

**Spatiotemporal Analysis of Ridesharing Services and Crime Patterns:
The Case of Chicago**

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Abstract

Sexual assaults and rapes are the costliest types of crime above all other types of crime. Sexual crime leaves intangible costs to society and victims. This paper studies the impact of ridesharing services on the number of sexual crimes in Chicago. By using hourly-community area level ridesharing service pickups and crime data spanning from January 1st to December 31st of 2019, this paper shows that the increase in the ridesharing service is positively correlated with the number of sexual crimes and that the size of the increase in sexual crime varies in different areas of the city and time. The findings of the research can contribute to the policy implication in the ridesharing service industry.

1. Introduction

1.1 Introduction of Paper

The development of information technology, including the introduction of new transportation methods like ridesharing services, has influenced society in many ways. This paper examines the spatiotemporal analysis of the detailed correlation between the number of ridesharing service trips and the crime rate in Chicago, under different circumstances, using hourly-community area-level crime and ridesharing service's trip data. The result suggests that there is a positive correlation between the sexual crime rate and the number of trips, that a one percent increase in the number of trips is expected to increase the hourly sexual crime case by 0.0001 per million people.

1.2 Definition of Ridesharing Service

Ridesharing service, also known as ride-hailing service, is a matching of passengers with drivers of vehicles that operates on the mobile application platform. If the potential passenger requests a ride to a certain destination, the application searches for an available driver nearby, and when the driver accepts the request, the driver will come to pick up and drive for the passenger to the requested destination. Both passenger and driver can see each other's photo and their ratings, rated on a scale from 1 to 5, from the previous rides and brief contact information. Once the trip is over, the payment is electronically sent to the driver through the passenger's credit card account saved on the application. Since the driver does not need to carry the cash due to electronic payment and brief information of the passenger, the driver has a reduced risk of getting into the crime (Feeney (2015)). Moreover, the ridesharing service provides the service at a cheaper price compared to taxis, except for specific circumstances with high traffic, and surge

in demand with lacking supply (Silverstein (2014)). Therefore, ridesharing service, as a lower cost cashless transportation method, brought disruption to the taxi industry.

1.3 Importance of Topic

The study of the economic effect of ridesharing service on sexual crimes is important because sexual crime is costly and there has been a large expansion of ridesharing service in recent years. The social cost of the crime is high; counting both tangible and intangible losses, including pain, suffering, and the lost quality of life of victims, the economic cost of the crime in the United States is \$450 billion annually (U.S. Department of Justice (1996, p6)). Moreover, comparing the estimated cost of different crimes from different studies, rape is far more costly than any other crime, causing both tangible and intangible damage to the victim (Chalfin (2015, p7)). As a result, any increase in crime is costly to society.

In addition to the high cost of sexual crime, there has been a large expansion in the ridesharing service industry. Ever since the launching of Uber, the most notable ridesharing service provider, in 2009, Uber has grown to the company with a market value of 72 billion US dollars in 2018, operating in 69 countries with 110 million users monthly in the United States in 2019 (Mazareanu (2020)). Along with the expansion of the ridesharing service industry, public attention on its effect on society, especially in its safety, has also increased. Such concerns on the safety of drivers and passengers have brought the debate on regulations on the ridesharing service industry (Lafrance and Eveleth (2015)). Regulations mandate ridesharing companies to report vehicle collisions, crime, and detailed trip data (Washington State Joint Transportation Committee (2019, p33)). Moreover, politicians' attempt to make ridesharing companies implement the drivers' fingerprint background check reflects the grown impact of the ridesharing service industry on crimes (Bensinger (2019)).

