MOBILE GUARDIANSHIP AND CRIME DETERRENCE: EVIDENCES FROM A NATURAL EXPERIMENT IN BRAZIL

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Resumo

Em julho de 2012, a Agência Nacional de Telecomunicações (ANATEL) implementou o uso do nono dígito nos telefones móveis de alguns municípios do estado de São Paulo, baseado no código de área da região. Com o objetivo de aumentar a capacidade do sistema para novos usuários, o nono dígito gerou uma inesperada e significante redução no número de acessos nos municípios afetados pelo novo padrão de ligações. Se a hipótese da "vigilância móvel" é verdadeira, espera-se que choques exógenos sobre a tecnologia de telefones móveis tenham impacto sobre a criminalidade. Este estudo testa a descontinuidade na queda do número de ligações sobre a atividade criminal. Utilizando os dados da Secretaria Estadual de Segurança Pública de São Paulo (SSP) e do Ministério da Saúde, são estimados o efeito médio e médio local do tratamento através de estimadores dinâmicos de diferenças em diferenças e de regressão descontínua, respectivamente. Os resultados sugerem que a inclusão do nono dígito teve impacto significante sobre homicídios e lesão corporal dolosa, mas sem evidências para roubos ou furtos de veículos e propriedades. Tais evidências sugerem o uso intensivo de políticas baseadas em tecnologia para o combate ao crime.

Palavras-chave: Nono dígito; Código de área; Telefones móveis; Criminalidade.

Abstract

On July 2012, Brazil's National Telecommunication Agency (ANATEL) released the implementation of the ninth digit in mobile phones numbers for some municipalities of the state of São Paulo, based on the area code. In order to increase capacity for new users, the ninth digit caused an unintended and significant drop in the number of mobile calls in the municipalities that experienced the new way of dialing. If the phone guardianship hypothesis for crime drop is true, one should expect that exogenous shocks in mobile technology have impact on crime. The present study tests the discontinuity in the number of mobile access and its effects on a range of crimes and on victimization. Using data from Secretaria Estadual de Segurança Pública de São Paulo (SSP) and Brazilian Ministry of Health I estimate average and local average effects through a dynamic difference-in-differences and regression discontinuity estimators, respectively. The estimates suggest that the ninth digit have a significant impact on homicides and bodily injury, but no effect on vehicle and property thefts. These results shed some light on the link and support the expansion of technology-based policies to deter crime.

Keywords: Ninth digit; Area code; Mobile phones; Crime.

JEL Classification: H56, O33, L63

"Perhaps a more significant factor inhibiting crime across the Western world is the universal growth in the possession and use of private security measures by households and companies over the past few decades."
van Dijk et al. (2005)

1 Introduction

The decline in crime rates observed in many industrialized countries from the mid-1990s to 2000s has led to a growing interest of criminologists and policy makers regarding the causes of the phenomenon. A range of relationships analyzed by theoretical and empirical researchers have been suggested as forces that could drive the crime drop, including the increase in police numbers (Evans and Owens, 2007), the growth in the prison population (Buonanno and Raphael, 2013; Zimring, 2011), more efficient security policies (Levitt, 1997; Marvell and Moody, 1996; Travis and Waul, 2002), gun law reforms (Lott, 2013), economic conditions and its impact on unemployment rate (Freeman, 2001), demographic changes (Blumstein et al., 2000), the access to drug markets (Levitt, 2004), as well as factors associated with the legalization of abortion (Donohue and Levitt, 2001). The conclusions drawn from these studies are sensitive to estimation methodology and tend to have little external validity. Besides, there is no single factor associated with a decrease in criminal activity.

In addition to the reasons explaining the crime drop, some authors suggest that the increase in private security in public spaces is associated with a significant reduction in the number of crimes (Brooks, 2008; Cook and MacDonald, 2011). Based on the security hypothesis framework, Farrell et al. (2011) discuss that changes in the quantity and quality of private security have played a major part in driving crime falls in most developed societies. Linked to routine activity and crime opportunity theories, Klick, MacDonald, and Stratmann (2012) suggest a novel and underappreciated link that may have contributed to the crime drop: the growth and improvements of mobile phone technology. Using available mobile phone data for the US, the authors found a negative association between mobile phones and violent crimes, although data limitation and the lack of natural experiment or instrumental variables are a critical barrier for causal interpretation.

In the classical work of Becker (1968), offenders commits a crime if the expected benefit of such activity exceed the associated costs. The expected benefits include any monetary or physical reward obtained by committing a crime. The expected cost associates the likelihood of being punished and the utility loss of the punishment. Most security policies are focused on that side of the equation, i.e., increasing the likelihood of offenders have been punished by committing illegal activities. In this sense, mobile phones provide additional surveillance and change criminal's perceived risk of apprehension.

This study contributes to the literature by using a natural experiment to identify the effect of mobile phone use on crime: the implementation of the ninth digit to mobile phone numbers in Brazil. This change was meant to eliminate the shortage of available numbers and increase the numbering capacity for new users. Conducted by Brazil's National Telecommunication Agency (ANATEL), the change in mobile dialing consisted to add the digit 9 before the current eight digits numbers. The introduction of the ninth digit was first implemented in the municipalities of the state of São Paulo with area code 11 on July 2012, while other area codes in the state remained with the eight-digit numbers[1].

The introduction of the ninth digit caused an unexpected and significant reduction in the number of accesses by users as some calls were not completed, either because systems adaptation or some widespread misunderstandings about the new rule. This episode has provided the environment for a natural experiment to identify the impact of the mobile phone on crime. If the "mobile guardianship" hypothesis for crime drop is true (Farrell, Tilley, and Tseloni, 2014), one should expect that exogenous shocks on mobile technology have impact on crime. Here I assume linearity in the sense that a reduction in the number of mobile access may cause an increase in the number of offenses.

