Cost-Effectiveness of CCTV Surveillance Systems: Evidence from a Polish City

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Abstract

Closed-circuit television (CCTV) surveillance has been increasingly popular worldwide as a crime prevention measure, while its effectiveness, efficiency, and related privacy issues are debated. In this paper, we investigated whether the municipal CCTV surveillance system is cost-effective in the case study of Poznan, Poland. The analysis comprised (a) the preventive effectiveness of CCTV, (b) costs of CCTV surveillance system installation and operation, and (c) costs of crime. We collected police data on three categories of street crimes: (a) car burglary/theft, (b) car damage, and (c) robbery, as well as data on the costs of CCTV surveillance system construction and maintenance. We searched for a year after installing the CCTV system when the accumulated, hypothetical financial cost of crime was higher than the actual accumulated cost of crime and CCTV installation and maintenance in any treatment area. The number of crimes in a given category was predicted based on a comparable control area, where there were no cameras. Our study suggests that CCTV surveillance is cost-ineffective in most areas. This result implies the cautious development of CCTV surveillance, taking into account the target crime types and costs, including social costs and benefits. Evaluating cost-effectiveness, although considered as a robust measure, is in practice difficult. However, analysis of the correlation between land use characteristics and cost-effectiveness may provide practical advice on where to develop CCTV surveillance monitoring.

Keywords Crime prevention · CCTV · Poland · Policy efficiency

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Introduction

Development of CCTV Surveillance

Although crime cannot be eliminated, innovative measures can be applied to cope with it, such as closed-circuit television (CCTV) monitoring. Among various situational crime prevention measures, CCTV has become a mainstream crime prevention method in public spaces in many countries across the world, but especially in Western nations (Armitage, 2002). For example, in 2006, the total number of public CCTV cameras in the UK was estimated to be 4.2 million, which was one fifth of all CCTV cameras worldwide. In the USA, local accounts indicate that CCTV cameras are installed at a high rate, and their popularity is not limited to large urban centers (Nieto, Johnston-Dodds, & Simmons, 2002; Savage, 2007). In 2015, half of all local police departments in the USA used CCTV (Reaves, 2015) in their day-to-day work. Its utility is also well recognized in Europe, Japan, China, and other countries (Welsh et al., 2015a, 2015b). The spread of CCTV has been enabled, thanks to technological progress that makes it cheaper to install and maintain.

CCTV in the Context of Evidence-Based Crime Policy

Notwithstanding the dynamic development of CCTV, there remain problems that were first raised 20 years ago, that commitment to and expenditure on CCTV is a matter of making unverified assumptions such as "security wish fulfillment," "blind faith in CCTV effectiveness," or "technological fixation" (Beck & Willis, 1999). Investing in CCTV can be validated via several criteria, such as measuring its effectiveness by monitoring any decrease in the number of crimes caused by installing CCTV surveillance cameras, which can be used to measure the benefits of CCTV systems. The research results on CCTV surveillance system effectiveness, although not univocal, support its preventive effects. However, these results can also enhance unjustified investment in this measure without taking into consideration other factors, such as the various categories of crime, that impact its effectiveness. It has been argued that policymakers investing in a public surveillance system should avoid reliance on such assumptions as well as on data provided by vendors and other interested parties (La Vigne et al., 2011). Although Welsh and Farrington (2004) claim that crime policies seldom rely on the basis of hard evidence, evidence-based crime prevention is needed to make informed decisions on tackling crime (Davies et al., 2000; Tonry, 2010). It requires independent evaluations (La Vigne et al., 2011; Welsh et al., 2008) using the highest-quality available data and methods of analysis to scrutinize the efficacy of crime prevention programs (Beck & Willis, 1999; Welsh et al., 2004, 2008).

In this spirit, the effectiveness of CCTV systems has been studied extensively in terms of their potential for reducing the number of crimes in certain areas (Lim, Kim, Eck, & Kim, 2016; Piza et al., 2019). However, those studies rarely take into account the intervention's cost or any savings that arise due to crime reduction, which is one of the key issues of evidence-based crime policy (Lawson et al., 2018).

In a cost–benefit analysis, the effects of an intervention are measured in monetary terms, allowing us to compare the outcome of the intervention with its costs. This approach is widely advocated (Marsh et al., 2008) and leads to justifiable public decision-making.