Ridesharing services can have a large economic effect on society by affecting sexual crime. Yet, the direction of its impact on the crime is mixed. Although ridesharing service has increased the concern of safety, it can also be an efficient method for a potential target to avoid dangerous situations and reduce the crime rate (Bryan S. Weber (2019), Park et al. (2021)). It implies the possibility of both effects neutralizing each other. Therefore, it is needed to study the correlation between the number of ridesharing service trip and the sexual crime when the ridesharing service in the city is widely settled, to verify if the initial impact from the introduction of ridesharing service persists years after and analyze how the change in the number of ridesharing service's trips is correlated to the sexual crime in different cities. This research identifies that the one percent increase of ride-sharing service's trip affects the hourly sexual crime case to increase by 0.0001 per million people and positively affects the incidence of overall crime, meaning that sexual crime has a positive correlation with the number of trips in the U.S. and that the citywide initial impact of Uber introduction in the U.S. in reducing crime rate no longer persists in Chicago.

1.4 Organization of the Paper

The remainder of the paper is organized as follows. The second section discusses the important works that provide the background in transportation and crime and the theoretical frameworks for sexual crime. The third section discusses the descriptions and the sources of data, including control data. The fourth section discusses the model and the primary result. The fifth section examines robustness checks and analyzes the results in detail, by different areas within Chicago, and different periods of time. Finally, the last section is the conclusion and suggestions for future research.

2. Literature Review

Numerous previous studies focused on the impact of the introduction of different types of transportation methods on the different types of crime, which can provide an idea of the impact of ridesharing service on sexual crime. However, the impact of transportation is mixed, and the introduction of the same transportation can have a contradictory impact on the crime depending on the region of introduction and the types of the crime. For example, according to Poister (2016), after tracking the 12 types of crime for three and a half years before the opening and 18 months after the opening of new railway station in 1993 in DeKalb, Georgia, the findings show the increasing pattern of reported crimes when the station opened. On the other hand, Billings, Leland, and Swindell (2011) find that the opening of a light rail line in 2007 in Charlotte, North Carolina, did not increase the crime around the station, and instead, property crimes decreased.

Impact of the transportation on the crime not just depends on the location or the type of crime. Other types of transportation method like safe-ride program in Milwaukee has decreased the crime by approximately 14 percent, according to Bryan Weber (2014). Weber's subsequent study with Heywood on the introduction of university bus service in addition to the existing safe-ride programs has also shown to further reduce crime (Heywood and Weber (2019)).

Lastly, the most relevant studies to this paper are the citywide impact of the introduction of Uber in the United States. Bryan S. Weber (2019) finds a 5 percent reduction in crime in the cities where Uber was introduced. Similarly, Park et al. (2021) find that the citywide introduction of Uber has decreased the rape incidents and that Uber is more effective in reducing sexual assaults in specific situations where the taxi transactions are lower, and alcohol serving stores are concentrated.

3. Data

3.1 Overview

This paper uses a community area – hour level panel data set, including ridesharing service and taxi trips data, crime data categorized into 77 distinct community areas, and 24 hours for every 365 days spanning from January 1st to December 31st of 2019. As each of 77 community areas has 8,760 ($24 \times 365 = 8,760$) distinct hourly observations, the total number of observations is 674,520. Also, this panel data set is supported with 8,760 observations of citywide hourly air quality data (not community-area level), and 77 observations of community area level racial and socioeconomic data (time fixed). Since all the taxi and ridesharing service operations are largely affected by the quarantine mandate caused by the Covid-19, this paper does not use data from 2020 for the consistency of the result.

3.2 Source

This research obtains data from three sources, the city of Chicago data portal, Chicago Metropolitan Agency for Planning (CMAP), and the U.S. Environmental Protection Agency's (EPA) AIRNow. The city of Chicago data portal has hourly-community area-level pick-up data of taxi and ridesharing companies in Chicago, and hourly-community area-level crime data in Chicago. Chicago Metropolitan Agency for Planning (CMAP) reports the median income and racial distribution of each community area. Lastly, the EPA's AIRNow records citywide hourly air quality data of Chicago.