The empirical strategy is based in two different (and complementary) approaches to estimate the causal effect of the reduced number of mobile calls on crime and victimization. First, I apply a dynamic difference-in-differences estimator to compare the trajectory of criminal activities between the municipalities affected by the adoption of the ninth digit and other municipalities in the state, but with different area codes during the period between January 2012 and June 2013. This time period allows us to disentangle the effects of other policies in the state of São Paulo during the 2000s, as the adoption of dry laws (Biderman et al., 2010), which restricted recreational consumption of alcohol by imposing mandatory closing hours for bars and restaurants in the São Paulo metropolitan region, or the nationwide firearms legislation control that restricted the legal firearms possession (Cerqueira et al., 2013), for example.

Second, this paper uses a regression discontinuity approach to estimate the local treatment effect on homicides. In particular, I compare the incidence of homicides before the implementation of the ninth digit with the incidence on the first day the new rule was applied. Falsification tests are conducted on the basis of untreated municipalities.

The results show that the ninth digit caused a significant impact on homicides and bodily injury, but only persistent for the latter. The results for rape show that there is a positive impact on the number of victims in the month following the introduction of the ninth digit. For vehicle and property theft, however, there is no significant effect. These finds are closely related to Klick et al. (2012), which hypothesize that mobile phones have the largest impact for violent crimes and a lesser impact for property crimes. The results have clear implications for security policies such as the expansion of mobile technology and other technology-based instruments to deter crime.

The rest of the paper is organized as follows. Section 2 presents a simple model that links mobile use and crime, as well as the institutional background for changes in numbering plan. Section 3 establishes the empirical strategy used to access the causal effect on crime. Section 4 describes the data. Section 5 contains the empirical results and discuss possible explanation for them. Section 6 offers some concluding remarks.

[1]According to ANATEL's schedule, all mobile phones in Brazil will be standardized with the ninth digit by the end of 2016.

2 Background and Numbering Plan in Brazil

In this section I briefly present a simple pathway linking the usage of mobile and crime deterrence. Next, I will show how the changes in numbering plan have occurred in Brazil, beginning in the state of São Paulo for the municipalities with specific code area. It is argued that the exogenous change provide a reliable scenario to identify the causal effect of the drop in the number of mobile calls on crime.

2.1 Theoretical link: a simple model

The routine activity theory suggests that the mechanism by which crime occurs is based on the convergence of three basic factors: (i) suitable targets; (ii) potential offenders; and (iii) lack of capable guardianship (Cohen and Felson, 1979). Within this context, Klick et al. (2012) argue that mobile phones provide additional surveillance against potential offenders and increase capable guardianship for suitable targets of crime. The mechanisms which explain how the mobile phones prevent crime are twofold. First, carrying a mobile phone could increase the likelihood of a victim provide quicker reporting of crimes and, in some cases, real time detailed information[2]. Second, the mobile phones can be used to anticipate the offenders decision and change the perceived risk of apprehension, increasing the probability of being punished.

The growth and the widespread usage of the mobile phones increases the probability of reporting crimes in a relatively short time interval since it has occurred. In this sense, the mobile technology greatly reduces the cost of reporting a crime, providing more detailed information on crimes occurred (*ex-post* actions) and real threats of the victimization (*ex-ante* actions). Although the relationship between the usage of mobile phones and crime reduction is in contact with the modern discussions of the private security expansion policies in preventing illegal activities, Klick, MacDonald, and Stratmann (2012) point out the lack of reliable data on mobile, strong instrumental variables or natural experiments to isolate the true causal effect. Thus, there is no definitive answer to this relationship in crime literature and studying the signal of the effect is of great relevance as benchmark for new security policies based in communication technologies.

In this part I present the structure of a fairly simple model following Doleac and Sanders (2013)[3], assuming that offenders engage in crime if the expected benefits are greater than the associated expected costs. Let the expected cost of crime be a function of the length of the sentence if arrested (T) and the likelihood of capture (P), which is a function of victim reporting crimes by using mobile phones (M). Also, there a set of factors associated with the expected costs such as law and social enforcement (F). An individual can attempt a crime if:

$$\mathbb{E}[Benefit_{crime}] > \mathbb{E}[Cost(T, P(M, F))_{crime}]. \tag{1}$$

In equilibrium, it is expected $\partial C/\partial P$ and $\partial P/\partial M$ to be positive. Greater mobile availability are likely to allow

[2] Spelman and Brown (1981) found that fast reporting to the police combined with fast police response are of crucial importance to the likelihood of arresting the offender at or near the crime scene.

[3] In their paper, Doleac and Sanders (2013) investigate how ambient light shifts induced by Daylight Saving Time (DST) affects crimes. The authors suggest that more light means witness as more likely to spot criminals committing crimes and more likely to being apprehended and punished.

real time communication and detailed information about the crime and the criminal, increasing the probability of being captured and hence the expected cost of committing crime.

Although the mobile phones have attested to be instrumental in reducing crime, they have also played a part in creating it. For example, mobile phone can increase benefits for offenders as instruments for organized crime. Also, the mobile phones are attractive targets for the thieves as their small size also makes them relatively attractive targets. If it is true, then we should expect the benefits as function of the mobile availability $\mathbb{E}[Benefit(M)_{crime}]$, with $\partial B/\partial M > 0$. Measure the magnitude of the effect between benefits and costs is a hard task, and the results should be interpreted as the net effect of the mobile deterrence on crimes. Knowing the signal of the effect is an empirical question. To this end, I benefit from the adoption of ninth digit in the mobile phones for municipalities with code areas 11 to isolate the causal effect.

A possible caveat regarding the relationships above is due to the fact that the addition of the ninth digit rule did not change the format for the public utility service phone, such as the 190 police emergency number. In fact, calls to the police were not affected during the analysis period even though the data from the São Paulo Military Police point out that only 13% of daily number of calls become police reports. Moreover, statistics show that the average response time exceeds 5 minutes, which may compromise the likelihood of punishment to the criminal. In this sense, the use of the regression discontinuity design is justified since it allows to smooth out potential confounders that may affect homicides.

In the following subsection I present the change in the mobile dialing plan in Brazil.

