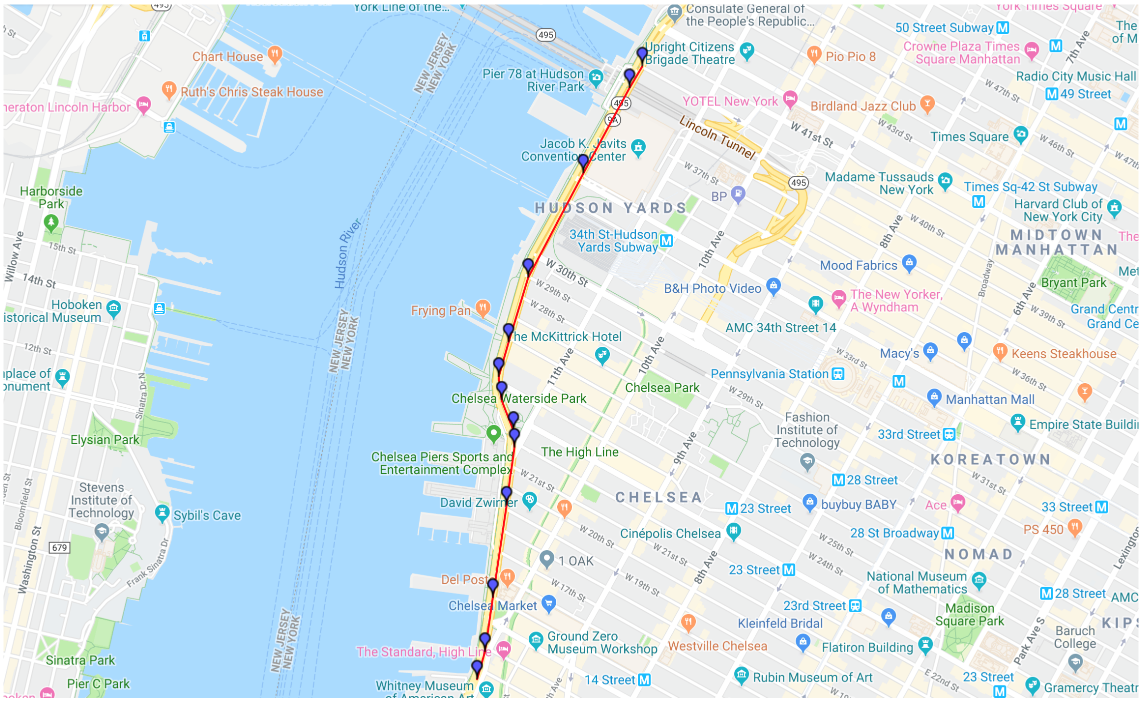


Figure A.1: Example of Recorded Road Section

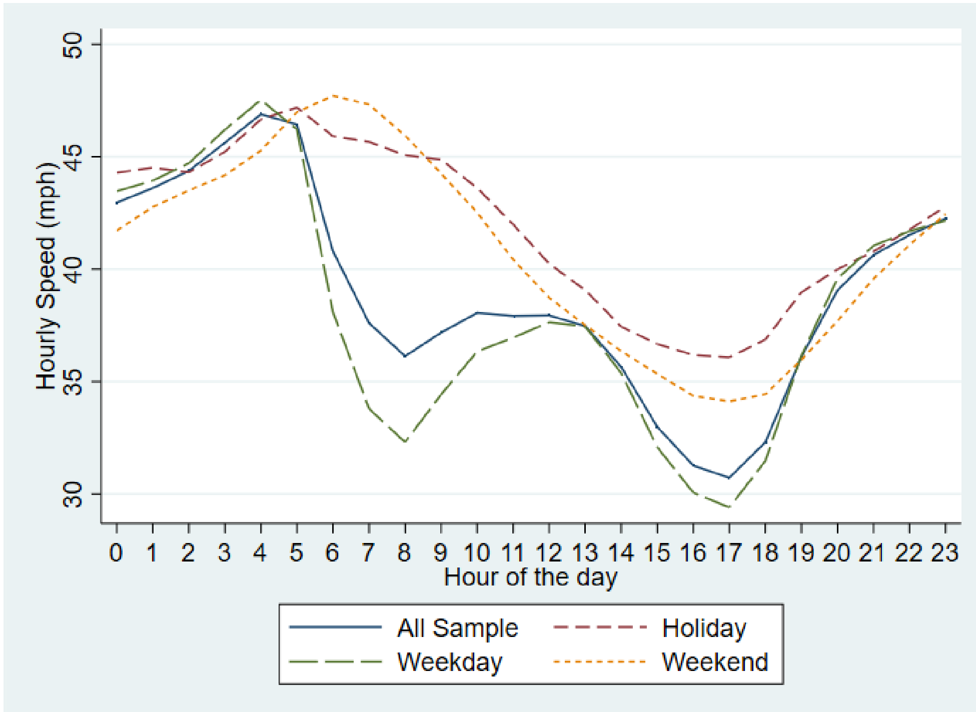


Figure A.2: Average Hourly Speed of Traffic

