Crime Prevention and Community Safety
https://doi.org/10.1057/s41300-024-00205-8

ORIGINAL PAPER

One crime wave, three hypotheses: using interrupted time series to examine the unintended consequences of criminal justice reform, computer tablet recording of crime and a long-term hot spots policing programme

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Accepted: 5 April 2024
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Abstract

After sustained reductions in robberies and thefts in 2016, the city of Montevideo, Uruguay, experienced a sudden increase in these crimes in late 2017. Using interrupted time series regressions, and controlling for seasonality using ARIMA models, we investigated three potential explanations for this increase: (1) the failure of a hot spots policing program to maintain crime decreases; (2) improved crime recording by police patrols using tablet computers; and (3) the change from an inquisitorial to an adversarial criminal justice procedure. We found that the hot spots policing program that began in April 2016 continued to be associated with crime reductions during 2017, that the increases observed after November 2017 were strongly associated with the new criminal justice procedure, and that tablets had a positive, albeit negligible, effect. The findings illustrate that criminal justice reforms, desirable as such reforms may be, can have unintended consequences on crime levels.

Keywords Hot spots policing · Adversarial system · Tablet computers · Latin America · Preventive detention

Introduction

In late 2017 and in to 2018, the capital city of Uruguay, Montevideo, experienced a sudden and substantial increase in robberies and thefts against pedestrians of over 45percent on the previous year (increasing from 15,093 of these crimes in 2017

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Published online: 02 May 2024

to 21,984 in 2018). Although increases were observed in other types of crime, the increases in robberies and thefts were greater than those against property (e.g., domestic burglary) or crime in non-public settings (e.g., domestic violence). This increase in robberies and thefts was surprising because it came after a sustained period of decreases in these crimes that were associated with a large-scale hot spots policing program in Montevideo (Chainey et al. 2021). Faced with this increase in robberies and thefts in 2018, Uruguayan authorities began to question the long-term crime prevention effect of the hot spots policing programme (named Programa de Alta Dedicación Operativa, PADO) and whether the resourcing commitment to the programme should continue. In 2018, Montevideo also implemented two changes in police practice and criminal justice policy. These changes involved a transition to police officers using handheld computer tablets to record crimes and a nationwide change to an adversarial criminal justice procedure. Little consideration had been given to the possible influence of these two changes on the increase in robberies and thefts.

In this paper we examine three potential explanations for the increase in robberies and thefts in Montevideo in 2018: the increase in crime was associated with the reduced effectiveness of the PADO hot spots policing program; the increase in crime was associated with an increase in crime reporting and recording associated with the use of tablet computers, and the increase in crime was associated with the change in the criminal procedure code.

The research aims to make three contributions to the existing research literature. First, the findings from the study contribute new insights into the impact on crime levels from the adoption of an adversarial criminal procedure code in countries that previously operated inquisitorial criminal justice systems. A feature of the inquisitorial criminal justice system involves a suspect of a crime being sent to prison until their case is heard at a court of law and a conviction decision is reached. The adversarial system minimizes the use of pre-trial detention and instead involves conditional release mechanisms whereby suspects can return home and wait for their trial. Most countries have used adversarial criminal procedures for decades; however, in Latin America, many countries have historically followed an inquisitorial criminal procedure. In recent years, these Latin American countries, including Uruguay, have transitioned to adversarial procedures. Adversarial procedures have been implemented to improve the slow and abuse-prone criminal justice processes that the inquisitorial system is susceptible to. To date, very few studies have examined how these criminal justice reforms may have influenced changes in criminal behavior, and consequently, crime levels (see Zorro Medina et al. 2020; Huebert 2019). We examine the impact of the adoption of the adversarial criminal procedure code (implemented on the 1st November 2017) on changes in crime levels in Montevideo.

Second, we assess if the adoption of new technology for front-line policing can affect crime reporting and recording levels. While the scholarship on the adoption and use of mobile technologies in policing is an established field (e.g., Lindsay et al. 2009; Lum et al. 2017; Koper et al. 2014; Allen et al. 2008), the potential impact that these technologies could have on crime levels remains unexplored.

Third, we add to the evidence on the long-term impact of hot spots policing by considering these effects for a large city. To date, we know of only one study that has examined the long-term effects of hot spots policing, with this being for a small city in the USA (Koper et al. 2021). The current study examines if the hot spots policing programme in Montevideo was no longer effective in reducing crime after operating for over a year.

The rest of the article is structured as follows: First, we introduce the context of the study and briefly review the relevant literature. Then we describe the data and methods used. This is followed by the results. Lastly, we discuss the findings and limitations, and end with conclusions including those that relate to crime prevention.

Hot spots policing in Montevideo: PADO

PADO, introduced in April 2016 in Montevideo, was the first hot spots policing programme in Latin America that involved the use of a large number of police officers solely dedicated to patrolling hot spots (Inter-American Development Bank and the Uruguay Ministry of Interior 2017). PADO involved the precise targeted deployment of police patrols to the specific streets where robberies and thefts were known to concentrate. Prior to the implementation of PADO, robberies and thefts had been increasing in Montevideo by at least ten percent per year for almost a decade. In 2015, drawing from the international evidence on the effects of hot spots policing (Braga et al. 2014) and an analysis of the geographic and temporal patterns of robberies and thefts in Montevideo, the Uruguay Police implemented PADO in the top 120 hot spot locations in Montevideo (Chainey et al. 2021). This involved groups of two or three police officers patrolling each hot spot location on foot, supported by a small number of motorbike police patrols (about two motorbike patrols for every 15 foot patrols). The PADO patrols operated between 17.00 and 01.00 h (informed by a temporal analysis of the crime hot spots) and required the foot patrols to remain within their assigned patrol area for the evening. The exception to this was when a person was arrested by a PADO patrol, requiring one of the PADO patrol officers to accompany the police response team (that had been called to the scene) and the suspect to a local police station. For every 15 patrols, a supervisor was assigned to ensure the patrols were where they needed to be and to coordinate any support to specific hot spots during a patrol shift. Every day, over 400 police officers were dedicated to PADO.