2.2 Changes in Brazilian numbering plan

The Brazilian telephone numbering plan was established in the year of 1998 by the National Telecommunication Agency (ANATEL), which regulates telecommunication services for fixed and mobile phones and other institutional aspects. The user access code for mobile phones was set in the format $[N_{10}N_9]\ N_8N_7N_6N_5{+}N_4N_3N_2N_1$, with the first two digits representing the area code[4] and the last 8 digits the current local number. On January 2012, ANATEL announced a change in the mobile phones dialing plan. All mobile phone numbers would be gradually changed from current 8 to 9 digits by including the digit 9 after the two digit area code and before the current number, $[N_{10}N_9]\ \mathbf{9}N_8N_7N_6N_5 + N_4N_3N_2N_1$. This change was meant to increase capacity from the current 44 million to 90 million users in the metropolitan area of São Paulo.

Figure 3 below shows the area codes in the state of São Paulo. The ninth digit was first introduced in municipalities in the São Paulo metropolitan region (area code 11) on July, 2012. The remaining code areas in the state of São Paulo (area codes 12 to 19) received the ninth digit one year later, on August 2013. It is expected that by the end of 2016 the ninth digit will be implemented in all Brazilian territory in order to standardize the numbering plan in the country and enable the expansion of mobile technology. The shift to the

[4]Area codes - or Direct Distance Dialing (DDD) - were ordered, according to ANATEL, by the development level of the Brazilian states, not directly related to the geography of each region. The codes that start by 1 were directed to the state of São Paulo, the one with the highest population density in 1969, year of creation of the area codes. The state has 9 area codes, ranging from 11 to 19. The codes beginning in 2 were allocated to Rio de Janeiro, and those starting with 3 to Minas Gerais. Currently, there are 67 different area codes in Brazil. For further information, see http://goo.gl/IIayCv.

ninth digit occurred gradually in favor of the network and the users adaptation. From the date of implementation to mid-October 2012 calls were intercepted with a message reminding users of the new rule. On January 2013, however, only calls with the 9 digits were completed.

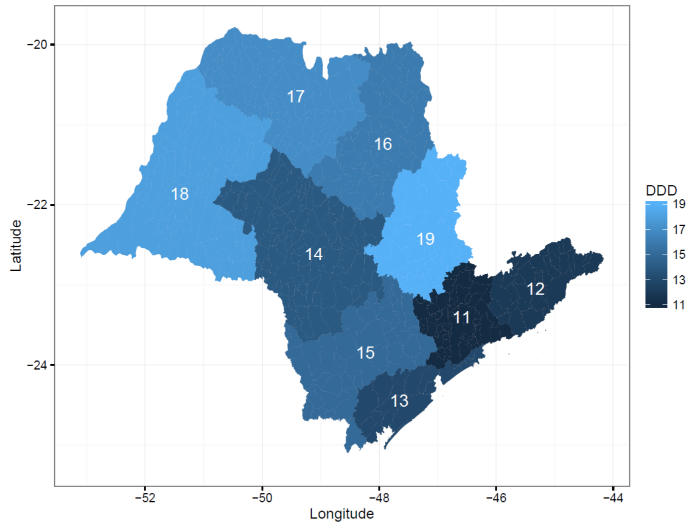

FIGURE 1: STATE OF SÃO PAULO DIVIDED BY AREA CODES

ANATEL's number of mobile calls data show that during the period of the transition and the adaptation there was a significant drop in the number of mobile access in the municipalities affected by the addition of the ninth digit[5]. The identifying strategy followed here exploit the fact that during the inclusion of the ninth digit there was a significant drop in the number of calls, which may unexpectedly influence criminal activities in the sense of lack of capable guardianship. I refer to the three expected cutoffs as the following: transition (I) refers to the date of introduction of the ninth digit (during this period all calls with 8 or 9 digits were completed); transition (II), in which all calls with 8 digit were intercepted with a message reminding users of the change; and transtion (III), where the use of nine digits was mandatory.

The plot of the number of calls is depicted in figure 2. This discontinuity can be exploited using the regression discontinuity approach (Imbens and Lemieux, 2008; Lee and Lemieux, 2010; Calonico et al., 2014). The graphs show linearized number of calls centered on the transition month. The graph on the left, which take into account municipalities in area code 11, shows that points on the right of cutoff are slightly shifted below. The graph on the right, on the other hand, presents that points evolved smoothly around the cutoff. The results considering all cutoffs are presented in table 1. Only for transition (II) there was a significant drop of about 1.6% in the number of calls for the treated municipalities. It represents a drop of nearly 1 million of calls during the month of October 2012. For unaffected municipalities, results are not different of zero. Results remain unchanged in relation to the bandwidth selectors choice.

[5]Despite the gradual change, operators faced some troubles in adapting all systems to the new technology (http://goo.gl/p76aD0). Users and companies that depend on mobile service reported disorders generated by the new rule (http://goo.gl/3UIav4).