Case Study

This article assesses the cost effectiveness of CCTV monitoring systems, based primarily on data from Poznan, one of the largest cities in Poland. In Poland, municipal CCTV monitoring systems were developed after 2005, when in most Polish municipalities, few cameras were in operation. Those systems are constantly developing, embracing larger areas, more cameras, and improved monitoring centers (Lewandowski et al., 2015). Taking into account the eight largest Polish cities, the number of cameras in municipal CCTV systems increased from 35 in 2005 to 1447 in 2015 (Fig. 1).

The number of monitoring cameras in use in Polish cities has increased gradually. It appears that the development of urban monitoring systems usually takes place in stages, with varying numbers of cameras installed in successive years.

CCTV monitoring is not well regulated in Poland. Since the responsibility and maintenance of such systems rely on municipalities, local authorities have established them independently without any coordinative supervision. Therefore, every city has its own CCTV system organized differently. Usually, local authorities are responsible for establishing a monitoring system, and municipal guards monitor the camera recordings. The responsibility for these differs between cities, however.

CCTV surveillance monitoring has a good reputation in Poland (Waszkiewicz, 2012b). Its development benefits from public support as well as support from the police and local policymakers. Critics of CCTV refer almost entirely to the danger of privacy law violations. In this study, we focused on the cost-effectiveness of the municipal CCTV surveillance system in the city of Poznan. We relied on comparing the cost of camera installation and maintenance with the financial gains, i.e., the monetary value of avoided crime. A quasi-experimental procedure was applied to estimate the decrease in the number of crime incidents. The decrease was calculated based on the observed number of crime incidents in comparison areas where no CCTV monitoring was applied, as compared with treatment
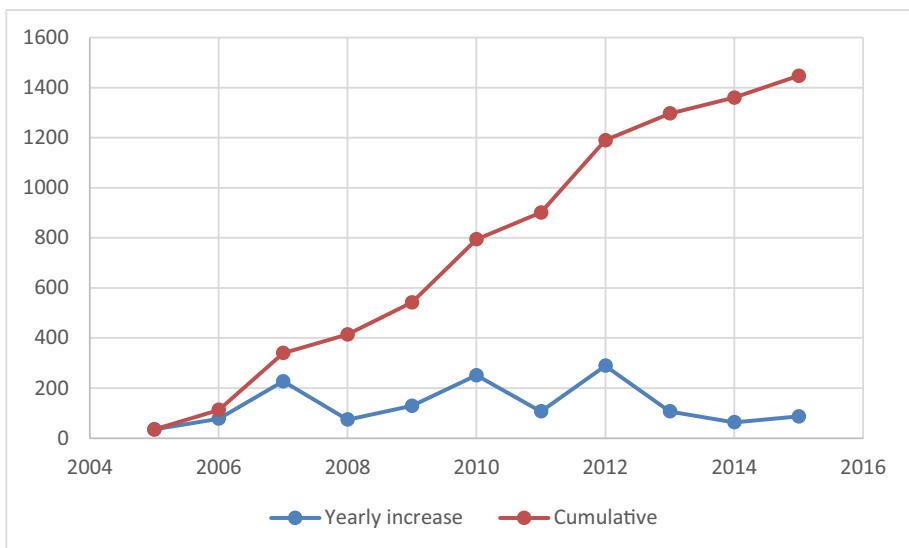

Fig. 1 Cumulative and yearly increase in numbers of cameras in municipal CCTV systems in eight Polish cities (Gdansk, Katowice, Kielce, Lublin, Lodz, Poznan, Warsaw, and Wroclaw)

areas. To assess the gains, the average cost of crime incident of each type was calculated based on police data. Our ultimate research objective was to determine if the financial benefits of CCTV monitoring (monetary value of crime decrease) exceed its costs (installation and maintenance).

Review of Previous Research

Although CCTV monitoring is continuously being developed, its justification is not straightforward. Evaluative studies concern its effectiveness, reflected in a decrease in the number of crime incidents and cost-effectiveness, taking into account the costs of building and operating CCTV surveillance systems and the monetary benefits of decreased incidents of crime.