The primary purpose of the PADO patrols was to act as a visible deterrent to offending behavior. Their purpose was not necessarily to be more active in making arrests, but instead to increase the perceived risk of offending in the locations where the foot patrols were deployed. It was rare for PADO foot patrol officers to make an arrest while on patrol, meaning their presence in the hot spot locations were maintained for the duration of their assignment. A quasi-experimental evaluation of PADO in 2016 showed the programme was responsible for a 23 percent decrease in robberies and thefts in PADO patrol areas compared to control areas, with no evidence of displacement to other areas or other crime types (Chainey et al. 2021). PADO continued throughout 2017 and 2018, with the same resourcing levels being maintained.

The implementation and use of tablet computers by police officers inMontevideo

To help improve the completion of administrative tasks while police officers were on patrol, in 2017 the Uruguay Police began the incremental roll out of tablet computers to police officers in Montevideo, including to PADO patrol officers. These tablets now meant that police officers could perform immediate identification checks of individuals and vehicles, and record offence details reported to them while they were in the field. The use of the tablets therefore made it potentially easier for victims to report crimes. Prior to the introduction of the tablets, crimes could only be reported at police stations. Tablets used by PADO patrol officers meant that victims could now report the offence to these patrol officers. This meant that robberies and thefts that may not have previously been reported because the victim decided not to visit a police station could more likely be reported. Also, the introduction of the tablets meant that when a PADO patrol officer did make an arrest, they did not need to accompany the person they had arrested to a local police station. Although arrests made by PADO officers were rare, the patrol officer could now complete the arrest details on the tablet and remain in their patrol location with their patrol colleagues.

After a period of pilot testing in 2017, a large roll out programme commenced in 2018 to equip all PADO patrol groups with at least one tablet. Hence, it was plausible that the increases in robberies and thefts experienced in 2018 were because of an increase in crime reporting to PADO officers while they were on patrol, rather than an actual increase in the incidence of robberies and thefts.

Uruguay's new criminal procedure code

Since the 1990s, more than 20 countries in Latin America have transformed their justice systems by replacing inquisitorial procedures (inherited from colonial rule) with an adversarial model presided over by an impartial judiciary. This "criminal procedural revolution" (Zorro Medina et al. 2020) was implemented to modernize the region's criminal justice systems. Its goals were to improve the efficiency of criminal justice processes by increasing clearance rates and shortening lengthy criminal procedures, and reducing abuses of the criminal justice system such as weak human rights protections that incentivized the use of torture to forcibly obtain confessions (Magaloni and Rodriguez 2020).

One of the aims of the transition from the inquisitorial to adversarial system was to reduce the use of pre-trial detention. Inquisitorial criminal justice systems rely on extensive secret pre-trial investigations and written records (rather than oral proceedings), lack alternatives to a formal trial (e.g., pre-trial diversions or plea bargains), and are overseen by judges who are responsible for prosecuting, defending and adjudicating cases (Hafetz 2003). As a consequence, pre-trial detention, referred to in Spanish as *prisión preventiva* (preventive detention), is a feature of the inquisitorial criminal justice system in Latin America. This involves a suspect (based on a judge's decision) being sent immediately to prison until their case is heard at a court of law and conviction decision is reached. The aim of this was to reduce the risk of suspects interfering with criminal investigations or fleeing justice (Fondevila and Quintana-Navarrete 2021). As Hafetz (2003) notes "many unconvicted inmates spend several years behind bars awaiting a verdict… some remain in prison for a longer period than if they had been convicted of the crime itself" (p 1758). Around 30 to 85 percent of the incarcerated population in Latin American prisons constitute these suspects that have not been convicted (Fondevila and Quintana-Navarrete 2021). This incarceration violates human rights and additionally subjects suspects to dismal conditions in Latin American prisons such as overcrowding, violence, physical and sexual abuse, and malnutrition (Hafetz 2003; Fondevila and Quintana-Navarrete 2021).

In Uruguay, reform to an adversarial system aimed to improve the general efficiency of the country's criminal justice system. This new system shifted the burden of proof to criminal prosecutors who are required to build and present cases before judges, who then rule on whether there are sufficient grounds to indict a suspect. The new system also aimed to minimize the use of pre-trial detention. In practice, the transition from *prisión preventiva* involved implementing conditional release mechanisms whereby suspects could return home and wait for their trial. On November 1, 2017, Uruguay replaced its inquisitorial system with the adversarial criminal procedure system. Before the implementation of this new criminal procedure code the percentage of all prison inmates in Uruguay that were in pre-trial detention (between 2000 and 2017) ranged between 94 and 63 percent of the prison population (Organisation of American States 2022). From November 1, 2017, suspects had a right to be given bail. Following this change, the percentage of the prison population that were suspects held in pre-trial detention decreased to 43 percent in 2018 and 22 percent in 2019 (Organisation of American States 2022).