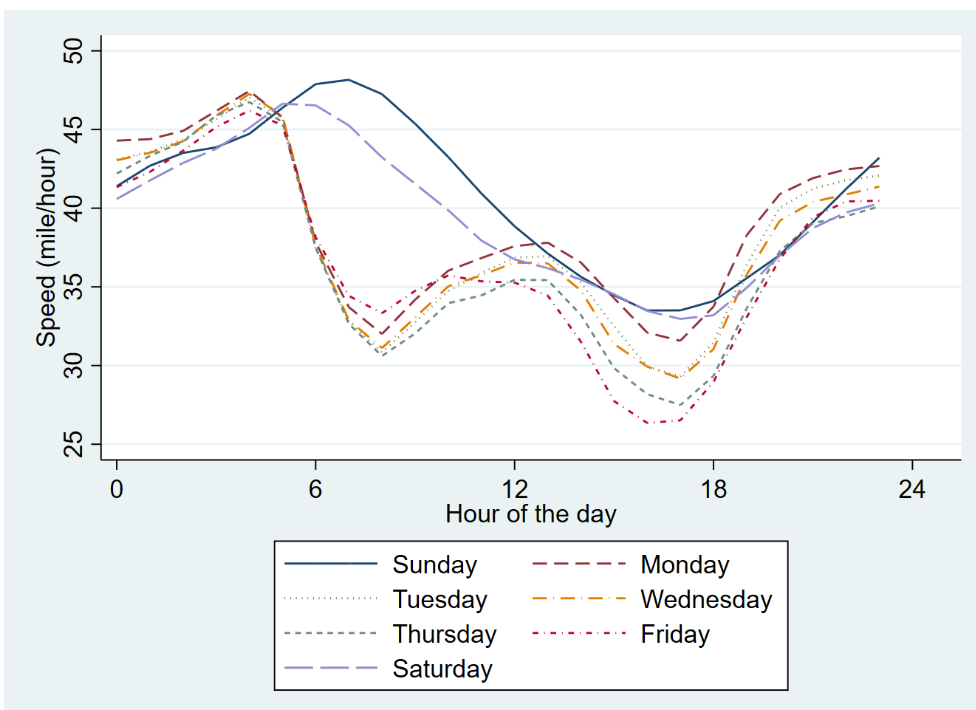


Figure A.3: Average speed for day of week

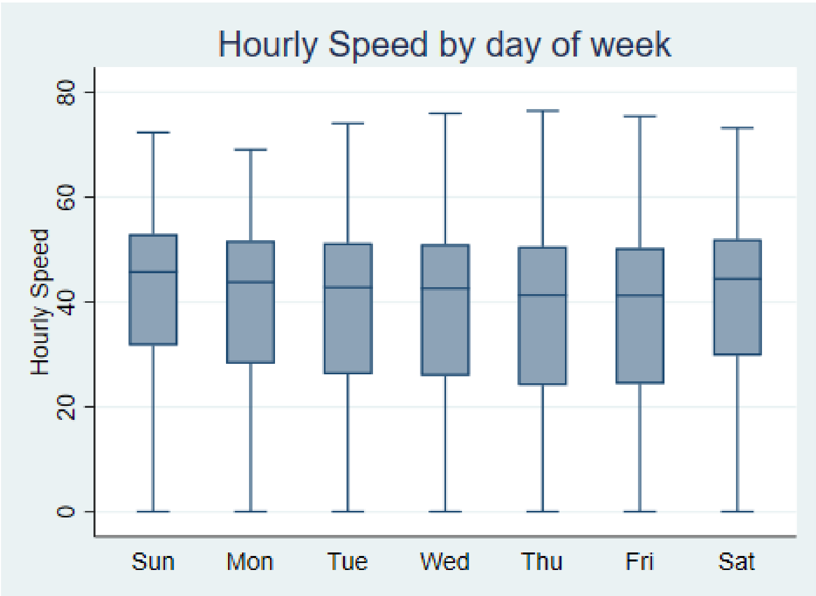
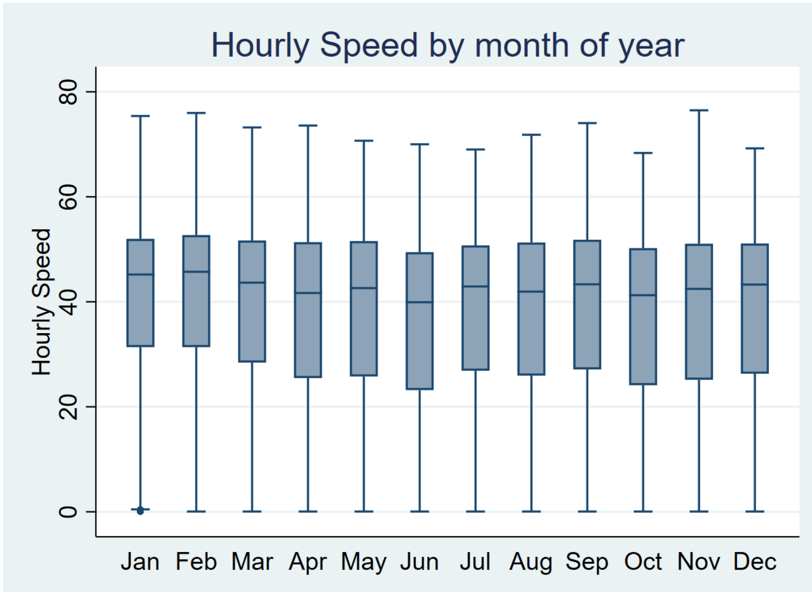
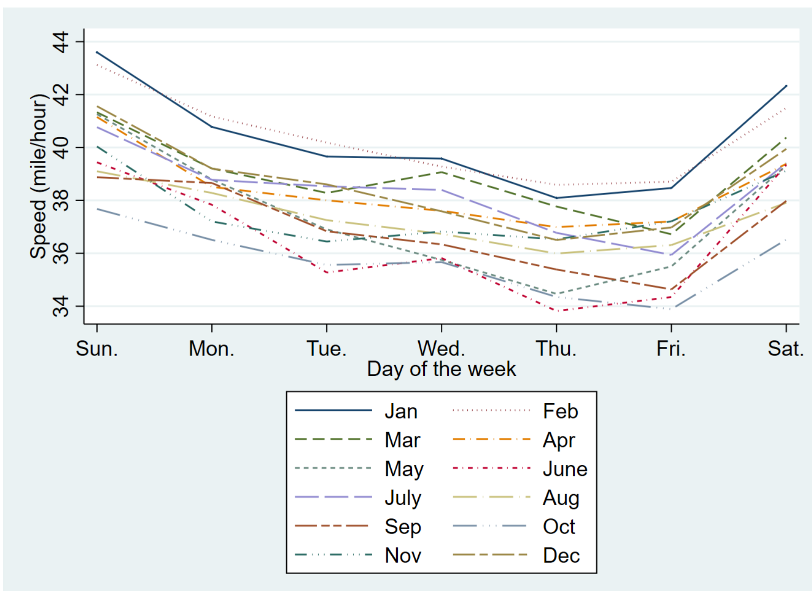