CCTV Effectiveness

CCTV effectiveness requires quantifying the benefits of crime prevention, i.e., a decrease in the number of crime incidents. In most cases, the crime prevention function of CCTV surveillance systems seems to be apparent (Armitage et al., 1999; Caplan et al., 2011; Ditton et al., 1999; Farrington et al., 2007; La Vigne et al., 2011; Ratcliffe et al., 2009; Tilley, 1993). A systematic review of studies focused on CCTV surveillance systems (Piza et al., 2019) shows that, in general, CCTV is associated with a decrease in crime incidence. Several mechanisms can explain this effect (Tilley, 1993). Due to CCTV surveillance, offenders are more afraid of being caught, security personnel can be better allocated to improve police and security operations, and potential victims are more cautious due to visible cameras acting as a warning message (Pawson & Tilley, 1997; Welsh et al., 2009). The effects, however, seem to be uneven across the various types of crime and differing locations. Some studies offer ambiguous results, which depend on crime type and other contextual/environmental factors (Caplan et al., 2011; Gill et al., 2006; La Vigne & Lowry, 2011; Lim et al., 2016; Piza et al., 2014b; Priks, 2015; Sivarajasingam et al., 2003). For instance, CCTV's most extensive and most consistent effects were observed in car parks for area-specific crime types, whereas no significant effect was observed for violent crimes (Piza et al., 2019; Welsh et al., 2015a, b). It is claimed that a strategy of targeting hot spots with the highest crime rates has the greatest potential for maximizing the cost-effectiveness of interventions (Lawson et al., 2018). CCTV is more effective in reducing crime in the UK than in other countries (Piza et al., 2019; Welsh et al., 2008), and research results can vary significantly even between study sites within one country (La Vigne et al., 2011). This effect may be due to non-linear effects of CCTV monitoring; e.g., a crime prevention effect may be observed when a critical mass in terms of the number of cameras is exceeded. CCTV may also work best when deployed alongside other interventions, such as street lighting, security guards, place managers, and changes in the planning of the built environment (La Vigne et al., 2011; Lawson et al., 2018; Piza et al., 2014a, 2015). All of these factors can further complicate research in the crime prevention field.

Although it may seem obvious that CCTV monitoring systems create a preventative effect for most types of crime, the effect remains disputable or even treated as a myth (Gill et al., 2006; Gill & Spriggs, 2005; Webster, 2009; Welsh et al., 2004). This is due to two main reasons. Firstly, CCTV appears to have its own lifecycle and any initial reduction in crime incidents can fade over time (Armitage, 2002). Secondly, it is claimed that in

some cases, a CCTV system can even be related to an increased number of registered crimes within the area it is installed. There are several suggested reasons for this (Farrington et al., 2007; Welsh et al., 2015a, b): (a) cameras can lead to building a false sense of security among people; (b) CCTV can discourage people and the police from being vigilant; (c) it can increase the levels of recorded crime due to an increased capability to record offenses. Moreover, it can be difficult to isolate the causal effects of surveillance cameras on crime since cameras are often installed in areas which already have elevated crime rates (Alexandrie, 2017). This means that any observable effects (i.e., a decrease or increase in the number of crime incidents) can be explained theoretically, allowing researchers to commit confirmation bias (Phillips, 2011). Moreover, CCTV may also lead to a displacement effect when any offenders deterred by cameras move to other places to avoid the danger of being detected (Bowers et al., 2003; Brown, 1995; Cerezo, 2013; Fyfe et al., 1996).

Nevertheless, there are some methodological challenges in evaluating CCTV effectiveness. A few studies are based on crime incident numbers before and after the intervention (installation of CCTV cameras) in treatment and control areas and involve randomization, taking into account any seasonal variations (Armitage, 2002; Piza et al., 2019; Welsh et al., 2004). Moreover, the models built to simulate CCTV implementation in a given place of interest are simplified, based on the average effects on crime, and do not include many factors present in real life (Kruegle, 2006; Lawson et al., 2018). The small number of analyzed cases and the non-comparability of methods make it difficult to compare and generalize results or to state which type of crime prevention program is more effective (La Vigne et al., 2011; Welsh, 2001; Welsh et al., 2000, 2015a, b).

Few studies have dealt with the effectiveness of CCTV surveillance monitoring in Poland. Waszkiewicz (2010, 2012a) examined the impact of CCTV monitoring on the sense of security and victimization, based on a sample of 400 Warsaw residents living in two treatment (with cameras) and two corresponding comparison areas (without cameras). The survey results, conducted before the installation of CCTV and a year later, showed that the appearance of cameras did not increase their sense of security. Lewandowski and Matczak (2015) focused on the effectiveness of the CCTV system in Poznan. They examined three treatment areas monitored by CCTV cameras and compared crime incidence before and after the installation compared to comparison areas. Four car-related crime categories were analyzed. In all of the three areas, a preventive monitoring function was observed. The highest decrease in crime incidence was noted in the category of car burglary, while the lowest referred to the category of car theft (Lewandowski et al., 2015).