Uruguay, like many other countries in Latin America, have implemented these criminal justice reforms to improve their previous inefficient and abuse-prone criminal justice systems. However, whether these reforms have unintended consequences on levels of crime is a topic that has received little attention. Certain empirical evidence does suggest that changes in criminal procedure codes do affect criminal behavior (for a review see Zorro Medina et al. 2020). The most notable of these is that the incarceration of offenders denies them of the ability to commit crime, which in turn reduces crime via their incapacitation (Cohen 1983). In an opposite manner, reductions in pre-trial detention could lead to increases in crime, because the incapacitation effect of pre-trial detention has been removed. Evidence from Colombia supports this hypothesis, where following the implementation of an adversarial criminal justice procedure, a 22 percent increase in crime was observed (Zorro Medina et al. 2020). We therefore hypothesize that one possible explanation for the increases in crime observed in Uruguay in 2018 was associated with the implementation the new adversarial criminal procedure code.

The current study tests three hypotheses for explaining the increase in robberies and thefts. First, we test if the increase in crime was associated with the reduced effectiveness of the PADO hot spots policing program. Second, we test if the introduction of tablet computers for recording offenses contributed to these increases in the recorded levels of robberies and thefts. Third, we test whether the transition to the adversarial criminal procedure system was associated with the increases in robberies and thefts. We examine each hypothesis using interrupted time series regression to detect whether changes in the levels of crime coincided with the timing of the changes in policing and criminal justice procedures we describe above.

Data and methods

We began the analysis using disaggregated data on every robbery and theft recorded in Montevideo between January 1, 2015, and November 25, 2018 ($n=70{,}016$). Incidents were aggregated by date into a daily time series covering the study period, consisting of 1425 daily observations. We then added two dummy variables to indicate the periods of interest: A “PADO” variable indicated whether the date was on or after April 11, 2016 (the date PADO began), and a “Justice” variable indicated whether the date was on or after November 1, 2017 (the day the new penal code came into force).

Tablets for recording crime were introduced in Montevideo over three stages. Between January and July 2017, the use of a small number of tablets was tested in Montevideo. From August to December 2017, the use of tablets incrementally increased, until January 2018 when the full roll out of tablets across Montevideo had been completed. The systematic recording of whether a crime had been recorded using a tablet only began in January 2018; however, two attributes captured in crime records prior to 2018 can be used as proxy variables to determine how many incidents were recorded using tablets. The first of these attributes was the median time (in minutes) that elapsed between when the robbery or theft occurred and when it was reported to the police. In 2018, the median time for a tablet-recorded robbery or theft to be reported was 6 min. In contrast, the median time-to-report for conventionally recorded robberies and thefts (that required the victim to visit a police station) was 66 min Chainey(Kruskal–Wallis $\chi^2 = 3769.2$, $df = 1$, $p < 0.001$, $n = 11,854$). On examining the median time-to-report per day, a clear trend emerged that coincided with the rollout of the tablets in Montevideo in 2017. This showed, see Fig. 1, that before January 2017, the median time between when the crime occurred and when it was reported to the police was stable. During 2017, this median time began to decrease as tablets were being rolled out, until January 2018 when the median time between when the crime occurred and when it was reported stabilized, which coincides with the completion of the tablet rollout program.

The second attribute we examined to determine the estimated number of robberies and thefts that were recorded using tablets was the proportion of robberies and thefts reported in 10 min or less per day. To identify the 10-min cutoff point, we fitted a logistic model to 2018 data using time-to-report to predict the odds of a crime being recorded using a tablet. This model found a significant and negative relationship between the time-to-report (log-transformed due to the highly skewed distribution of time-to-report) and the odds of a crime being recorded with a tablet (Wald χ_(df=1)^2=2417.14, $p<0.001$, see Fig. 2 for coefficient parameters). To