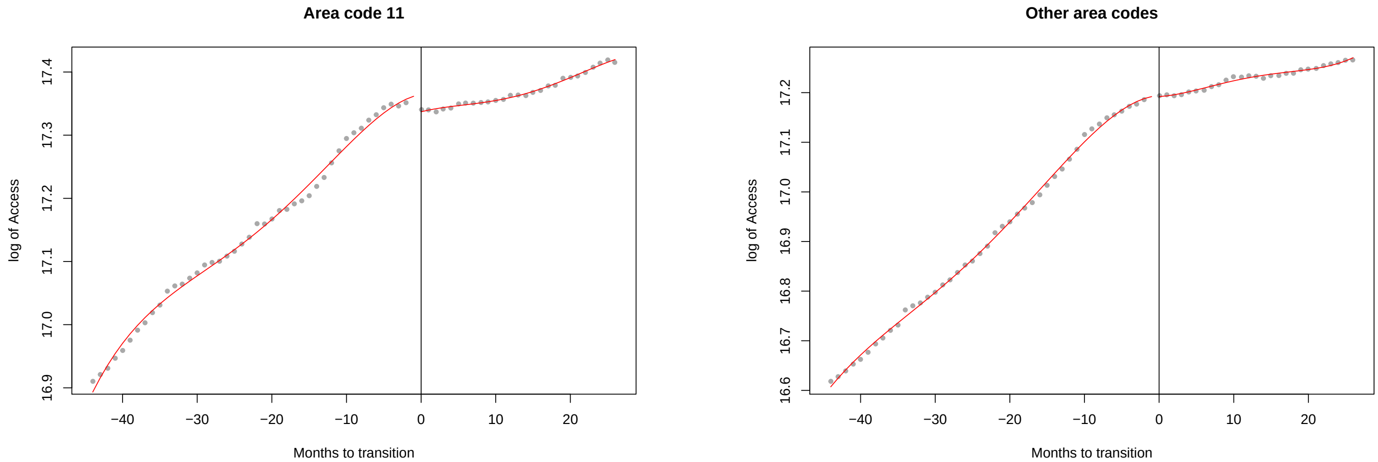

FIGURE 2: DISCONTINUITY IN THE NUMBER OF CALLS: TREATED AND UNTREATED MUNICIPALITIES

TABLE 1: MONTHLY ESTIMATES OF LOCAL LINEAR RDD ON NUMBER OF ACCESS

	Area code 11			Other area codes		
Transition	(I)	(II)	(III)	(I)	(II)	(III)
$Digit9_{LATE}$	-0.0106	-0.0157***	0.0108	-0.0107	-0.0048	-0.0063
	(0.0101)	(0.0039)	(0.0080)	(0.0078)	(0.0114)	(0.0032)
Bandwidth	CCT	CCT	CCT	CCT	CCT	CCT
Polynomial order	Linear	Linear	Linear	Linear	Linear	Linear
Kernel	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform
Observations	432	432	432	432	432	432

Note: *p<0.1; **p<0.05; ***p<0.01. Standard errors are clustered at the municipality level. The outcome variable is the log of user's access. (CCT) bandwidth refers to Calonico, Cattaneo, and Titiunik (2014).

3 Empirical Strategy

The empirical strategy used in this study to access the effect of the inclusion of the ninth digit on several categories of crimes follow two different approaches. The first consists to estimate the difference in monthly level of crimes before and after the introduction of the new digit for both affected and non-affected municipalities through a difference-in-differences setup. The second approach estimates the immediate impact on homicides for treated municipalities through a regression discontinuity design (RDD).

I start with the estimation of the following benchmark model:

$$Crime_{itm} = \gamma Digit9_{ik=0} + \sum_{k>0} \delta_k Digit9_{ik} + \Psi X_{itm} + \omega_m + \eta_i + \phi_t + \epsilon_{itm}, \tag{2}$$

where i is the indicator for municipality, t for year and m for month. $Digit9_{ik=0}$ assumes value 1 if municipality

i was affect by the introduction of the ninth digit in the intervention period (on October 2012, which presented significant drop in the number of calls as discussed in subsection 2.2). $Digit9_{ik}$ for $k > 0$ captures treatment effects for k months after October 2012. The parameters γ and δ_k are the parameters of interest, which capture the average treatment effect for municipalities that received the new digit. The dependent variable $Crime_{itm}$ measures several crime categories related to violence, such as the number of homicides victims, rape, theft and robbery. η_i, ω_m and ϕ_t are dummies controlling for municipalities, month and year fixed effects, respectively. These fixed effects are included to control for seasonality and specific factors that affects criminality in a given year and/or month. For all regression the term error, ϵ_{itm}, is heteroskedasticity robust and clustered on municipality level (Bertrand, Duflo, and Mullainathan, 2002).

The vector of characteristics X_{itm} takes into account other factors affecting criminal activity. For example, municipality GDP per capita is included in the vector characteristics since it may account for some of the increase in the mobile penetration, as well as the capability of the municipalities adopt other policies that may deter crime. Following Biderman et al. (2010), I also include the demographics characteristics such as population, the ratio of male population in ages 15 to 30 years and urbanization ratio. It also includes state-level enforcement variables as the presence of a municipal police force and monthly data on the number police investigation, the number of guns apprehended and the number of arrests.

To identify the parameters of interest one have to attest that outcome variable trends are similar for both treated and control groups, the Common Trend Assumption (Angrist and Pischke, 2008). Such hypothesis can be tested through the inclusion of anticipatory effects, $Digit9_{ik}$, for k periods preceding the intervention. The model can now be written as:

$$Crime_{itm} = \sum_{k<0} \tau_k Digit9_{ik} + \gamma Digit9_{ik=0} + \sum_{k>0} \delta_k Digit9_{ik} + \Psi X_{itm} + \omega_m + \eta_i + \phi_t + \epsilon_{itm} \quad (3)$$

Equation 3 also captures anticipatory effects of the intervention by adding leads and lags to the benchmark specification. If the trends in the outcome variable for treated and control groups are similar, then it is expected that the anticipatory effect is null. Another assumption to validate the estimates is the Stable Unit Treatment Value Assumption (SUTVA). Such hypothesis attests that the vector of potential outcome for municipality i is not directly associated with treatment status of municipality j, that is, there is no spillover effect in space (Angrist et al., 1996; Imbens and Rubin, 2015). If SUTVA is not observed estimators tend to be biased and inconsistent. It is hard to argue, however, that SUTVA is valid in this case since municipalities close to the border code area may be also affected. It may reflect economic and social interaction with municipalities in the treated area. An exercise to check SUTVA validity consists in restrict the sample with neighbor municipalities in both treated and control groups (see figure 3).

The second strategy identify the local average treatment effect of transition to the ninth digit on the number of homicides using a regression discontinuity design (RDD). In particular, the approach consists in comparing the evolution of violent deaths around the transition day for municipalities in the area code 11. For that end, the following model is estimated:

$$log(Homic_{it}) = \varphi \mathbb{1}(Digit9_{it} \geq 0) + g(Digit9_{it}) + \mu_{it}, \tag{4}$$

with $Homic_{it}$ corresponding to the number of victims in municipality i in day t. $Digit9_{it}$ is the running variable, defined as the number of days in relation to the implementation to the ninth digit. Negative values for the running variable refers to the pre-treatment period and positive values is related to post-treatment period. The function $g(.)$ controls for unobserved factors that evolved smoothly over time and are unrelated to the dialing plan change. The random term of error is μ_{it}.