3.3 Description

The trip data of ridesharing and taxi companies include 107 million records of all ridesharing service transactions with the pick-up timestamp and community area of pick-up location from January 1st to December 31st of 2019. Under Transportation Network Providers Rule (TNP Rule), the ridesharing companies in Chicago are obligated to report their activities to the Department of Business Affairs and Consumer Protection every month (Lapacek and Evans (2017)). To avoid the data being used to identify the passenger, the exact pickup time is rounded to 15 minutes intervals, and the exact location is rounded to eight square miles as one of the eight-hundred census tracts (Open Data Portal Team (2019)).

The crime data includes 200,000 records of reported crimes with the crime timestamp, crime code, and community area of crime location from January 1st to December 31st of 2019. The crime location identified in crime data corresponds to 77 community areas described in trip data. The Chicago Police Department's (CPD) updates data using Citizen Law Enforcement Analysis and Reporting System (CLEAR) (Chicago Police Department (2021)). This paper uses CLEAR data because it is reported by CPD, where crimes in Chicago are directly reported to, and it also reports sex offense cases in addition to sexual assault cases, which Uniform Crime Reporting system (UCR) from Federal Bureau of Investigation (FBI) does not.

In CPD's CLEAR data, each crime is categorized by 1 of 402 Illinois Uniform Crime Reporting (IUCR) codes (Chicago Police Department (2021)). 28 of these codes are related to sexual crimes, which consists of 13 distinct types of criminal sexual assaults and 15 distinct types of sex offenses. This paper follows the categorization of IUCR, defining sexual crime as all crimes categorized as a sex offense and criminal sexual assault, including rape as a criminal sexual assault (Chicago Police Department (2021)). For the privacy of victims, the location of the crime shows the block level only (Chicago Police Department (2021)).

Table 3.1 introduces the summary of the data this paper is using. First, in the trip and crime variables section, column (2),(3) and (4) shows that there is a disparity in the number of trips for both ridesharing services and taxi trips depending on the hour and area. Column (1) shows that the mean number of reported sexual crimes is 1 percent of all other reported crimes, and the mean number of reported crimes is the same for both types of sexual crime, the criminal sexual assault, and the sex offense. Second, in the racial and socioeconomic variables section, column (3) shows that there is a community area where only 0.4% of the population is identified as White, which is an interesting observation but suspicious. Comparing columns (3) and (4), there is about a \$100,000 gap between the highest and the lowest-earning area in median income. Lastly, in the Air Quality Index (AQI), column (1) shows that the average air quality of Chicago in 2019 was good, as EPA's guideline suggests that the AQI between 0 to 50 is considered good, and 51 to 100 is moderate (US EPA (2016)).

Table 3a: Summary Statistics*

Variables	Mean (1)	Std. Dev. (2)	Min (3)	Max (4)	N=674,520
Ridesharing Service Trips	137.102	358.726	0	8703	
Taxi Trips	22.049	113.771	0	2341	
Other Crime	0.382	0.772	0	36	
Sexual Crime	0.004	0.064	0	3	
- Criminal Sexual Assault	0.002	0.049	0	2	
- Sex Offense	0.002	0.041	0	2	
Population	35295.95	22862.52	2336	100547	
White Population Ratio**	0.278	0.269	0.004	0.843	
White Population	11585.68	15770.96	10	78805	
Non-White Population	23710.25	16585.66	1950	90199	
Median Income***	53334.56	25173.94	13518	115756	
Air Quality Index (AQI)	40.194	18.361	0	115	

Note: *Original data is in 3 separate data sets. Trip and crime data set with 107 million observations, racial and socioeconomic data set with 77 observations and Air Quality Index data with 8,760 observations. However, for the empirical model, each data set is merged into a single data set with 674,520 (77*24*365) observations. It is because STATA requires all variables to have same number of observation in a single data set for the regression. **Percentage point. *** U.S. Dollars(\$).