CCTV Cost-effectiveness

Although practitioners often treat the value of implementing CCTV surveillance as a straightforward case, attempts to scrutinize their cost-effectiveness appear to be a challenging task (Beck & Willis, 1999; Piza et al., 2019; Webster, 2009; Welsh et al., 2008, 2015a, b). Measuring costs and benefits in monetary terms offers a grounded rationale for applying crime-preventive measures. It is a highly recommended method of evaluating particular crime preventive measures and policies (Welsh et al., 2015). It has been applied in criminology (Domínguez et al., 2015), and the results of the research can offer justification for crime prevention measures. There are, however, several caveats concerning cost–benefit analyses. The main concern is the choice of the costs and benefits that will be assessed and their specific measurement. Some costs and benefits can be straightforward, while others

can be difficult to grasp. Notably, measurements based on contingent valuations, such as willingness to pay, are considered to provide uncertain results (Nagin, 2015).

Cost–benefit analysis is very demanding when it comes to the data needed to perform an analysis. Three main dilemmas appear when considering measurements of cost-effectiveness. Firstly, what costs and benefits should be taken into account? There are many social costs and social benefits, and not all can be included in such an analysis. Some need to be ignored due to lack of data or other reasons. Secondly, how should the costs and benefits be measured? Even essential costs and benefits are often difficult to estimate. Some costs and benefits are intangible. Methods developed to measure them, such as willingness to pay, are often criticized for their imprecision. Thirdly, how accurate are available data? Data on the number of crimes are not always easily accessible and can be subject to errors.

These difficulties apply to both the cost of CCTV and the cost of crime. The cost of CCTV can be defined in several ways. In this study, it is treated as the cost of system installation and maintenance, but it could also include costs of the judicial process or police force operations. La Vigne et al. (2011) claim that in cost–benefit analysis, the cost of the cameras themselves is minimal compared to the costs of installation, maintenance, and monitoring. However, the costs of CCTV include also unanticipated costs such as repairing vandalized cameras (La Vigne et al., 2011). Moreover, more advanced monitoring systems (technologically high-level cameras actively monitored by a supervisor) seem to be more cost-beneficial by reducing public loss covering capital expenditure (Beck & Willis, 1999; La Vigne et al., 2011).

Determining the cost of crime, understood as all costs that would not exist in the absence of illegal behavior (Anderson, 2012), is an important but debated issue (Wickramasekera et al., 2015). There are significant variations in crime cost estimations, due to changes in unit costs, changes in crime trends, and variations in the methods used to estimate costs. There can also be differences in the estimations of losses and what proxies should be used. The displacement effect should also be taken into account (Bowers et al., 2003). Assessing the impacts of CCTV can be difficult, as the quality and availability of data are often crucial issues that can hamper any analysis.

By taking into account various possible measures, existing studies about crime prevention policies provide an ambiguous picture of their cost-effectiveness. A review of 106 evaluations of criminal justice interventions (including CCTV) conducted by Marsh et al. (2008) shows that the size of any effect is weakly related to the net benefits. Gill and Spriggs (2005) present in their report an economic aspect of CCTV cost-effectiveness, measured by the ratio of costs incurred to the final results. However, the authors stipulate that the results of analyses cannot be simply interpreted in terms of "profitable" vs. "unprofitable." A meaningful comparative analysis assumes to express the ratio of expenditure to the results obtained.

Nevertheless, the value of the efficiency ratio of all the analyzed systems was low. This happened even in the case of the most effective system, whose installation resulted in an 82% reduction in car crime. A simulation by Lawson et al. (2018) shows that there are few situations where CCTV is more cost-effective in reducing street crime than a comparative measure of street lighting.

Besides the analyses of effectiveness and cost-effectiveness, CCTV systems are also assessed in terms of the potential violation of privacy and civil liberties, which appears to be a controversial issue. CCTV monitoring systems touch on several legal issues in relation to recording individuals (Welsh et al., 2004, 2009). Although privacy and civil liberties are not directly connected to cost-effectiveness, which is analyzed in this article, one should keep in mind that they are, indeed, a part of the social costs and are difficult to

measure (Dolan et al., 2007). Therefore, CCTV should not be perceived as a panacea for crime reduction, and it should never be assumed that it will reduce crime regardless of the broader context (Armitage, 2002).