Estimators are obtained nonparametrically using a Sharp RDD and accessed using local-polynomial point estimators (Skovron and Titiunik, 2015). I use two optimal data-driven bandwidth selectors vastly used in literature, (IK) Imbens and Kalyanaraman (2011), (CCT) Calonico, Cattaneo, and Titiunik (2014), and an alternative cross-validation method (CV) by Ludwig and Miller (2005).

4 Data

Throughout this paper I analyze the introduction of the ninth digit effect on the incidence of criminal activity in the state of São Paulo. In order to obtain credible estimates, I restrict the analysis for the period between January 2012 and July 2013. The choice of this time horizon is intended to minimize the effect of any other security policies that may affect crime. Furthermore, this period allows us to examine the presence of any seasonality and observe pre- and post- treatment periods of comparison.

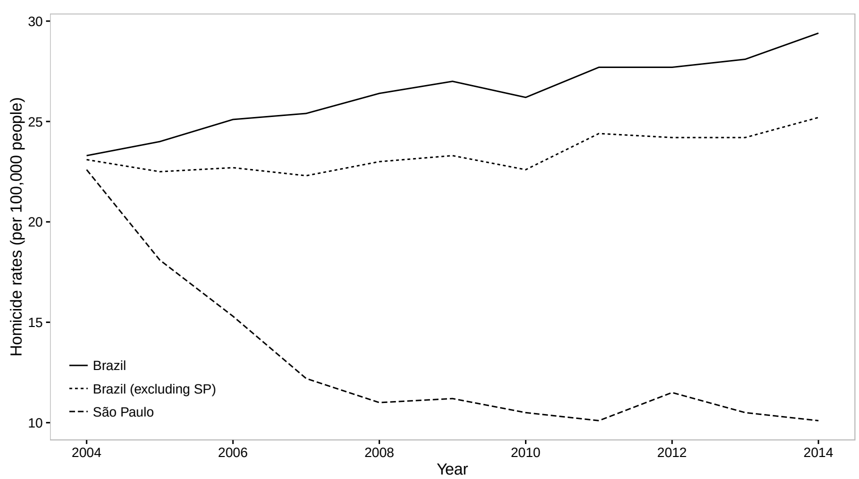

FIGURE 3: HOMICIDE RATE IN BRAZIL AND SÃO PAULO. DATA FROM SECRETARIA DE ESTADO DA SEGURANÇA PÚBLICA (2016). RATES PER 100,000 INHABITANTS.

The choice of the state of São Paulo for this study is justified in figure 3. Like many industrialized countries and with a GDP per capita of US$23,700 in 2010 (IBGE, 2010), São Paulo has experienced a drop in the number of violent crimes during the period between 2004 and 2014. The solid line represents the homicide rate per 100,00 inhabitants in Brazil, and the dashed line depicts the rate for the state of São Paulo. It can be seen that homicide rate in Brazil increased slightly during the period, presenting a small drop in the year of 2010. The same pattern is observed if excluding São Paulo (dotted line in graph). On the other hand, the homicide rate for São Paulo fell sharply between 2004 and 2008. After this period, it remained steady until 2014. Interesting to notice is that the homicide rate for São Paulo showed a slight increase in 2012, year the introduction of the ninth digit.

Data used in this study come from different sources. The dependent variable is a collection of crime categories obtained from the *Secretaria Estadual de Segurança Pública de São Paulo* (SSP). Criminal statistics are reported at the municipal-level such as homicides, bodily injury, rape, vehicle and property thefts. Such data are available since January 2011 and are published monthly. Also from SSP, it is possible to collect data on police productivity referred to the number police investigation, the number of guns apprehended and the number of arrests.

From the Brazilian Bureau of Statistics (IBGE) comes information on municipal-level policies such as the establishment of the police forces and the existence of municipal police departments. Demographic information are extracted from São Paulo's State Foundation for Statistical Analysis (*Fundação Sistema Estadual de Análise de Dados* - SEADE). The data presents a variety of social and economic aspects of the state and municipalities, collected in different lengths of time.

For the regression discontinuity approach is used daily municipality-level homicides compiled by the *Sistema de Informações sobre Mortalidade* (SIM), implemented by the Brazilian Ministry of Health. Death causes are distinguishable following International Classification of Diseases (ICD-10)[6].

Summary statistics of municipalities where the ninth digit was implemented (area code 11) and those that remain with the 8 digits (other area codes) are in table 2. GDP per capita is higher for municipalities in are code 11 than for other municipalities in the state, as well as the population size. Urbanization rate and the proportion of male population between 15 and 30 years old are quite similar between these two groups. The crime rates tend to be greater for area code 11 municipalities, except for bodily injury. Even excluding the city of São Paulo from the sample of treated group, mean values remains unchanged.

To obtain pre- and post-treatment period, I use nine-month periods to/from treatment. The period analyzed is inserted between January 2012 and July 2013. This is important for seasonality analysis and minimization of confounders that may affect crime. Other municipalities in the state (those with code areas 12 to 19) received the ninth digit in August 2013, the second wave of changes in the mobile numbering plan. In this sense, it is ensured that the control group is not affect by exogenous shocks during the the studied period.

5 Results and Discussion

This section presents the main results of the ninth digit introduction impact on criminal activity in the state of São Paulo. First, I present and discuss the results for the dynamic difference-in-differences estimators, which

[6]More details of released ICD-10 codes in World Health Organization page `http://apps.who.int/classifications/icd10/browse/2016/en`.