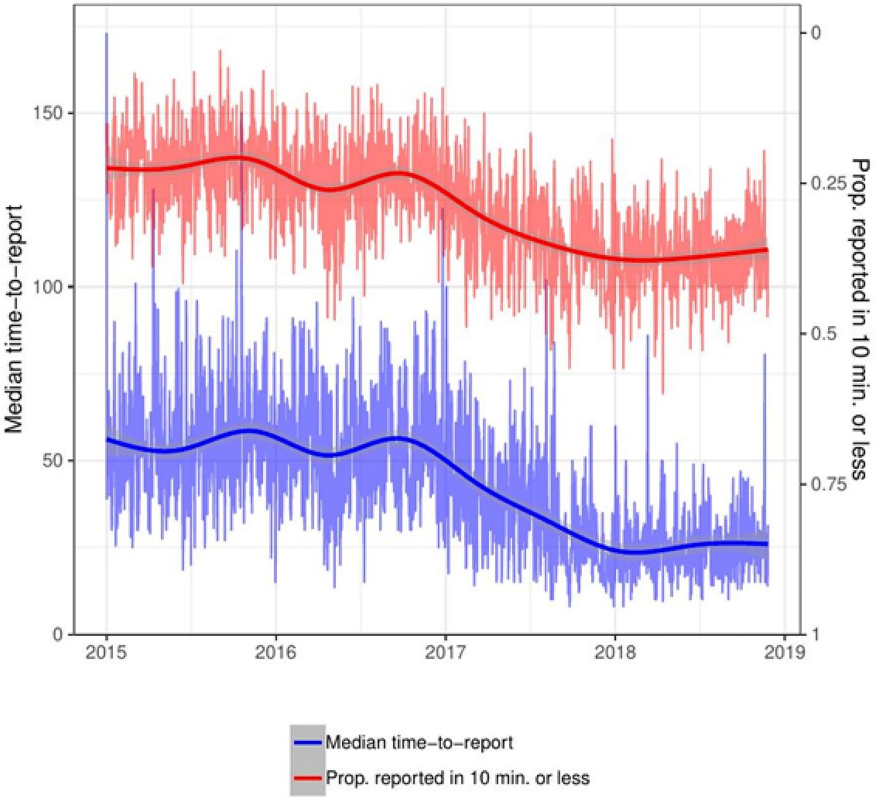

Fig. 1 Time series of the daily median time-to-report and the proportion of robberies and thefts reported in 10 min or less during the study period. Thick lines represent generalized additive model smooth trends

identify the suitable cutoff point in minutes, we calculated predicted probabilities for 0 to 120 min in time-to-report and found that the probability of a crime being recorded in a tablet was greater than 50% when the time-to-report was 10 min or less (see Fig. 2). We then examined the trend in the daily proportion of robberies and thefts reported in 10 min and found that it matched the pattern of the median time-to-report, with proportions of robberies and thefts reported within 10 min increasing while tablets were being introduced in Montevideo (see Fig. 1).

To examine if the change in the criminal procedure code and the introduction of tablets for recording crime were associated with the increase in robberies and thefts experienced in Montevideo, we used interrupted time series (ITS) regression. ITS is used to evaluate the effects of macro-level interventions that have a clear implementation period. Lopez Bernal et al. (2017) provide a good theoretical and practical introduction to the technique. Essentially, an ITS is an ordinary least squares (OLS) regression in which the dependent variable (y) is primarily modeled as a function of time (T) with at least one dummy variable representing the implementation of an intervention (x) at T_x. Additionally, the model can

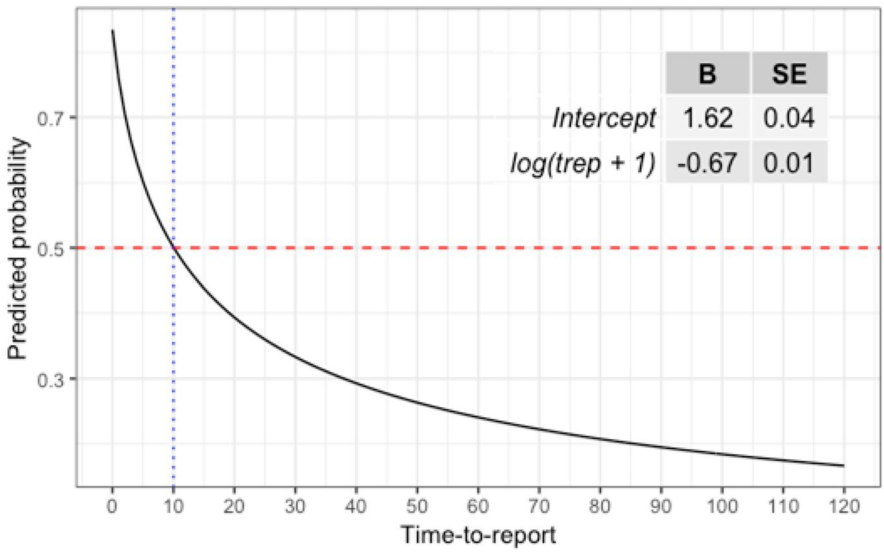

Fig. 2 Predicted probabilities of robberies and thefts being recorded on a tablet during 2018 conditional on the time-to-report. Coefficient estimates from the logistic model are shown in the table insert

include the effect of an interaction between $x \times T$ to indicate a change in slope after the implementation of x. The general form of the ITS model is:

$$y_t = \beta_0 + \beta_1 T + \beta_2 x + \beta_3 T \times x + e_t \tag{1}$$

where β_0 corresponds to the value of y when $T = 0$, β_1 represents the baseline trend before the intervention of x, β_2 represents the baseline change in y after the intervention x, β_3 is the change in trend after the intervention, and e is an error term. We used two intervention dummies to control for the effects of PADO and the implementation of the new CJS (x_1 = PADO. and x_2 = Justice). Additionally, we used two models to separately control for the use of tablets (x_{3t}) using the daily median time-to-report (Model 1) and the proportion of robberies and thefts reported in 10 min or less (Model 2).

A crucial element of fitting an ITS model is to appropriately capture the underlying functional form of the trend as well as controlling for seasonal patterns. Crime trends are not always linear, thus more complex growth functions can be approximated using polynomial terms. We used second-order orthogonal polynomials to capture the underlying trend, as they were significantly better than a first-order polynomial ($F\_(df=2)=20.4$, $p<0.001$). A model using third-order polynomials was not significantly better than a model using second-order polynomials ($F\_(df=2)=0.2$, $p=0.8$). To control for seasonal effects, we first used OLS models with day of the week and week of the year dummy variables. However, when time series models experience residual autocorrelation (a common issue in time series analysis of crime events), the assumption of independence underpinning OLS is violated, leading to biased standard errors and potentially spurious inferences. Thus, to deal with residual autocorrelation we estimated linear models with ARIMA errors (Hyndman 2010; Hyndman and Athanasopoulos 2019). ARIMA errors are a powerful method to control for serial autocorrelation and can also be used to control for seasonal autocorrelation—providing a more flexible approach for controlling seasonality than the dummy variable approach we used in the OLS models. Therefore, in our ARIMA models we controlled seasonality using seasonal ARIMA components instead of day of the week and week of the year dummy variables.