Methods and Materials

Methods

Cost-effectiveness analysis examines the impact (effectiveness) of the expected reduction in crime incidents, expressed in monetary terms. The experimental method is widely advocated and applied for analyzing CCTV. It compares selected treatment (experimental) areas, where cameras are installed, against control areas, where cameras are absent. The randomized experimental design offers the most robust examination of the causal effect. However, it requires a careful design, which is seldom feasible. Instead, for cases where it is not possible to apply the randomized experiment, the difference-in-differences (DiD) analytical approach is often applied (Piza, 2016), an approach which enables researchers to detect the degree to which cameras had an impact on crime, in both the selected treatment (with cameras) and comparison (without cameras) areas. DiD relies on examination of the time series number of crime incidents in both areas, before and after the treatment, to determine the crime reduction effect of the cameras. The DiD method can be combined with the cost–benefit analysis by monetizing crime incidents (La Vigne et al., 2011). Attributing monetary value to costs of incidents and savings from avoided crimes, and adding the costs CCTV, allows for a causal analysis in monetary terms. To apply the DiD method, it is necessary to check if all conditions are satisfied. Notably, in our case, the assumption of parallel trends is not satisfied (see Section 3.3). Therefore, we propose an alternative approach inspired by the DiD method (La Vigne et al., 2011).

The economic costs and benefits of an intervention need to be taken into consideration, in order to analyze the cost-effectiveness of CCTV systems. The cost–benefit analysis aims to determine the cost of the costs of camera installation, use, monitoring, and maintenance, versus the money saved through prevented crimes (La Vigne et al., 2011).

Prevented crimes decrease their social costs, as the product of the number of avoided crimes (the difference between the actual and the counterfactual number of crimes) and the average cost of individual crimes. Several types of costs related to crimes are usually distinguished: (a) victimization costs; (b) individual security costs; (c) costs of prudential behavior; (d) costs of the justice system; (e) costs of public crime prevention programs; (f) and the price of the lasting effects on individuals, the community, and others (Brand & Price, 2000; Cohen, 2004). In this study, only financial victimization costs are taken into consideration, narrowed down to the costs related to damaged or stolen property. This is a simplification, stemming from limited data availability. Following La Vigne et al. (2011), in this study, the cost of the CCTV comprises initial implementation costs (installation) and recurring costs (technical maintenance) of the cameras:

$$\text{Costs}_{cctv} = \text{costs of installation} + \text{costs of maintenance}$$

It is hypothesized that installation of CCTV entails certain decrease in the number of crime incidents. The social benefit of the avoided crime is the product of the decrease in the number of incidents and unit cost per crime incident:

Social benefits = decrease in the number of crime incidents × unit costs of one crime incident

However, to justify the installation of a CCTV system, in terms of cost-effectiveness, the social benefits from the reduction of crime must exceed the costs of the CCTV system. The general assessment as presented above depends essentially on the estimation of social benefits, i.e., the reduction of the crime costs due to installation of the cameras. These benefits are presented in "Data," below.

Data

This study focuses on the city of Poznan, but initially, eight Polish cities were selected for the investigation: Gdansk, Katowice, Kielce, Lublin, Lodz, Poznan, Warsaw, and Wroclaw. They represented the largest Polish agglomerations, including the capital (Warsaw). Each of the cities had a CCTV system, but data on the costs of installation and maintenance, as well as data on crime incidents, were not continuously recorded. Therefore, we focused on the city of Poznan, as in this city the available data were the most exhaustive. Data from other cities are presented for comparison, where appropriate. For this study, cameras monitoring private areas, traffic, and shops were not taken into consideration, due to difficulties with obtaining data.

Selected Categories of Crimes

In this study, street crimes were taken into consideration because they are most strongly curtailed by cameras mounted to supervise public spaces, and are customarily used to analyze CCTV monitoring systems. We focus on three categories of street crimes: (a) car burglary/theft, i.e., car theft, theft from a caror breaking into a car; (b) car damage; and (c) robbery. This categorization and aggregation were driven by Polish Police crime records. Car burglary/theft records kept by Polish Police may fall into three categories: car theft, theft from a car, and breaking into a car. The data obtained from the National Police Headquarters did not distinguish between car theft, theft from a car, and breaking into a car, so we created a cumulative category for all of three. Another street crime category that is often used in studies on CCTV monitoring systems is "fights and beatings (street fight)," but no data were available on the number and cost of crimes related to this category in Poznan.