TABLE 2: SUMMARY STATISTICS - TREATED AND CONTROL MUNICIPALITIES

	Area code 11		Other area codes		Area code 11 (excluding SP)	
Variables	Pre 9th digit	Post 9th digit	Pre 9th digit	Post 9th digit	Pre 9th digit	Post 9th digit
GDP per capita	33.690	36.182	22.382	24.090	33.484	35.980
	(29.242)	(30.491)	(17.814)	(20.128)	(29.428)	(30.690)
Population	337.358	339.283	35.024	35.251	162.092	163.301
	(1,408.927)	(1,414.613)	(82.582)	(83.208)	(217.269)	(218.469)
% Male population	0.2617	0.2606	0.2511	(0.2504)	0.2619	0.2608
15-30 years old	(0.0143)	(0.0144)	(0.0262)	(0.0259)	(0.0144)	(0.0144)
Urbanization rate	0.9114	0.9127	0.8424	(0.8444)	0.9102	0.9115
	(0.1439)	(0.1428)	(0.1384)	(0.1378)	(0.1447)	(0.1436)
Homicides	1.1952	1.2989	0.7178	0.6302	1.1989	1.3020
	(2.0513)	(2.2523)	(3.1010)	(2.8215)	(2.0673)	(2.2697)
Bodily injury	34.7315	33.9991	48.6027	48.1127	34.7754	34.0656
	(14.9343)	(15.3426)	(34.1810)	(33.7140)	(15.0449)	(15.4502)
Rape	3.1692	2.9785	2.9805	2.9923	3.1836	2.9881
	(3.6196)	(3.2391)	(6.9563)	(7.1169)	(3.6463)	(3.2636)
Vehicle thefts	25.0128	25.9881	7.5270	7.9317	24.3776	25.3305
	(20.8773)	(21.9222)	(12.6088)	(12.9668)	(20.4047)	(21.4427)
Property thefts	106.0005	106.7681	85.2382	85.7791	104.0599	104.7532
	(41.2502)	(41.8489)	(65.4614)	(64.1196)	(38.5068)	(38.9477)

Note: Data are collected from Secretaria Estadual de Segurança Pública de São Paulo (SSP), Brazilian Bureau of Statistics (IBGE) and Department of Statistics of the State of São Paulo (SEADE). All means (except for population variable) are computed using population as a weight per 100,000 inhabitants. GDP per capita is calculated in Reais (R$) in constant prices of 2010.

considers the signal of the effect and the persistence over time. The results are expanded for several categories of crime. Further, I explore the immediate impact on homicides victims using the regression discontinuity design.

5.1 Main estimates

Table 3 presents the results for homicides victims considering the second phase of the introduction of the ninth digit, since it had a significant drop in the number of mobile connections.[7] Column (1) shows the estimate for the basic difference-in-differences model, without municipality fixed effects and without control variables. The dummy treatment variable is equal to 1 for municipalities where the ninth digit took place in July 2012. As can be seen, there was a significant positive impact on homicides of 0.61 homicides for each 100,000 inhabitants. Considering the homicide rates for municipalities adopting the ninth digit between January 2012 and June 2012 (1.19, according table 2), this estimated value means approximately 51% increase in the number of homicides victims per 100,000 inhabitants, a remarkable effect.

[7]The estimation results for the other two transition phases (I and III) are available upon request to the author. Nonetheless, the estimated results do not show evidence of impact on crime.

TABLE 3: ESTIMATES OF THE IMPACT OF NINTH DIGIT INTRODUCTION ON HOMICIDES

	(1)	(2)	(3)	(4)
$Digit9(t)$	0.6082***	1.0151***	0.5031*	0.5133*
	(0.1095)	(0.2882)	(0.3011)	(0.3020)
$Digit9(t+1)$	-	0.8764**	0.3643	0.3745
		(0.4254)	(0.4081)	(0.4083)
$Digit9(t+2)$	-	0.8987**	0.3866	0.3968
		(0.3494)	(0.3560)	(0.3564)
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Municipality FE	No	No	Yes	Yes
Controls	No	No	No	Yes
Observations	12,255	12,255	12,255	12,255
F-Statistic	4.144	2.565	1.414	1.411

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. The dependent variable is the homicide rate per 100,000 inhabitants.

In columns (2)-(4) are presented the estimates for the dynamic model in the equation 2. Column (2) presents the dynamic effect without municipality fixed effects nor control variables. The effect remains significant and positive for two months after treatment. Columns (3) and (4) add municipality fixed effects and control variables, respectively. The results remain unchanged, even though the effect is only significant in the treatment month. The drop on the number of calls is likely to reduce mobile deterrence for victims of crime only in the month that municipalities experienced the change in mobile dialing. In the months following the treatment, the impact of the new rule on homicides is not different of zero.

The results for bodily injury are presented in table 4. Again, the results area present from the simple (1) to the full specification (4). In all specifications the ninth digit introduction caused a drop in bodily injury for treated municipalities, relative to control municipalities. In column (4), the model with fixed effects and control variables, the drop is significant with magnitude of -10,62 per 100,000 inhabitants, which means a drop of 30.6%. One month after treatment ($t + 1$), the size of the impact is smaller but still significant.

The mechanisms that explain the results for homicide and bodily injury are relevant for security policies, mainly because these types of crime are likely to occur among strangers and most plausibly deterred by the use of mobile phones (Orrick and Piquero, 2015). As mobile phones increases surveillance and apprehension, an expansion of this technology would increase the costs of crime perceived by potential offenders. One possible explanation for the previous results is as the following. A potential homicide victim could avoid the murder if she could use the mobile phone in a threatening situation. Once homicide data are rarely under-reported this reduced

TABLE 4: ESTIMATES OF IMPACT OF NINTH DIGIT INTRODUCTION ON BODILY INJURY

	(1)	(2)	(3)	(4)
$Digit9(t)$	-14.423***	-23.713***	-10.596***	-10.6209***
	(1.402)	(2.770)	(2.376)	(2.3801)
$Digit9(t+1)$	-	-16.600***	-3.483*	-3.5080*
		(2.371)	(1.919)	(1.9233)
$Digit9(t+2)$	-	-15.792***	-2.675	-2.7001
		(2.470)	(2.113)	(2.0972)
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Municipality FE	No	No	Yes	Yes
Controls	No	No	No	Yes
Observations	12,255	12,255	12,255	12,255
F-Statistic	30.77	20.53	7.821	7.782

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. The dependent variable is the rate of bodily injury per 100,000 inhabitants.

communication lower the likelihood of deter criminals. On the other hand, the difficulty of communication caused fewer reports of bodily injury which helps improve statistics.