Figure A.4: Box graph for hourly speed by day of week



(a) Box Graph



(b) Average speed over day of week & month of year

Figure A.5: Hourly traffic speed by month of year

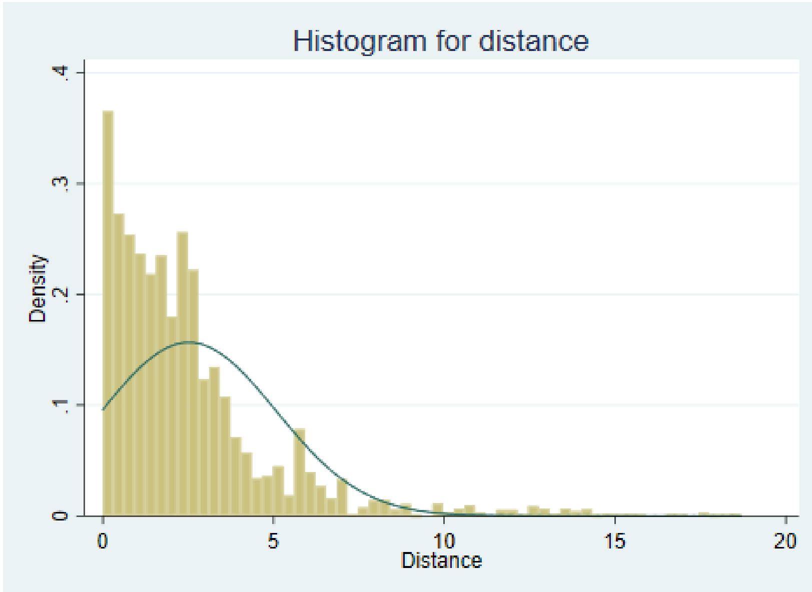


Figure A.6: Histogram and normal distribution for distance

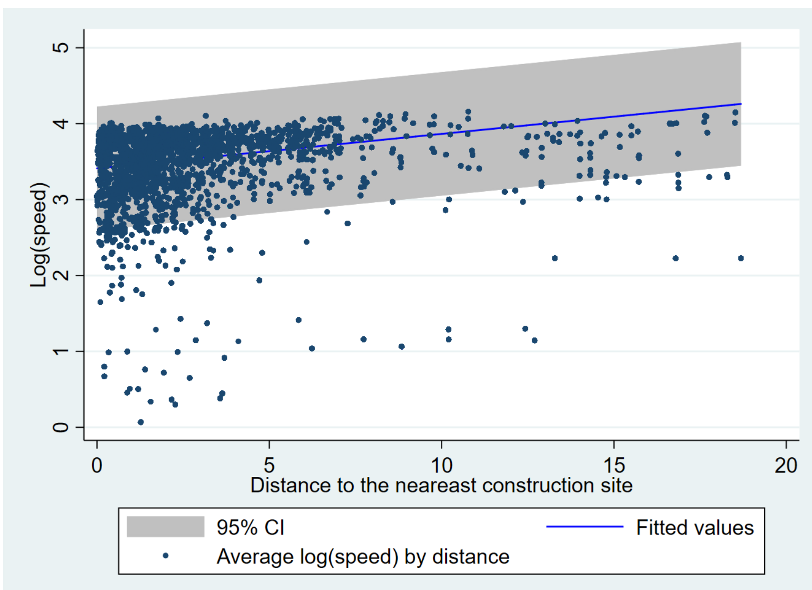


Figure A.7: Scatter plot and linear regression curve for log(speed) and distance

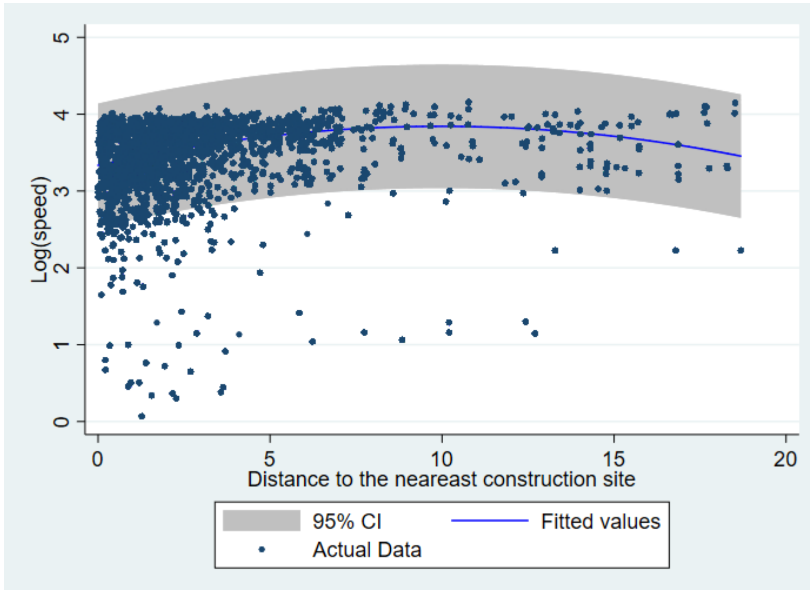


Figure A.8: Scatter plot and quadratic regression curve for log(speed) and distance