In the analysis, we used data on verified crimes (i.e., events that were identified as criminal offenses after the initial police investigation). Thus, the data did not include all of the events registered by the police, but only the criminal acts that were classified as criminal offenses in the investigation. Therefore, we did not include in our calculations the costs and benefits of all investigations. For instance, installing a CCTV camera may provide additional evidence during an investigation, helping to classify some of the incidents as a verified crime. Table 1 presents the numbers of cameras and crimes for the years 2008–2014.

Data on Costs of Crime

Information on crime costs was obtained from the National Police Headquarters. The data contained information on the total annual cost of crime per crime category, and the number of crimes in each category, which allowed us to calculate the average costs of a crime in a given category.

Table 1 Numbers of cameras and crime incidents in treatment (*T*) and comparison (*C*) areas in Poznan. The first camera in each treatment area was installed in 2010 or later. Three categories of crime are car burglary/theft, car damage, and robbery

Area ID	Street name	Statistic	2008	2009	2010	2011	2012	2013	2014
6 T	AlejaNiepodległości	Cameras installed	0	0	1	0	0	0	3
		All crimes	31	27	11	22	22	18	9
6C	Murawa	All crimes	18	12	9	13	3	6	4
7 T	Szamarzewskiego	Cameras installed	0	0	3	0	0	1	0
		All crimes	67	58	30	30	31	17	12
7C	Niedziałkowskiego	All crimes	10	20	12	10	7	9	7
8 T	Bułgarska	Cameras installed	0	0	0	10	7	0	0
		All crimes	16	17	25	13	14	15	18
8C	Murawa	All crimes	18	12	9	13	3	6	4
11 T	Kościelna	Cameras installed	0	0	1	1	0	0	0
		All crimes	8	16	16	15	23	9	8
11C	Chłapowskiego	All crimes	7	11	5	5	1	8	3
13 T	Polna	Cameras installed	0	0	3	1	0	0	0
		All crimes	67	32	14	14	6	2	3
13C	Sienkiewicza	All crimes	12	6	8	3	8	3	2
15 T	Rybaki	Cameras installed	0	0	0	0	1	0	0
		All crimes	11	18	9	16	15	11	15
15C	Łąkowa	All crimes	8	15	9	22	6	4	11
16 T	Szpitalna	Cameras installed	0	0	0	1	0	0	0
		All crimes	4	16	13	11	13	10	10
16C	Serbska	All crimes	13	11	11	10	10	16	10
17 T	Szwajcarska	Cameras installed	0	0	0	0	10	0	0
		All crimes	30	34	26	26	28	19	23
17C	OsiedleDębina	All crimes	14	17	7	13	19	12	15

For the "car damage" category, information detailed the number of crimes and the amount of total losses resulting from those crimes in the eight cities studied between 2005 and 2015. However, records kept on crimes committed between 2004 and 2012 were subsequently categorized differently. As a result, data from the category "car burglary/theft" turned out to be partly incomplete, i.e., until 2012, the files sent by the police contained all the data we requested, but were missing or incomplete for the years between 2013 and 2015, which made it impossible to directly include that time frame in our analysis. For the categories "car damage" and "robbery," only data covering the years 2005–2012 were obtained (Table 2).

In our analysis, the data from Poznan did not include information on the costs and number of "car burglary/theft" and "robbery" crimes for the years 2013 and 2014, while data on the "car damage" category was available for these years. To compensate, we conducted an extrapolation with a second-degree polynomial in order to estimate the missing data (Appendix 1).

Table 2 Costs of a single crime across ears with respect to its type (in USD, inflation adjusted)

Year	Car damage	Robbery	Car burglary/theft
2008	607	123	3777
2009	536	286	3889
2010	671	270	4310
2011	508	365	5051
2012	747	543	5927
2013	331	475	6890
2014	410	501	8113

Data on Costs of CCTV

Two categories of costs were considered in this study: implementation — the cost of installing cameras during the 2005–2014 period — and maintenance, which is a yearly cost estimate. There is no systematic public record of these costs in Poland. Within municipal budgets, the CCTV costs are allocated to different categories of budget expenditures, depending on local regulations and public task allocations. The request for access to data on costs was sent to the municipal entities responsible for the eight cities' CCTV systems. However, the administrative bodies of the cities provided data on costs aggregated to various periods. In some cases, these were yearly data, while in others, they were aggregated for several years (Table 3).

The data on the maintenance costs of the CCTV systems were provided for different periods (Table 4), but only data for the city of Poznan was available for two or more consecutive years.