4. Empirical Model

4.1 Regression Introduction

This paper presents two regression models to find a correlation between the number of ridesharing pickups and the sexual crime rate in Chicago. Model (1) uses Two-Stage Least Squares (2SLS) method for an instrumental variable estimation. Using model (1) this paper aims to discuss the potential issues of endogeneity, and the validity of instrumental variables. Model (2) uses simple linear regression without instrument variable. Using model (2), this paper aims to achieve two goals. First, finding the correlation between the ridesharing service and all sexual crimes, criminal sexual assault, and sex offense. As mentioned in the data description, criminal sexual assault and sex offenses are two main types of sexual crime. Second, analyzing how the correlation between the ridesharing service and sexual crimes changes under specific locational conditions, and temporal conditions. The followings are two models:

(1) 2SLS Instrumental variable regression

$$y_{it} = \alpha_i + \beta \log(\text{RidesharingPickups})_{it} + \gamma \log(\text{taxipickups})_{it} + Z_{it}\delta + \theta_t + u_{it}$$

(2) Simple Linear Regression without Instrumental Variable

$$y_{it} = \alpha_i + \beta \log(\text{RidesharingPickups})_{it} + \gamma \log(\text{taxipickups})_{it} + Z_{it}\delta + \theta_t + u_{it}$$

In both models (1) and (2), the dependent variable y_{it} is a *sexual crime rate* per 100,000 people in community area i at time t . The reported number of crimes is divided by the population of each community area and multiplied by 100,000 to display the crime rate per 100,000 people, as the number of crimes depends heavily on the population. The independent variable is the number of *ridesharing service pickups* in community area i at time t , log-transformed after

adding 1 for 0 values. Both models use control variables Z_{it} , to control for the supply of potential offenders and sexual crime and the demand of overall transportation. For the supply of potential offenders and sexual crime, the crime rate for all other types of crime except for sexual crime is used. Other types of crimes are used to control for the supply of potential offenders and sexual crime because different types of crimes are related in their pattern, according to Andresen and Malleson (2010). For the demand of transportation, the number of *taxi pickups* is used. The number of taxi pickups is also log-transformed after adding 1 for 0 values to correct the skewness of the number of trips. Both model (1), and model (2) use fixed effect. Using fixed effect, the model does not need to control for community-area specific conditions over the year 2019 and can be removed by the community area, and date-hour fixed effects, α_i and θ_t .

4.2 Instrument Variable

Only model (1) uses instrumental variable regression to fix the potential endogeneity in the correlation between ridesharing service pickups and the sexual crime rate. The unobserved omitted variables can affect both ridesharing service pickups and the sexual crime rate, causing the estimated coefficients to be biased. In addition to the omitted variable bias, there is the possibility of reverse causality. For example, the people at high crime areas may be influenced to take use more ridesharing services to avoid the danger of a possible crime. To fix such a problem, this paper uses Air Quality Index (AQI) as an instrumental variable. AQI is an adequate instrument variable because while it is safe to assume that the air quality is not correlated to the number of sexual crimes, it is closely related to the number of traffic because the value of AQI considers the level of particulate matter (PM2.5), which is related to the pollutant emissions of vehicles (Anjum et al. (2019)).

4.3 Variations of model (2)

As described in the data description, CPD's CLEAR crime data set categorizes sexual crime data into two types, criminal sexual assault and sex offense. The crime data set's detailed categorization of sexual crime allows this paper to further analyze how both criminal sexual assault and sex offense are correlated with the ridesharing service. For this purpose, this paper changes the dependent variable of the model (2) to criminal sexual assault rate and sex offense rate. Running modified models in addition to the original model (2), this paper finds how the ridesharing service is correlated with all sexual crimes, criminal sexual assault, and sex offenses.

In addition to finding a general correlation between the ridesharing service and the sexual crimes in Chicago, model (2) also aims to find how the correlation changes in areas with different racial and socioeconomic conditions and time. For this analysis, model (2) uses different conditions, like the daytime and nighttime, weekdays and weekends, community areas with high and low white population ratio, and median income, instead of fixed effects. As a result, the table 5a presents the result from the model (1) and (2) using fixed effects, and table 5b presents the result from the model (2) under correlation under various conditions for detailed spatiotemporal analysis.