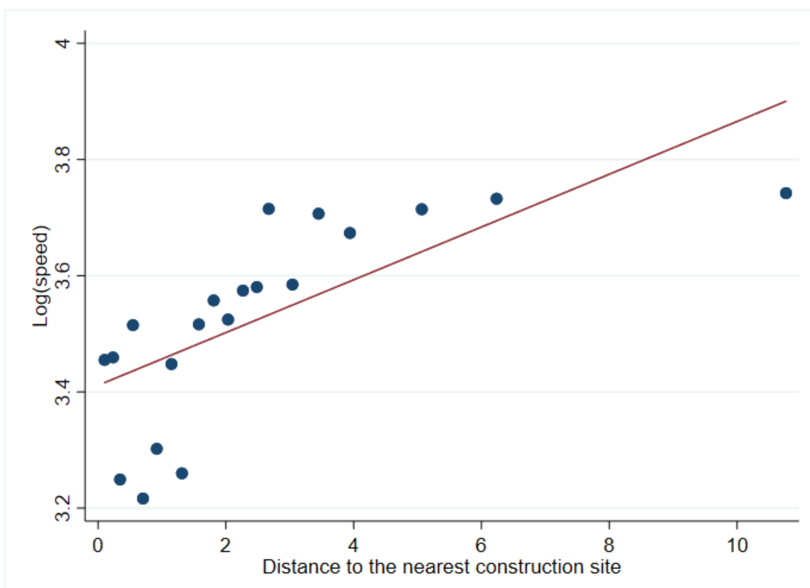


Figure A.9: Binned Scatter plots and linear regression curve for log(speed) and distance