A fundamental difference between OLS and the linear model with ARIMA errors is that the error term expressed in Eq. 1 (e_t) is not assumed to be independent and identically distributed, but is rather assumed to exhibit complex short-, medium-, and long-term dependencies (Box-Steffensmeier et al. 2014). The ARIMA model captures such dependencies by specifying the order of non-seasonal and seasonal autoregressive (p), integration (d), and moving average parameters (q)—denoted as ARIMA$(p, d, q) \times (P, D, Q)_m$—that are required to reduce the error term to a white noise process (Box-Steffensmeier et al. 2014; Estévez-Soto 2021). Formally, the errors are assumed to take the following form:

$$e_t = \frac{\theta(B)\Theta(B^m)}{\phi(B)\Phi(B^m)} z_t \tag{2}$$

where θ and ϕ are the non-seasonal autoregressive and moving average parameters, Θ and Φ are the autoregressive and moving average parameters for a seasonal period of length m, B is the backshift operator, and z_t are white noise residuals (Estévez-Soto 2021). If (non-seasonal) integration is present, $\phi(B)$ is replaced by $\nabla^d \phi(B)$, where ∇ is the differencing operator $(1 - B)$(Hyndman 2010; Hyndman and Athanasopoulos 2019). While a detailed discussion of ARIMA modeling is beyond the scope of this study, readers interested in technical details are directed to Box-Steffensmeier et al. (2014) and Hyndman and Athanasopoulos (2019).

Implementation of the linear models with ARIMA errors followed Estévez-Soto (2021), using Hyndman and Khandakar's (2008) algorithm for automatically selecting ARIMA parameters that minimize the Akaike information criterion (AIC) as implemented by the 'fable' package (O'Hara-Wild et al. 2020) in R (R Core Team 2020).

Model fits were assessed by inspecting model residuals visually and statistically. Visually, we inspected residual time series plots, residual autocorrelation plots, and residual density plots (see Fig. 3). Statistically, we used the Ljung–Box test (Ljung and Box 1978) to identify if there was statistically significant autocorrelation in the residuals, Engle's (1982) ARCH test to rule out autoregressive conditional heteroskedasticity, and KPSS tests (Kwiatkowski et al. 1992) to ensure residuals were stationary. These tests help diagnose if the models have captured the underlying temporal dependencies that could otherwise bias our results. Lastly, counterfactual trends were estimated for each intervention by calculating the values predicted by the estimated coefficients while holding the coefficient for the intervention dummy to zero (see Fig. 4).