5. Result and Interpretation

Table 5a: The Correlation Between Ride-Sharing Pickups and Sexual Crime

	2SLS IV		Simple Linear Regression	
	Model (1)		Model (2)	
<i>Dependent Variables</i>	<i>Sexual Crime</i>		<i>Criminal Sexual Assault</i>	<i>Sex Offense</i>
	(1)	(2)	(3)	(4)
log(ridesharing pickups) =AQI in model(1)	-0.195 (0.408)	0.014*** (0.005)	0.003 (0.004)	0.012*** (0.003)
log(Taxi pickups)	0.122 (0.223)	0.005 (0.006)	-0.001 (0.005)	0.006*** (0.004)
Other Crime	0.002 (.001)	0.001*** (0.000)	0.001*** (0.000)	0.000** (0.000)
Fixed Effect: Date-Hour	Yes	Yes	Yes	Yes
Fixed Effect: Area	Yes	Yes	Yes	Yes
R ²	0	0	0	0
observations	674,520	674,520	674,520	674,520

Note: log(ridesharing pickups) is instrumented by Air Quality Index only for Model (1). log(ridesharing pickups) is not instrumented in Model(2); *p < 0.1, **p < 0.05, ***p < 0.01

Table 5a shows the correlation between sexual crime and the ridesharing service, using two different regressions. Model(1) in column (1) is using the instrumental variable air quality index, AQI to instrument the main independent variable ridesharing service. As seen in column (1), although it shows that the 1 percent increase in the number of ridesharing services can influence the sexual crime rate to decrease by 0.002 cases per million people, none of the findings are statistically significant. Since the air quality index is only recording the citywide air quality, not each community area's air quality, there is a possibility that AQI is not a correct proxy for the ridesharing service data, causing the result to be statistically insignificant.

Model (2), without the instrumental variable, shows more statistically significant results. Looking at the column(2) and (4), the 1 percent increase in the number of ridesharing service is related to the increase of sexual crimes by 0.0001 cases per million people, and the increase of sex offense by 0.0001 cases per million people. Although it shows that there is also a positive correlation with criminal sexual assault, the result cannot be concluded due to low statistical

significance. As a result, looking only at statistically significant results, ridesharing service is positively correlated with both all sexual crimes and sex offenses.

Coefficients from other crimes, which are non-sexual crimes, suggest that there is a correlation between the different types of crimes, that 1 case increase of other crime can influence both hourly all sexual crime and criminal sexual assault to increase by 0.001 cases. It shows the link between the crimes and that reduction in one type of crime is correlated with other types of crimes.

Table 5b: Spatiotemporal Analyses Under Various Conditions

Dependent Variable: <i>Sexual Crime Rate</i>	Simple Linear Regression with conditions							
	Model (2)							
	Fri-Sat Night Populous Area	Sun-Thu Daytime All Area	High White Population	Low White Population	High Income	Low Income	High Taxi Transactions	Low Taxi Transactions
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log(ridesharing pickups)	-0.039 (0.032)	0.012*** (0.005)	0.007** (0.003)	0.012** (0.005)	0.010*** (0.003)	0.010** (0.005)	0.016*** (0.004)	0.015*** (0.004)
log(taxi pickups)	0.052** (0.021)	0.010** (0.004)	0.012*** (0.003)	-0.007 (0.016)	0.010*** (0.003)	0.017*** (0.006)	0.004 (0.003)	-0.010 (0.014)
other crimes	0.006*** (0.002)	0.001*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.001*** (0.000)	0.002*** (0.000)	0.001*** (0.000)	0.002*** (0.000)
R ²	0.006	0	0	0	0.001	0	0.001	0
observations	4,160	321,552	289,080	385,440	245,280	492,240	192,720	481,800