Determination of Costs of Installing Cameras and Their Maintenance The installation cost per camera in Poznan varied considerably between years (Table 5).

Therefore, the average cost was calculated over a 3-year period. For personnel and technical maintenance costs, the total amount was divided by the number of cameras operating in the system. The missing data for 2013 and 2014 were estimated as follows: (a) we assumed the installation costs to be the same as in previous years; (b) we assumed the same personnel costs for both years, since the same number of people were able to support the newly installed cameras in 2013 and 2014 (i.e., personnel costs showed that employment

Table 3 Costs of installation of CCTV surveillance systems in Polish cities (in USD). In Bold: data for Poznan, taken for the final analysis. Data for Lublin are not available

City	Total cost of installation	No. of installed cameras	Period	Average cost per camera
Poznan	**2,203,640**	**212**	**2010–2012**	**10 395**
Lodz	2,070,794	269	2009–2017	7 698
Warsaw	15,411,324	458	2002–2015	33 649
Wroclaw	2,040,328	103	2009–2013	19 809
Kielce	303,352	176	2010–2015	1 724
Katowice	85,621	5	2017	17 124

Table 4 Maintenance cost of CCTV surveillance systems (in USD). In Bold: data for Poznan, taken for the final analysis. Data for Warsaw, Wroclaw, Kielce, Katowice, and Lublin are not available

City	Technical maintenance costs	Salaries of employees	Period	Total cost per year
Poznan	**226,130**	**1,018,961**	**2010–12**	**415,030**
Gdansk	57,999	442,597	2016	500,596
Lodz	28,106	306,157	2016	334,263

Table 5 Installation and maintenance (personnel and costs of the technical maintenance) CCTV system in Poznan (in USD)

Year	Cameras installed	Installation cost	Personnel cost	Technical maintenance cost	Cost per camera
2010	19	1,362,180	264,416	71,866	89,393
2011	32	316,821	379,221	61,372	23,669
2012	161	524,639	375,325	92,891	6167

Table 6 Costs of installing and maintaining the monitoring systems per camera in the municipal CCTV system in Poznan (in USD, inflation adjusted)

Year	Installation cost per camera	Personnel cost per camera	Technical maintenance cost per camera
2010	11,639	1898	516
2011	11,344	2201	356
2012	10,876	1125	278
2013	10,488	963	268
2014	10,394	867	266

increased in 2011 but not in 2012, despite the installation of new cameras, so, the same amount of money was spent on personnel). With the increase in the number of cameras, the personnel cost per camera decreased in subsequent years (Table 6).

Steps of the Analysis

The analytical procedure comprised four steps (Fig. 2), presented in detail below.

Selection of Treatment and Comparison Areas

In the first step, the treatment areas (with CCTV cameras installed) and their respective comparison areas (without CCTV cameras) were selected.

In spatial crime analysis, the exact place of an incidentis the most accurate type of data (Cerezo, 2013; Lim et al., 2016; Piza et al., 2014a; Ratcliffe et al., 2009). However, in our study, the locations of crime incidents were aggregated to the street level. Thus, the lowest possible level of analysis (without a complicated disaggregation of the data, which is prone to error) was the street level. This forced us to apply a special method to identify the treatment-comparison pairs of streets. To do so, we used a method developed by
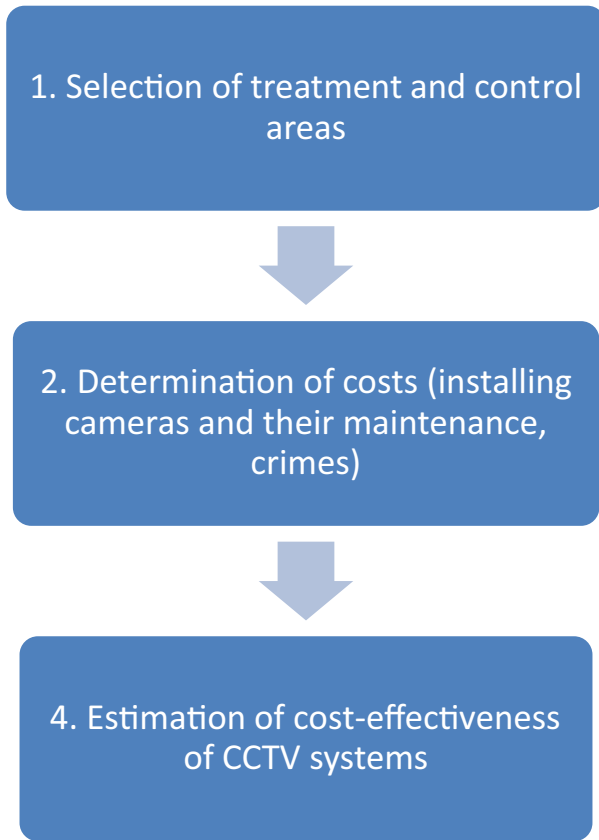
Fig. 2 Steps of the analytical procedure