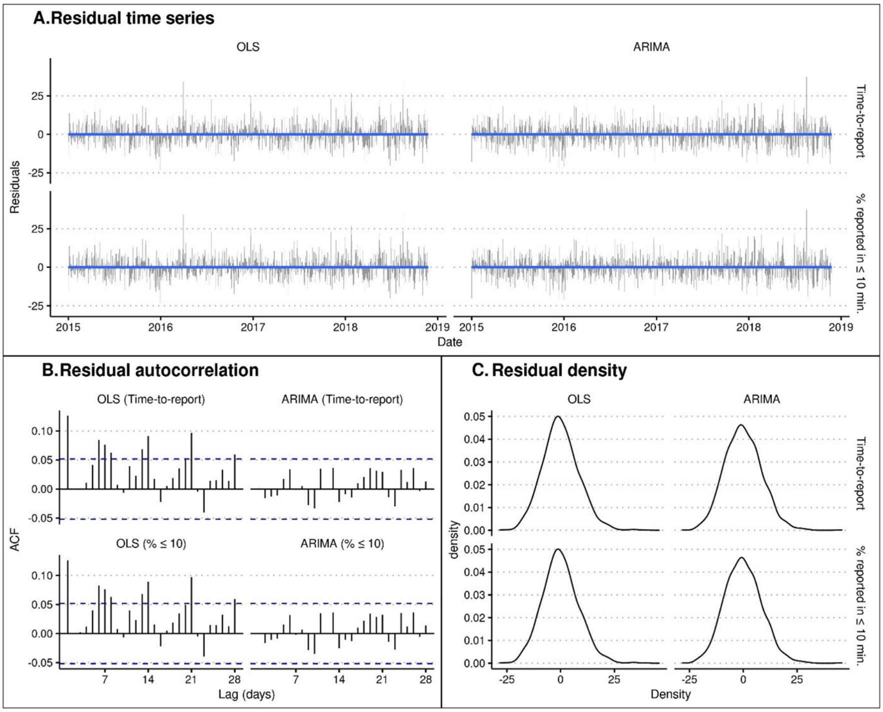

Fig. 3 Residual diagnostic plots for OLS and ARIMA error models

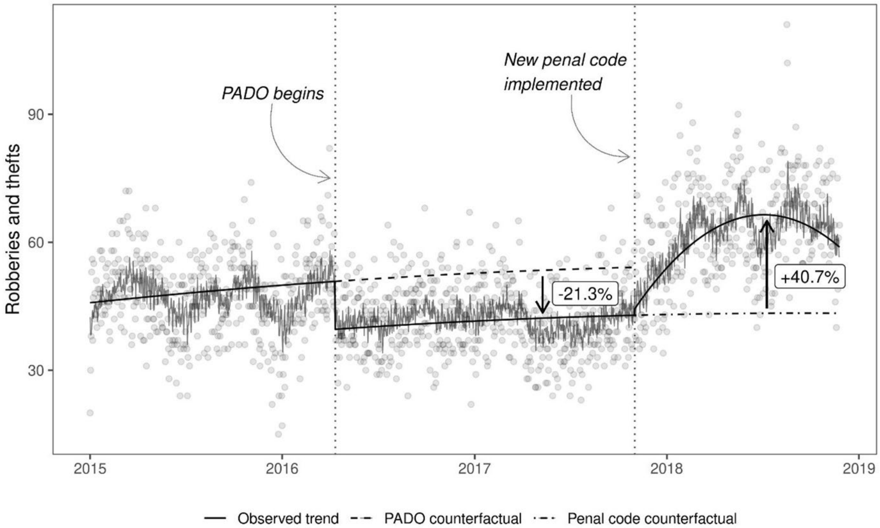

Fig. 4 Plot with observed and counterfactual trends estimated by ARIMA model 2

Results

In Table 1, we report the results of the two specifications used: Model 1 used daily median time-to-report to control for the introduction of tablets, and Model 2 used the proportion of robberies and thefts reported in 10 min or less (expressed as a percentage). For each specification, we estimated coefficients using OLS and ARIMA methods. Reviewing first the model diagnostic results, OLS estimates consistently experienced a high degree of residual autocorrelation as evidenced by the significant Ljung–Box statistic (Ljung and Box 1978). Engle's (1982) ARCH tests did not suggest the presence of autoregressive conditional heteroscedasticity in either OLS or ARIMA estimates. KPSS tests (Kwiatkowski et al. 1992) suggested the residuals of all models were stationary. Further model diagnostics can be found in Fig. 3, showing that the residual time series (Panel A) did not suggest neglected temporal

Table 1 Results of ITS regression models

	Model 1		Model 2	
	OLS	ARIMA	OLS	ARIMA
Intercept	36.14***	53.38***	34.28***	49.61***
	(2.11)	(3.44)	(2.22)	(3.49)
T	−90.60**	110.28	−96.22**	95.48
	(34.48)	(125.04)	(35.02)	(123.26)
T^2	−14.92	−23.31	−15.87	−27.32
	(20.87)	(83.16)	(20.75)	(82.32)
PADO	−2.55*	−11.32**	−2.54*	−11.23**
	(1.15)	(3.44)	(1.15)	(3.43)
Justice	−125.40***	−152.64**	−125.89***	−154.27**
	(20.98)	(50.83)	(20.97)	(50.60)
$T \times$ Justice	5457.49***	6285.57**	5479.26***	6363.22**
	(789.62)	(1999.34)	(789.43)	(1988.78)
$T^2 \times$ Justice	−1718.02***	−2046.53**	−1722.96***	−2063.71**
	(281.17)	(688.86)	(281.11)	(685.41)
Time-to-report	−0.01	−0.03*		
	(0.02)	(0.01)		
% reported in ≤ 10 min			0.04	0.08*
			(0.03)	(0.03)
Log-like	−5054.65	−5088.07	−5054.30	−5087.83
AIC	6199.33	10,206.14	6198.62	10,205.67
Ljung–Box	22.84***	0.00	22.68***	0.00
Engle's ARCH	0.02	0.02	0.02	0.02
KPSS	0.03	0.04	0.03	0.04
N	1425	1425	1425	1425

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$. ARIMA errors: $p(2,0,1)$ x $P(2,0,1)[7]$. OLS models control for seasonality using day of the week and week of the year dummy variables patterns nor evidence of heteroscedasticity in all models. The autocorrelation plots (Fig. 3: Panel B) confirm the results of the Ljung–Box tests, indicating residual autocorrelation in OLS residuals. The density plots (Fig. 3: Panel C) suggest the residuals for all models were reasonably normal and centered around zero.

The results indicated that OLS residual autocorrelation was adequately captured by an ARIMA(2,0,1)x(2,0,1)[7] error model, thus we do not discuss OLS estimates in further detail. Overall, ARIMA estimates for Models 1 and 2 were similar. Both models indicated that the trend (T and T^2) in robberies and thefts before the implementation of PADO was not significant, meaning that robberies and thefts were stable at around 52 incidents per day in Montevideo after controlling for non-seasonal and seasonal autocorrelation. ARIMA estimates for the PADO variable were also similar for Models 1 and 2: In both cases the PADO variable was negative, of similar magnitude, and significant ($p < 0.01$). The models suggest that PADO was associated with 11.3 fewer robberies and thefts per day in Montevideo after its implementation in April 2016 to the end of October 2017. That is, in addition to the results reported by Chainey et al. (2021) on the significant reductions in robberies and thefts associated with PADO between April 2016 and December 2016, PADO continued to be associated with a consistent significant city-wide reduction in the daily average rate of robbery and thefts in Montevideo to the end of October 2017.

The Justice dummy variable, and the interactions between Justice and time were significant ($p < 0.001$ and $p < 0.01$, respectively) and of similar magnitude in ARIMA Models 1 and 2, suggesting that robberies and thefts changed both in baseline level as well as trend. However, because the orthogonal polynomials transform the scale of the time variable, it is not possible to interpret the direction and magnitude of the effect from the coefficient estimates. We return to the interpretation of these results below.