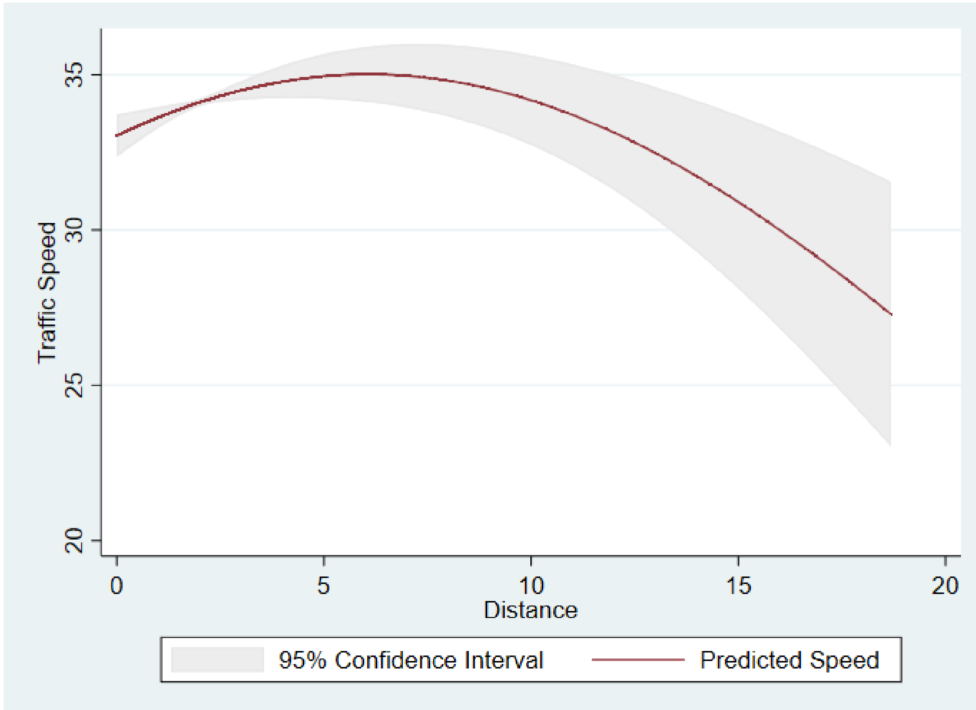


Figure A.10: Predicted quadratic regression curve

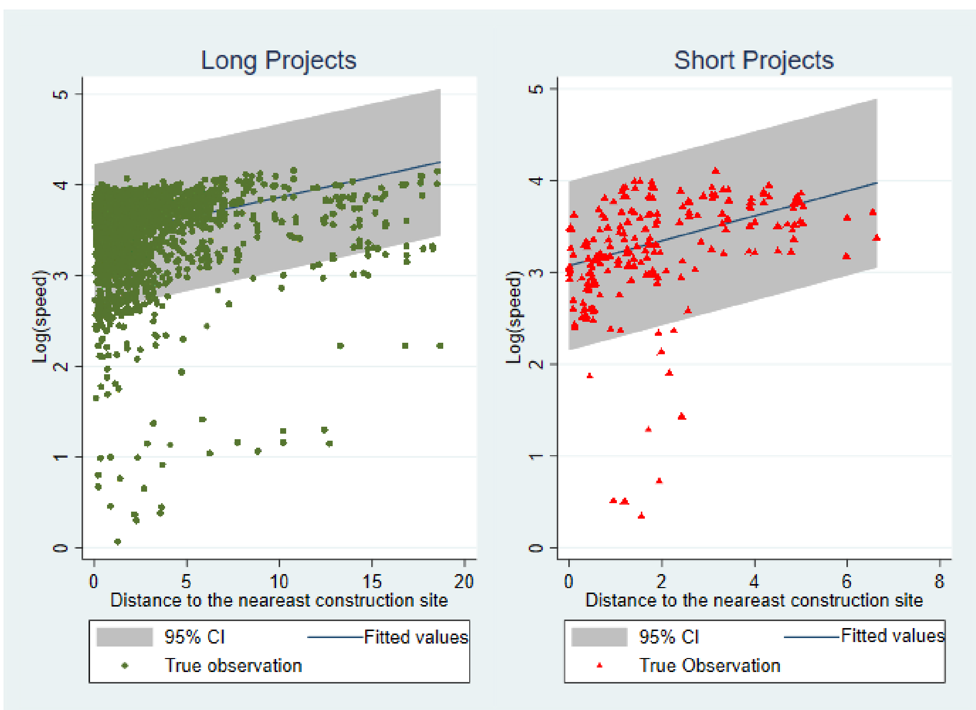


Figure A.11: Scatter plots for long and short project samples

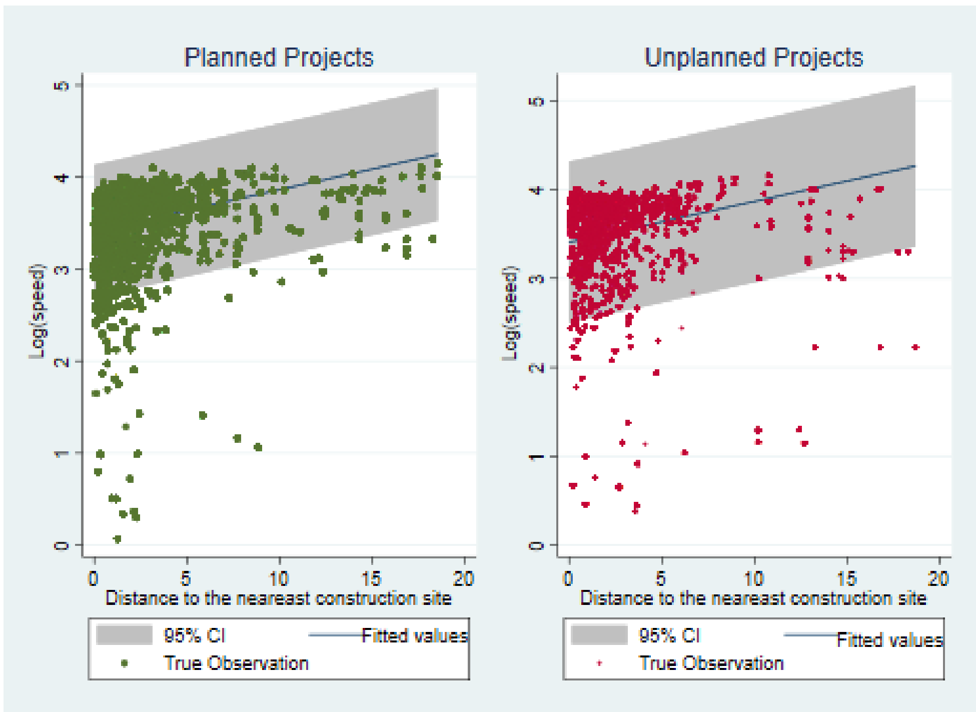
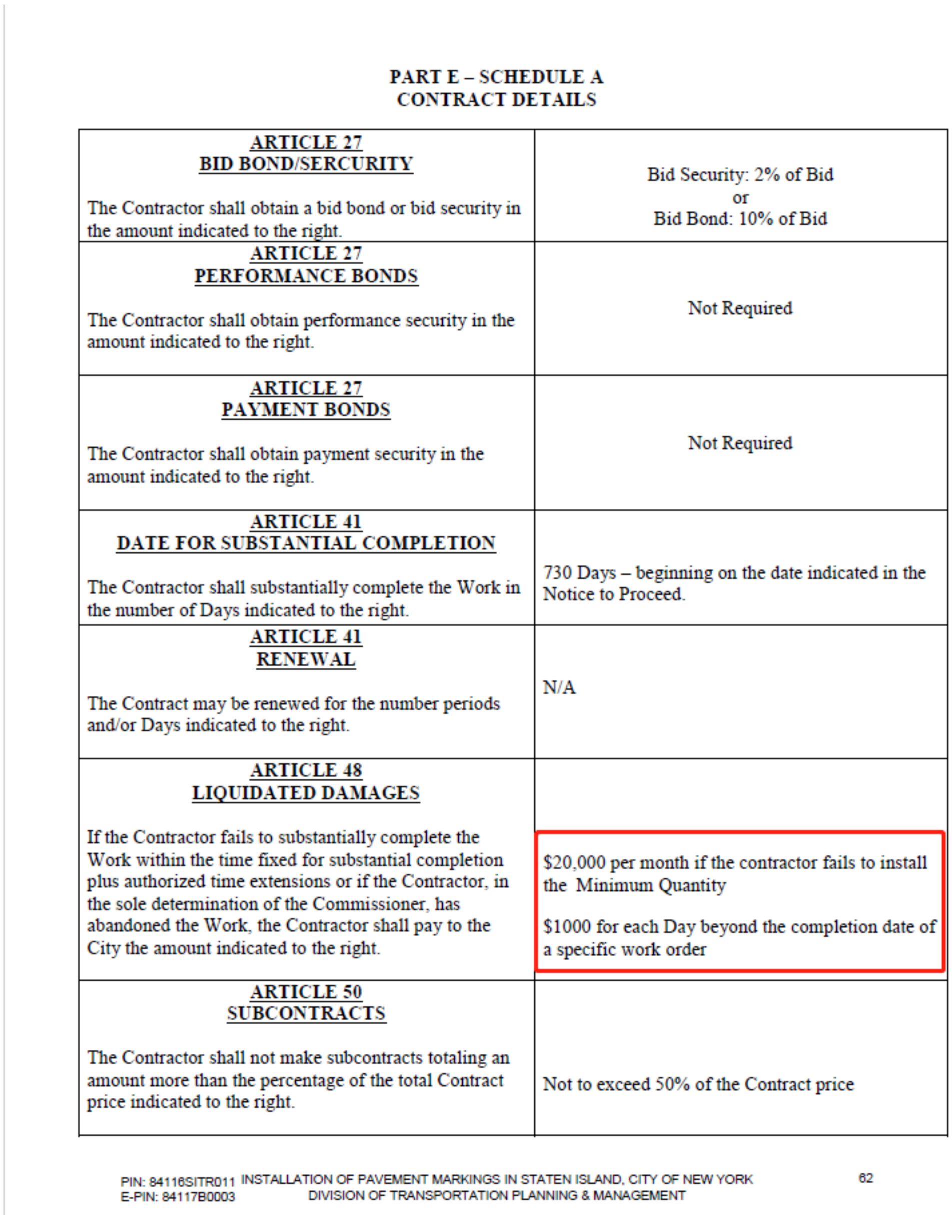