Another category of crime within this context is rape, defined by the Brazilian penal code as "the act of embarrass someone by violence or serious threat, to have sexual intercourse or to perform or allow him to practice other libidinous acts". In many countries rape statistics are unreliable or misleading. In Brazil, rape is severely under-reported and official data is not accurate[8].

The results for rape are presented in table 5. The result in the basic model (column 1) demonstrate no effect on rape. The dynamic estimation, however, presents a significant increase in rapes at the rate of 1 in the first period after treatment. In the following months the effect is null.

Other categories of crimes that are less likely to predict (such as theft or robbery) are not easily deterred by the use of mobile phones (Klick et al., 2012). The estimates for vehicle and property theft and robbery are presented in table 6. According to the results, there is no dynamic effect for these types of crime when compared treated and control municipalities.

[8]Security policies aimed at protecting women exist, but are still quite inefficient in Brazil. One possible explanation for under-reporting is that women often feel guilty and ashamed, so they do not report being raped, especially as they know the extent of existing impunity. See more in http://goo.gl/3UIav4

TABLE 5: ESTIMATES OF IMPACT OF NINTH DIGIT INTRODUCTION ON RAPE

	(1)	(2)	(3)	(4)
$Digit9(t)$	0.0312	0.4444	0.4237	0.4141
	(0.1646)	(0.4599)	(0.4739)	(0.4734)
$Digit9(t+1)$	-	1.0126*	0.9918**	0.9822**
		(0.5206)	(0.4984)	(0.4921)
$Digit9(t+2)$	-	-0.2280	-0.2488	-0.2582
		(0.5602)	(0.5822)	(0.5838)
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Municipality FE	No	No	Yes	Yes
Controls	No	No	No	Yes
Observations	15,480	15,480	15,480	15,480
F-Statistic	1.99	1.831	1.613	1.603

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. The dependent variable is the rate rape per 100,000 inhabitants.

TABLE 6: ESTIMATES OF IMPACT OF NINTH DIGIT INTRODUCTION ON VEHICLE AND PROPERTY THEFT

	Vehicle theft		Property theft	
	(1)	(2)	(3)	(4)
$Digit9(t)$	0.8217	0.9409	4.2699	4.2120
	(1.2708)	(1.2706)	(3.5383)	(3.5563)
$Digit9(t+1)$	-0.3500	-0.2307	-2.2403	-2.2981
	(1.0287)	(1.0205)	(2.4370)	(2.4553)
$Digit9(t+2)$	1.5752	-1.4558	-0.1395	-0.1974
	(1.3581)	(1.3521)	(2.8659)	(2.8881)
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Controls	No	Yes	No	Yes
Observations	15,480	15,480	15,480	15,480
F-Statistic	42.01	41.78	34.44	34.25

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. The dependent variable is the rate of vehicle and property theft per 100,000 inhabitants.

5.2 Robustness checks

The key assumption for any difference-in-difference estimation is that the outcome in treatment and control groups would follow the same time trend in the time period before treatment. In some aspects, the common trend assumption is not easy to verify and the most widely strategy used to check its validity is to use pretreatment data to show that the trends are similar (Autor, 2003). Estimated results of equation 3 are presented in table 7.

TABLE 7: ESTIMATES OF IMPACT OF NINTH DIGIT INTRODUCTION: ANTICIPATORY EFFECTS

	Homicides (1)	Injury (2)	Rape (3)	Vehicle (4)	Property (5)
$Digit9(t-2)$	-0.1586	-2.9711	0.4880	0.8584	1.9946
	(0.3115)	(1.9907)	(0.6624)	(1.2631)	(4.1138)
$Digit9(t-1)$	-0.1804	-4.8934	0.2088	-1.0433	5.2950
	(0.2761)	(2.1546)	(0.4861)	(1.2100)	(3.3610)
$Digit9(t)$	0.4490*	-10.7169***	1.0279	-2.7001	4.7786
	(0.2179)	(2.4086)	(0.4814)	(1.3102)	(3.6965)
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Observations	12,255	12,255	12,255	12,255	12,255
F-Statistic	1.409	7.784	1.602	41.78	34.25

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. All dependent variable are rates per 100,000 inhabitants.

From table 7 we observe that for all categories of crime there are no anticipatory effects, i.e., the inclusion of the ninth digit did not caused any change in crime patterns in the pretreatment period. This is also true for the phase (I) treatment and consistent with discontinuity exploited in the subsection 2.2. Consistent with previous results, the treatment effect in the period t is significant for homicides and bodily injury.

With population around 11,3 million (IBGE, 2010) São Paulo is the most populous municipality in Brazil and the 12th largest city proper by population in the world. It also has the largest economy by GDP in Latin America and Southern Hemisphere. Economic and social interaction, thus, makes the mobile phone a important component in people routine. In order to check if result presented in last section were driven mainly by the city of São Paulo, table 8 report the results excluding the most populous city in the sample.

As can be seen in table above, excluding the city of São Paulo does not change significantly previous results. The impacts size - for the model with fixed effects and control variables - are slightly lower compared to the results with the inclusion of São Paulo. This corroborates to the fact that the impact on crime was homogeneous for the region with area code 11 and negligible for control regions.

TABLE 8: ESTIMATES OF IMPACT OF NINTH DIGIT INTRODUCTION: EXCLUDING SÃO PAULO

	Homicides (1)	Injury (2)	Rape (3)	Vehicle (4)	Property (5)
$Digit9(t)$	0.5138*	-10.4967***	0.4154	0.9147	4.3082
	(0.3115)	(2.3937)	(0.4787)	(1.2937)	(3.6154)
$Digit9(t+1)$	0.3751	-3.4163*	0.9846*	-0.1880	-2.0769
	(0.4145)	(1.9410)	(0.5047)	(1.0315)	(2.5041)
$Digit9(t+2)$	0.3993	-2.6262	-0.2550	-1.4054	-0.0348
	(0.3613)	(2.1204)	(0.5913)	(1.3733)	(2.9456)
Month FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
Observations	12,236	12,236	12,236	12,236	12,236
F-Statistic	1.411	7.773	1.603	40.46	34.25

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$. Standard errors are clustered at municipality level and are presented in parentheses. The dependent variable is the rate of bodily injury per 100,000 inhabitants.