Both ARIMA models suggested that the introduction of tablets had a significant ($p < 0.05$), albeit only modest association with the levels of robberies and thefts. The time-to-report coefficient (Model 1) suggested that a one-minute decrease in the median time-to-report was associated with 0.03 more robberies and thefts per day. Similarly, the coefficient for the percentage of robberies and thefts reported in 10 min or less suggested that a one-percentage point increase was associated with 0.08 more robberies and thefts per day. To better appreciate these estimates, we can predict the increases in robberies and theft for the absolute changes in reporting times observed after the introduction of tablets. Considering that between 2015 and 2018 the median time-to-report decreased by approximately 29 min and the proportion of robberies and thefts reported in 10 min or less increased by 16 percentage points, our estimates suggest that the use of tablets was associated with increases of 0.87 (based on median time-to-report) or 1.28 (based on the proportion of robberies and thefts reported in 10 min) in the daily number of robberies and thefts. Both results indicate that the introduction of tablet computers for recording offenses were associated with only a miniscule share of the observed increases in the number of robberies and thefts.

As noted earlier, interpreting the effect of the Justice dummy variable is difficult because of the orthogonal polynomials. Thus, to facilitate interpretation, Fig. 4 presents a graphical summary of the main effects of ARIMA Model 2. We used

ARIMA Model 2 because it had a slightly better fit, as indicated by the AIC statistic. The light gray dots represent the observed counts of robberies and thefts in Montevideo for every day of the study period. The gray solid line represents the fitted values of the model. The black solid line represents the observed trend, holding constant the proportion of robberies and thefts reported in 10 min or less at the mean and controlling for serial and seasonal dependencies. The vertical gray dotted lines indicate the beginning of PADO (April 11, 2016) and the day the change to the adversarial system was implemented (November 1, 2017). Lastly, the two dashed black lines represent counterfactual trends of the number of robberies and thefts expected if PADO or the adversarial system had not been implemented.

We can estimate the overall effect associated with the interventions by comparing the amount of crime predicted by the counterfactual trends with the observed trend. In the case of PADO, there were 6389.8 fewer robberies and thefts between April 11, 2016, and October 31, 2017 (569 days). This corresponds to 11.2 fewer robberies and thefts per day, a 21.3 percent decrease in robberies and thefts in Montevideo in comparison to the counterfactual expectation. Although the observed trend between April 2016 and November 2017 was slightly upward (see Fig. 4), the difference in the observed trend and the PADO counterfactual was consistent during this period. In contrast, there were 6,865.9 more robberies and thefts than those expected after the implementation of the adversarial system. This corresponds to an increase of 17.6 robberies and thefts per day from November 1, 2017, until the end of the study period (390 days) and represents a 40.7 percent increase in robberies and thefts in Montevideo from the counterfactual expectation.

Discussion and limitations

The results from the current study suggest that PADO, a large-scale hot spots policing program in Montevideo, was responsible for long-term reductions in robberies and thefts. Not only did PADO appear to halt the continual increases in robberies and thefts that had been experienced in Montevideo before its implementation in April 2016, PADO also appeared to have a sustained effect in decreasing these crimes before November 2017: In 2015, an average of 47.4 robberies and thefts per day were experienced in the city; between April 2016 (when PADO was implemented) and October 2017 the number of robberies and thefts decreased to an average of 41.9 per day. The decrease in the number of robberies and thefts for the period April 2016 and October 2017 was equivalent to a city-wide decrease of over 21 percent in these types of crime, assuming pre-PADO trends had continued. This 21 percent difference between the observed levels of crime and the counterfactual measure was consistent between April 2016 and October 2017.

From November 2017 to November 2018, robberies and thefts increased in Montevideo by over 40 percent over the expected incidence level—reaching an average of 61.9 robberies and thefts per day during this period. Our analysis revealed that the introduction of tablets was associated with a negligible proportion of this increase. Although tablets used by patrol officers were likely to provide an easier means for members of the public to report crimes (rather than victims needing to visit a police station to report an offense), their implementation was responsible for an increase of about one robbery or theft in the daily incidence rate.

Our findings indicate that the change from an inquisitorial to an adversarial system of criminal justice in Uruguay was likely the main reason for the increase in robberies and thefts: the additional 17.6 robberies and thefts per day (on average) from November 1, 2017, until the end of the study period were most likely, we hypothesize, associated with suspected offenders being 'free' to commit crime (and perhaps commit several crimes) compared to the situation prior to November 2017 when it was likely these same suspects would have been retained in *prisión preventiva*. We recognize the important human rights advantages that the adversarial system of criminal justice provides over the inquisitorial system that was previously in operation in Uruguay. However, our findings indicate that the change in justice system may have had adverse effects by significantly increasing robbery and thefts in Montevideo (which we anticipate were also experienced nationwide).

At the time when the increases in robberies and thefts were being experienced in Montevideo, decision-makers (including the President of Uruguay and the Minister of Security) and the media questioned the Uruguay Police about their overall ineffectiveness in catching offenders and the effectiveness of PADO. No one could easily explain the increases in robberies and thefts. The findings provided in this study helped the government of Uruguay and the Uruguay Police identify the likely reasons for the increase in these crimes. These results directly contributed to PADO continuing into 2019 and helped to identify ways to reduce any possible additional offending by suspects who had been released on bail. The latter included requirements for suspects with a criminal record to routinely report-in to the police about their movements, and a more coordinated approach between the police, prosecutors, and the courts (El Pais 2018). Future research, therefore, could examine the impact these monitoring procedures of suspects had on robberies and thefts in Montevideo. Future research could also more specifically examine the change in robberies and thefts in the locations where PADO patrols were deployed from November 2017 to determine if the increase in these crimes was less significant in PADO areas than in other areas of Montevideo. This research would help to further examine the long-term impacts that hot spots policing interventions can have on crime.