Figure A.12: Scatter plots for planned and unplanned project samples



PART E – SCHEDULE A
CONTRACT DETAILS

ARTICLE 27 **BID BOND/SERCURITY** The Contractor shall obtain a bid bond or bid security in the amount indicated to the right.	Bid Security: 2% of Bid or Bid Bond: 10% of Bid
ARTICLE 27 **PERFORMANCE BONDS** The Contractor shall obtain performance security in the amount indicated to the right.	Not Required
ARTICLE 27 **PAYMENT BONDS** The Contractor shall obtain payment security in the amount indicated to the right.	Not Required
ARTICLE 41 **DATE FOR SUBSTANTIAL COMPLETION** The Contractor shall substantially complete the Work in the number of Days indicated to the right.	730 Days – beginning on the date indicated in the Notice to Proceed.
ARTICLE 41 **RENEWAL** The Contract may be renewed for the number periods and/or Days indicated to the right.	N/A
ARTICLE 48 **LIQUIDATED DAMAGES** If the Contractor fails to substantially complete the Work within the time fixed for substantial completion plus authorized time extensions or if the Contractor, in the sole determination of the Commissioner, has abandoned the Work, the Contractor shall pay to the City the amount indicated to the right.	$20,000 per month if the contractor fails to install the Minimum Quantity $1000 for each Day beyond the completion date of a specific work order
ARTICLE 50 **SUBCONTRACTS** The Contractor shall not make subcontracts totaling an amount more than the percentage of the total Contract price indicated to the right.	Not to exceed 50% of the Contract price

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Figure A.13: Example 1 for the road construction contrast(Liquidated Damage part)

PART E – SCHEDULE A
CONTRACT DETAILS

ARTICLE 27 **BID BOND/SERCURITY** The Contractor shall obtain a bid bond or bid security in the amount indicated to the right. For Bid Bond Form see Attachment 3d.	Bid Security: 2% of Bid or Bid Bond: 10% of Bid
ARTICLE 27 **PERFORMANCE BONDS** The Contractor shall obtain performance security in the amount indicated to the right. For Performance Bond see Attachment 2b.	100%
ARTICLE 27 **PAYMENT BONDS** The Contractor shall obtain payment security in the amount indicated to the right. For Payment Bond Form see Attachment 2a.	100%
ARTICLE 47 **DATE FOR SUBSTANTIAL COMPLETION** The Contractor shall substantially complete the Work in the number of Days indicated to the right.	730 Days – beginning on the date indicated in the Notice to Proceed.
ARTICLE 41 **RENEWAL** The Contract may be renewed for the number periods and/or Days indicated to the right.	No Renewal.
ARTICLE 48 **LIQUIDATED DAMAGES** If the Contractor fails to substantially complete the Work within the time fixed for substantial completion plus authorized time extensions or if the Contractor, in the sole determination of the Commissioner, has abandoned the Work, the Contractor shall pay to the City the amount indicated to the right.	Two hundred dollars ($200) for each Day the Work is delayed past the due date specified in each Work Order, if such due date is specified.
ARTICLE 50 **SUBCONTRACTS** The Contractor shall not make subcontracts totaling an amount more than the percentage of the total Contract price indicated to the right.	Not to exceed 49% of the Contract price

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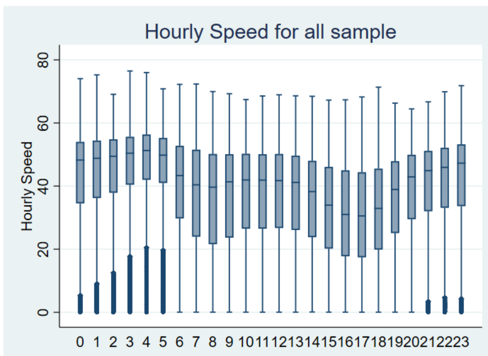
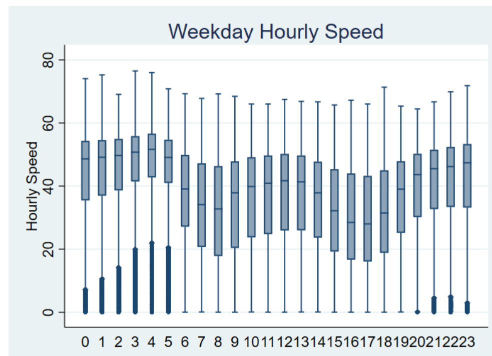
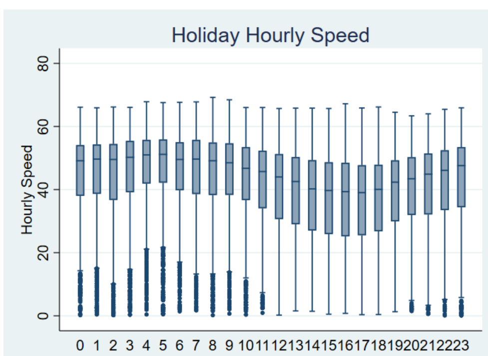
Figure A.14: Example 2 for the road construction contrast(Liquidated Damage part)



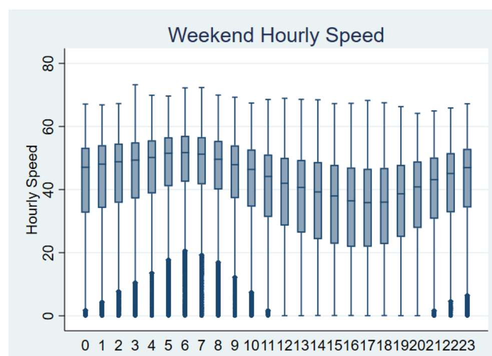
(a) Entire sample



(b) Weekday



(c) Federal Holiday



(d) Weekend

Figure A.15: Box graphs for hourly traffic speed

APPENDIX B

APPENDIX II: TABLES

Table B.1: Average Speed by distance group

Distance	Obs	Average Speed
0-1km	325829	31.52
1-2km	273963	36.10
2-3km	230098	40.52
3-4km	126386	43.64
4-5km	163470	45.00
>5km	30397	47.76