5.3 RDD results

Figure 4 presents the main findings for log of homicides for treated and untreated municipalities. In the panel on the left are the results for municipalities where the ninth digit for mobile phone numbers were implemented. Following Smith (2016), the outcome variable is demeaned to minimize the persistent day-of-week effects.

It can be observed a slightly shift upward, implying in a moderate increase in the number of homicides once users could not complete mobile calls. In the panel on the right I consider contemporaneous homicide levels for the untreated municipalities. There is no significant discontinuity around the cutoff for other area codes.

The detailed estimates are presented in table 9. Considering all bandwidth selection - IK, proposed by Imbens and Kalyanaraman (2011); CCT by Calonico et al. (2014); and CV, a cross-validation method proposed by Ludwig and Miller (2005) - procedures the results for both treated and untreated municipalities. Even though the impacts for both groups are negative, they are not statistically different from zero. These findings support the fact that the impact of the drop in the mobile calls caused by the implementation of the ninth digit does not occur immediately after the transition date.

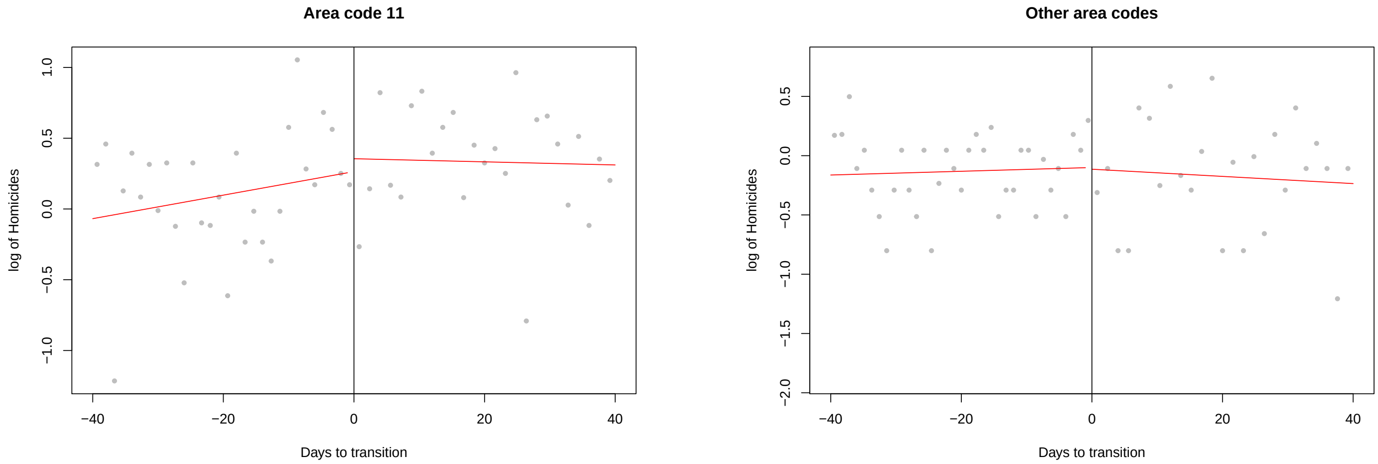

FIGURE 4: IMPLEMENTATION OF THE NINTH DIGIT

TABLE 9: ESTIMATES OF LOCAL LINEAR RDD ON HOMICIDES

	Area code 11			Other area codes		
$Digit9_{LATE}$	-0.4450	-0.2818	-0.2818	-0.5243	-0.5412	-0.5412
	(0.5704)	(0.5704)	(0.6180)	(0.2961)	(0.2961)	(0.3440)
Bandwidth	CCT	IK	CV	CCT	IK	CV
Polinomyal order	Linear	Linear	Linear	Linear	Linear	Linear
Kernel	Uniform	Uniform	Uniform	Uniform	Uniform	Uniform
Observations	4067	4067	4067	2716	2716	2716

Note: *p<0.1; **p<0.05; ***p<0.01. Standard errors are clustered at the municipality level. The outcome variable is the log of homicides. Bandwidth codes: (CCT) Calonico et al. (2014); (IK) Imbens and Kalyanaraman (2011); (CV) Cross-Validation Ludwig and Miller (2005).

6 Concluding Remarks

In addition to the factors discussed by theoretical and empirical economists to explain the decline in the crime rate in most of industrialized countries, some scholars have focused in the study of other potential correlations based on the security hypothesis. In this sense, a potential and underappreciated link is related to the increase of mobile phone technology and crime deterrence.

In this paper I present the first attempt to estimate the causal effect of the use of mobile phone on crime. A natural experiment induced by the introduction of the ninth digit for some municipalities in the state of São Paulo is used to estimate the signal and size of the effect of interest. At our benchmark estimate, the drop in the number of mobile calls caused monthly homicide rates per 100,000 inhabitants to increase by around 0.5, which means nearly 50% increase. For bodily injury rate there was a fall of 10.62 in the first month, which means a drop of 30.6%, and a drop of 3.5 in the second month after treatment. For rape, I find an increase of 0.98 in the rate per 100,000 inhabitants only one month after treatment, but no immediate effects. The results for vehicle and property theft are not statistically significant, supporting the findings in Klick, MacDonald, and Stratmann (2012), which hypothesize that mobile phones have the largest impact for violent crimes. The regression discontinuity estimates show, however, no immediate impact of mobile calls drop on crime.

According to Farrell et al. (2014), phone guardianship is unlikely to prove to be a major contributor to the crime drop. Nonetheless, the results of this study is consistent to the modern discussions in the crime literature and appealing toward the use and expansion of private security instruments in crime prevention.

This study paves the way for further studies interested in estimating the effect of the mobile phones use on crime through different instruments and empirical strategies in favor of external validity. Noteworthy, shutdown in telecommunications services in specific contexts or judicial bans to the use of chat platform can be also explored as instruments to access the causal effect.

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