The change in the criminal procedure code in Uruguay from an inquisitorial to adversarial criminal justice system is a change that other countries in the world, in particular countries in Latin America, have adopted in recent years, yet research of its effect on crime levels is limited. Although Mexico made a similar change from an inquisitorial model to an adversarial system of criminal justice in 2018, no known study has examined if the criminal justice reform in Mexico was associated with crime increases that were also observed over this period (UNODC 2017). Evidence from Colombia supports the findings from the current study that suggest that a 22 percent increase in crime coincided with when the adversarial criminal justice procedure was implemented (Zorro Medina et al. 2020). We also note that although conditions associated with changes in demography, social conditions and the economy (such as increases in the size of the youth population, increases in inequality and increases in unemployment) may have an influence on increases in crime levels, these types of factors slowly change over time and hence are unlikely to have a sudden dramatic effect on the level of crime (Croci and Chainey 2023). Also, we know of no significant demographic, social or economic factor that changed at the end of 2017 in Montevideo that could have had an instant effect on the observed increases in robberies and thefts. We encourage further research that examines whether other countries have experienced similar crime increases following criminal justice reform.

Although the analyses presented herein are statistically robust, there are three main limitations in terms of threats to internal validity. First, the ITS approach is a 'pre-post' test that compares the change in the outcome before and after an intervention. However, in the absence of an appropriate control group, it is not possible to fully rule out competing explanations for the changes observed. This is particularly relevant for the effect of the change in the CJS. The findings from a previous evaluation of PADO using a quasi-experimental approach consisting of a comparison between treatment and control groups (see Chainey et al. 2021) are in line with the findings on the impact of PADO that we observe in the current study. However, the change to an adversarial system was implemented simultaneously across Uruguay, meaning there are no suitable cities in the country that could serve as controls in this study. Thus, despite its limitations, the ITS approach represents the best method to evaluate the impact of the new penal code on robbery and thefts in Montevideo. The impact of the change to the criminal justice system on crime across the whole of Uruguay was beyond the scope of the current study. Montevideo, however, accounts for over 40 percent of Uruguay's population and for over 70 percent of crime experienced in the country, so we anticipate our results are representative of the national experience but recommend a national study as an area for future research.

Second, the concurrent implementation of three interventions during the study period (PADO, the introduction of tablets, and the change in the CJS) makes it challenging to isolate the specific effect of each intervention. While it would have been methodologically ideal to implement and evaluate each intervention independently, the study was concerned with analyzing real-world policy changes that were beyond our control. Thus, while we acknowledge that the analysis cannot completely disentangle the effects of each intervention, we believe that the fact that each intervention was implemented at a different time during the study period mitigates the risk of confounding to a reasonable extent.

Third, although the results point to a causal effect (albeit with the limitations noted above), the study does not address the potential mechanisms linking the increase of robberies and thefts to the change from an inquisitorial to adversarial criminal justice system. We hypothesize that increases may be related to the reduction in the use of preventive detention, meaning more suspected offenders were free to continue offending while awaiting trial, compared to the previous system in which they would have been incapacitated. Furthermore, the reduction in the use of preventive detention may have also altered the perceived risk of offending, enlarging the pool of potential offenders and increasing their propensity to commit crime. We were unable to probe which mechanism (or mechanisms) may be responsible for the increases observed as this was beyond the scope of our study. However, this would seem to be an important avenue for future research, should suitable data become available.

In terms of external validity, the findings are valid for the period, city and crimes under study. It is not known how the patterns observed in robbery and theft may have continued after the study period. Though the trend line suggested a downward slope, it would be incorrect to extrapolate beyond the data at hand. Future research could focus on the medium- and long-term effects of the adversarial system to explore whether crime levels increased, plateaued, or drifted down toward pre-November 2017 levels. Lastly, the current study focused on robberies and thefts, though it is possible that other crimes may have experienced similar changes, and future research could explore this topic. Data on these other crime types were not available at the level required to permit a similar analysis of other types of crime.

Conclusions and recommendations for crime prevention

Most hot spots policing programs operate for no longer than 6 months. While there is extensive evidence that shows that hot spots policing reduces crime (Braga et al. 2014), there is little evidence about its longer-term impact. PADO was a large-scale long-term hot spots policing programme that operated in Montevideo from April 2016. From the date it was implemented to November 2017, PADO was responsible for a consistent city-wide decrease of over 21 percent in robberies and thefts. This result shows evidence of the long-term crime prevention effect of hot spots policing and from this we recommend that hot spots policing programs should operate for longer than has been the norm. In 2017, Uruguay implemented a change from an inquisitorial to an adversarial system of criminal justice and issued tablet computers to police patrol officers to improve crime recording processes. Using interrupted time series regressions for a 4-year period we identified that the 40 percent increase in robberies and thefts were mainly associated with the change in criminal justice processes. Although these findings should not be construed as a criticism of the change to an adversarial criminal justice system, as there are many societal benefits to reducing preventive detention, the findings suggest that practitioners should be aware of the potential unintended consequences of such reforms (at least in the short term) and may wish to adjust their plans to mitigate the risk of increases in crime.

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