Table B.2: Summary Statistics

Variable	Obs	Mean	SD	Min	Max
Speed(mph)	1,150,143	39.3100	15.3038	0.62	118.68
Distance(km)	1,150,143	2.5236	2.5461	0.0008	18.6835
Temperature (°C)	1,150,143	10.1609	9.9599	-16.71	34.57
Pressure(hPa)	1,150,143	1018.576	8.4972	979	1047
Humidity(%)	1,150,143	63.5684	20.5596	12	100
Wind Speed(m/s)	1,150,143	3.0745	1.9896	0	16
Wind Degree(°)	1,150,143	168.2606	122.1534	0	360
Rain(mm)	1,150,143	0.1516	0.5245	0	12
Snow(mm)	1,150,143	0.0348	1.0224	0	59.5
Cloudiness(%)	1,150,143	45.6999	40.4638	0	92
Holiday	1,150,143	.0281	0.1652	0	1
Planned	1,150,143	0.5334	0.4989	0	1
Duration(hour)	1,150,143	1701.642	631.5566	47	2183

[1] Note: Distance is the minimum distance to the nearest construction site.
[2] Rain/Snow is rain/snow volume for last hour.
[3] Planned is defined in Section 4.3. Planned is data with the start time in the well-organized pattern, otherwise visa.
[4] Duration is the time between the start time and the end time of project in hour.

Table B.3: Empirical results for all sample (Including Weather Controlling Variables)

	Dependent Variable: log(*speed*)	
	(1)	(2)
Distance (km)	0.0041	
	(0.0062)	
Distance^2	-0.0005	
	(0.0004)	
Distance (0-1km)		0.0566
		(0.0454)
Distance (1-2km)		0.0312*
		(0.0164)
Distance (2-3km)		0.0217**
		(0.0104)
Distance (3-4km)		0.0103
		(0.0072)
Distance (4-5km)		0.0040
		(0.0052)
Distance ($\geq$ 5km)		-0.0015
		(0.0033)
Controlling Variables		
Temperature (°C)	0.0005	0.0004
	(0.0006)	(0.0006)
Pressure (hPa)	0.0006***	0.0006***
	(0.0002)	(0.0002)
Humidity (%)	-0.0002**	-0.0002**
	(0.0001)	(0.0001)
Wind speed (m/s)	0.0008*	0.0007*
	(0.0004)	(0.0004)
Rain(mm)	-0.0232***	-0.0232***
	(0.0015)	(0.0015)
Snow(mm)	-0.0008*	-0.0008*
	(0.0005)	(0.0005)
Holiday (=1 if federal holiday)	0.1105***	0.1100***
	(0.0079)	(0.0079)
Constant	2.5881***	2.5542***
	(0.2054)	(0.2136)
N	1150143	1150143
R^2	0.0996	0.1004

[1] Note: Standard errors (in parentheses) are clustered at the Road section level. Fixed effects include hour-of-day, day-of-week, month-of-sample and road-ID.

[2] Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

[3] Note: Distance is the minimum distance to the nearest construction site.

[4] Rain/Snow is rain/snow volume for last hour.

Table B.4: Empirical results for all sample (Road & Hour of sample FE)

	Dependent Variable: log(*speed*)			
	(1)	(2)	(3)	(4)
Distance (km)	0.0191***		-0.0053	
	(0.0060)		(0.0056)	
Distance^2	-0.0016***		-0.0005	
	(0.0004)		(0.0004)	
Distance (0-1km)		0.0793*		0.0449
		(0.0463)		(0.0287)
Distance (1-2km)		0.0423***		0.0123
		(0.0154)		(0.0124)
Distance (2-3km)		0.0347***		0.0046
		(0.0103)		(0.0084)
Distance (3-4km)		0.0214***		-0.0007
		(0.0071)		(0.0075)
Distance (4-5km)		0.0134***		-0.0002
		(0.0049)		(0.0051)
Distance ($\geq$ 5km)		-0.0044		-0.0034
		(0.0034)		(0.0026)
Constant	3.4978***	3.4663***	3.3734***	3.3507***
	(0.0106)	(0.0219)	(0.0104)	(0.0182)
FEs: Road	Y	Y	Y	Y
FEs: Hour of sample	Y	Y	Y	Y
FEs: Road * Month of sample			Y	Y
N	1150143	1150143	1150143	1150143
R^2	0.0012	0.0022	0.1964	0.1964

[1] Note: Standard errors (in parentheses) are clustered at the Road section level.
[2] Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[3] Note: Distance is the minimum distance to the nearest construction site.

Table B.5: Empirical results for long & short projects

	Dependent Variable: log(*speed*)			
	Long Projects		Short Projects	
	(1)	(2)	(3)	(4)
Distance (km)	0.0197***		-0.0383	
	(0.0061)		(0.0368)	
Distance^2	-0.0016***		0.0061	
	(0.0005)		(0.0057)	
Distance (0-1km)		0.0856*		-0.1183
		(0.0472)		(0.1562)
Distance (1-2km)		0.0444***		-0.0460
		(0.0158)		(0.0584)
Distance (2-3km)		0.0361***		-0.0217
		(0.0106)		(0.0355)
Distance (3-4km)		0.0230***		-0.0281
		(0.0073)		(0.0251)
Distance (4-5km)		0.0140***		-0.0102
		(0.0050)		(0.0152)
Distance ($\geq$ 5km)		-0.0040		0.0000
		(0.0035)		(.)
Constant	3.5000***	3.4663***	3.3881***	3.4164***
	(0.0108)	(0.0225)	(0.0400)	(0.0807)
FEs: Road	Y	Y	Y	Y
FEs: Hour of sample	Y	Y	Y	Y
N	1128185	1128185	21958	21958
R^2	0.0013	0.0024	0.0006	0.0014