Note: Night is from 21:01-05:00. Day is from 05:01-21:00. Populous areas are areas with population higher than or equal to 80,000, 5 community areas are in this category. White population is the proportion of the white population in total population in ratio. High means higher or equal to the mean. Low means lower than the mean. Taxi transaction is categorized by the log number of taxi trips. *p < 0.1, **p < 0.05, ***p < 0.01

The result from table 5b, is consistent with the findings from table 5a. Column (2) to (5) shows that although the size of correlation varies by conditions, under any condition, the increase in the ridesharing service is positively correlated to sexual crime positively. Specifically, a 1 percent increase in the number of ridesharing services can influence the hourly sexual crime case to increase from 0.0001 to 0.0002 per million people. The correlation is stronger at the

community areas where the number of taxi transactions is higher, (7), and the correlation is lower at the areas where the proportion of the white population is higher, (3).

Comparing columns (1) and (2), the sexual crime correlation with the number of taxi trips, and other types of crime increases by more than five times. It shows that sexual crime is more affected under specific conditions like populous areas on Friday and Saturday night time. It implies that the correlation between sexual crime and the ridesharing service can change in different conditions, and the magnitude of change can vary in certain conditions. This explains why this paper's result does not align with previous studies by Park et al. (2021), that the increased number of ridesharing services is negatively correlated with sexual assault cases, and Bryan S. Weber (2019), that the crime is negatively correlated with the increased method of transportation.

6. Discussion

6.1 Limitations

Although this paper finds the correlation between the ridesharing service and sexual crime, it doesn't explain the full relationship between the ridesharing service and the crime. This paper assumes that ridesharing services can be used as a transportation method for potential victims to avoid the situation and a place for potential sexual offenders to commit crimes. However, with the result we have, it is still not possible to conclude what aspect of ridesharing service is increasing sexual crime.

Moreover, there can be a different factor that is causing the crime to increase that is being missed in this paper. For example, it may be the number of other cars on the street that deters potential offenders to commit crimes on the street. If that is the case, since more ridesharing

pickups do not necessarily mean more cars on the street, without controlling the number of cars on the street at each hour, it will be hard to fully understand the mechanism behind the decreased crimes. Since crime is connected to so many different aspects of society, such as infrastructure, weather, and economics, it is challenging to fully count the factors that can affect the crime.

Most importantly, as mentioned in the instrumental variable section, there is a possibility that the number of sexual crimes can affect the number of ridesharing services. Such possibility of reverse causality disturbs the clear understanding of the relationship between the ridesharing service and sexual crimes. As seen in model 5a, although this paper uses AQI as a possible instrumental variable, the result is still not clear.

6.2 Further Study and Implications

First of all, as the ride-sharing service industry is getting bigger, it is taking a bigger share in daily transportation. Although there are many studies on the relationship between transportation and crime, however, there are not many studies specifically on ridesharing services. This paper shows that there is a positive correlation between the ridesharing service and crime. Since the ridesharing service industry is growing and crime is costly to society, studies on the future trend in the impact of ridesharing service in different cities are needed.

Secondly, sexual crime is the costliest crime to society and leaves much intangible cost to the victim (Chalfin (2015, p7)). As ridesharing service provides a closed environment for the potential sexual offenders, ridesharing service is especially vulnerable to sexual crimes. Increased vulnerability of ridesharing service can affect the safety of other transportations too. Therefore, studying the impact of ridesharing service specifically on sexual crime is needed in addition to studies on general crime.

The result of previous studies on the effect of Uber on crime has shown that at the citywide level, there is a decrease in crime, specifically in personal crime and sexual assaults (Bryan S. Weber (2019), Park et al. (2021)). However, this paper's result in Chicago is different from the city-wide result. This paper shows that the impact of ridesharing services on sexual crime can vary by different conditions like time and area.

For future studies, it may be useful for each community to assess their community conditions for ridesharing services, because different conditions can affect the correlation between the ridesharing service and the crime. Also, identifying in what circumstance ridesharing service can decrease or increase the chance of sexual crime can lead to more sophisticated regulations on the ridesharing service industry.

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