1 Note: Standard errors (in parentheses) are clustered at the Road section level.

2 Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

3 Note: Distance is the minimum distance to the nearest construction site.

Table B.6: Empirical results for duration groups

	Dependent Variable: log(*speed*)							
	≤1 week		1 week - 1 month		1 month - 2 months		≥ 2 months	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance (km)	-0.0383		0.0923**		0.0172		0.0175**	
	(0.0368)		(0.0418)		(0.0258)		(0.0071)	
Distance^2	0.0061		-0.0156**		0.0030		-0.0016***	
	(0.0057)		(0.0065)		(0.0028)		(0.0005)	
Distance (0-1km)		-0.1183		0.3163***		0.0354		0.0347
		(0.1562)		(0.0899)		(0.1001)		(0.0515)
Distance (1-2km)		-0.0460		0.1183***		0.0495		0.0360*
		(0.0584)		(0.0436)		(0.0324)		(0.0212)
Distance (2-3km)		-0.0217		0.0811***		0.0476		0.0260**
		(0.0355)		(0.0271)		(0.0376)		(0.0127)
Distance (3-4km)		-0.0281		0.0451**		0.0093		0.0173*
		(0.0251)		(0.0190)		(0.0082)		(0.0091)
Distance (4-5km)		-0.0102		0.0307**		0.0321*		0.0085
		(0.0152)		(0.0134)		(0.0176)		(0.0061)
Distance (≥ 5km)		0.0000		0.0000		0.0825***		-0.0063
		(.)		(.)		(0.0150)		(0.0039)
Constant	3.3881***	3.4164***	3.3610***	3.2712***	3.4475***	3.4254***	3.5192***	3.5011***
	(0.0400)	(0.0807)	(0.0390)	(0.0544)	(0.0283)	(0.0541)	(0.0136)	(0.0285)
N	21958	21958	92561	92561	176382	176382	859242	859242
R^2	0.0006	0.0014	0.0025	0.0061	0.0038	0.0052	0.0014	0.0020

[1] Note: Standard errors (in parentheses) are clustered at the Road section level.
[2] Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[3] Note: Distance is the minimum distance to the nearest construction site.

Table B.7: Empirical results for planned & unplanned projects

	Dependent Variable: log($speed$)			
	Planned projects		Unplanned projects	
	(1)	(2)	(3)	(4)
Distance (km)	0.0121**		0.0384***	
	(0.0054)		(0.0098)	
Distance^2	-0.0006		-0.0040***	
	(0.0004)		(0.0009)	
Distance (0-1km)		0.1058		0.0736
		(0.0803)		(0.0615)
Distance (1-2km)		0.0247		0.0655***
		(0.0177)		(0.0248)
Distance (2-3km)		0.0337***		0.0391**
		(0.0122)		(0.0175)
Distance (3-4km)		0.0240***		0.0182
		(0.0086)		(0.0113)
Distance (4-5km)		0.0139**		0.0238***
		(0.0057)		(0.0074)
Distance ($\geq$ 5km)		0.0047		-0.0246***
		(0.0037)		(0.0084)
Constant	3.5211***	3.4818***	3.4586***	3.4360***
	(0.0112)	(0.0290)	(0.0134)	(0.0326)
FEs: Road	Y	Y	Y	Y
FEs: Hour of sample	Y	Y	Y	Y
N	613513	613513	536630	536630
R^2	0.0005	0.0017	0.0042	0.0068

[1] Note: Standard errors (in parentheses) are clustered at the Road section level.
[2] Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[3] Note: Distance is the minimum distance to the nearest construction site.

Table B.8: Empirical results for duration groups (planned & unplanned)

	Dependent Variable: log(*speed*)							
	Planned projects				Unplanned projects			
	≤1 wk.	1 wk. - 1 mo.	1 - 2 mos.	≥ 2 mos.	≤1 wk.	1 wk. - 1 mo.	1 - 2 mos.	≥ 2 mos.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Distance (0-1km)	-0.1488	0.2863***	-0.1322	0.0755	0.0000	0.5772***	0.1280	0.0546
	(0.1569)	(0.0888)	(0.0853)	(0.0928)	(.)	(0.1927)	(0.1757)	(0.0686)
Distance (1-2km)	-0.0525	0.1141**	-0.0112	0.0023	0.0000	0.0657	0.2159*	0.0548**
	(0.0608)	(0.0440)	(0.0261)	(0.0375)	(.)	(0.0595)	(0.1089)	(0.0262)
Distance (2-3km)	-0.0256	0.0796***	0.0109	0.0216	0.0000	0.1306***	0.1155	0.0371**
	(0.0368)	(0.0292)	(0.0253)	(0.0227)	(.)	(0.0473)	(0.0862)	(0.0175)
Distance (3-4km)	-0.0311	0.0545***	-0.0320***	0.0133	0.0000	0.0000	0.0038	0.0093
	(0.0260)	(0.0188)	(0.0095)	(0.0159)	(.)	(.)	(0.0118)	(0.0111)
Distance (4-5km)	-0.0123	0.0323**	0.0089	0.0061	0.0000	0.0000	0.0391*	0.0167**
	(0.0158)	(0.0145)	(0.0103)	(0.0105)	(.)	(.)	(0.0206)	(0.0070)
Distance (≥ 5km)	0.0000	0.0000	0.0121***	-0.0016	0.0000	0.0000	0.0000	-0.0232***
	(.)	(.)	(0.0016)	(0.0048)	(.)	(.)	(.)	(0.0071)
Constant	3.4303***	3.2564***	3.4580***	3.5754***	3.1758	3.2739***	3.4814***	3.4324***
	(0.0835)	(0.0574)	(0.0320)	(0.0541)	(.)	(0.0706)	(0.1036)	(0.0342)
N	21623	68670	113129	410091	335	23891	63253	449151
r2	0.0017	0.0068	0.0019	0.0010	.	0.0016	0.0215	0.0049

[1] Note: Standard errors (in parentheses) are clustered at the Road section level.
[2] Significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[3] Fixed effects include road specified and hour of the sample.
[4] Note: Distance is the minimum distance to the nearest construction site.

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