Dąbrowski et al. (2018). In essence, a comparison area should be as similar as possible to the treatment area, excluding the intervention. Since it was difficult to establish all of the variables that should be included in calculating the similarities between any two areas, only two factors have been included: (a) similarity of crime time series prior to the intervention and (b) similarity of land cover. Both similarities have been calculated as the standardized, inverse Euclidean distance between the two factors (time series of crime incidents aggregated monthly, and land cover treated as percentage covered by distinguished land cover classes). The final comparison area was always the one with the smallest Euclidean distance to treatment areas, in terms of both factors.

If the distance to any of the two factors exceeded three standard deviations from the mean of distance distributions, we excluded that area as being too different, hence incomparable to the treatment area. The treatment areas for which it was impossible to find a suitable comparison were excluded from further analysis. We also excluded the streets where cameras were installed intermittently over a longer period (which made it more difficult to assess the impact of the intervention), as well as streets where the cameras were installed at the end of the analyzed period, which did not leave sufficient time (at least 2 years) for an analysis of the impact of the intervention. Moreover, only areas that had the first camera

installed in 2010 were included in the analysis. The treatment and comparison areas, with the number of crime incidents per category of crime, are presented in Table 1, above.

Estimation of Camera Installation and Maintenance Costs, Versus Cost of Crime Incidents

Costs of installing and maintaining of cameras, as presented in "Data on Costs of CCTV" above, comprise the initial investment and further maintenance costs. The costs are straightforward, comprised of an initial investment that is paid back by the following social benefits, which accumulate over time. The social benefits are more difficult to estimate. In principle, they can appear the next day after the installation. However, we obtained number of crime incidents aggregated to years. Therefore, we take as a reference the number of crime incidents in the year before the installation, not taking into account which exact date the camera was installed (a simplification of the scenario).

Furthermore, to estimate the size of the effect, we take the comparison areas for reference, by controlling the relative change in the number of crime incidents occurring in the treatment areas. This estimate is presented in detail in the following section.

Examination of Cost-effectiveness of the CCTV Systems in Treatment Areas

To examine the cost-effectiveness of CCTV systems in treatment areas, we looked for evidence of any "pay back" of the installation and maintenance costs, taking into account the benefits. As we mentioned in "Methods," a common method of estimating this effect is the DiD method, which assumes, among other things, parallel trends before intervention. In our case, there are different years of camera installation in each experimental area. Following the comprehensive DiD methodology by Callaway and Sant'Anna (2021), we verified whether the assumption mentioned above is satisfied in our data (Fig. 3).

In our case, not all confidence bands cover zero, point-wise, for all pre-treatment periods. The Wald test ($p < 0.001$) also indicates that the assumption of parallel trends is not met in our case. We can check how the total costs related to crimes (i.e., the number of crimes multiplied by their unit cost) differ across areas and years. Among the treatment areas, the moments of the first intervention (i.e., installation of the first camera) were 2010, 2011, or 2012. For each such area group, the average treatment effect (in thousands of USD) in subsequent years was estimated. Under the null hypothesis of the parallel trends assumption, the pre-treatment years should be equal to zero. As mentioned above, in our case, not all confidence bands cover zero in all pre-treatment periods. Therefore, the DiD method cannot be applied directly, and we applied an alternative, simplified method that draws inspiration from DiD and follows the methods applied by La Vigne et al. (2011). We searched for a year after the CCTV systems' installation when the counterfactual accumulated cost of avoided crime was higher than the actual (real) accumulated cost of crime and the initial investment in cameras in any treatment area. The counterfactual cost arose from crime, but after installing the first camera, the number of crimes in a given category was predicted based on the comparison area, where there were no cameras. From a comparison area, we derived the percentage change in the number of crimes, year-by-year. If there were no crimes in a given year in a given category, we set that category to a value of 1, so that we were able to calculate the percentage change. Thus, if the number of crimes increased by a certain percentage, year-by-year, in the comparison area in a given category, it was assumed that the situation would be similar in the treatment area.
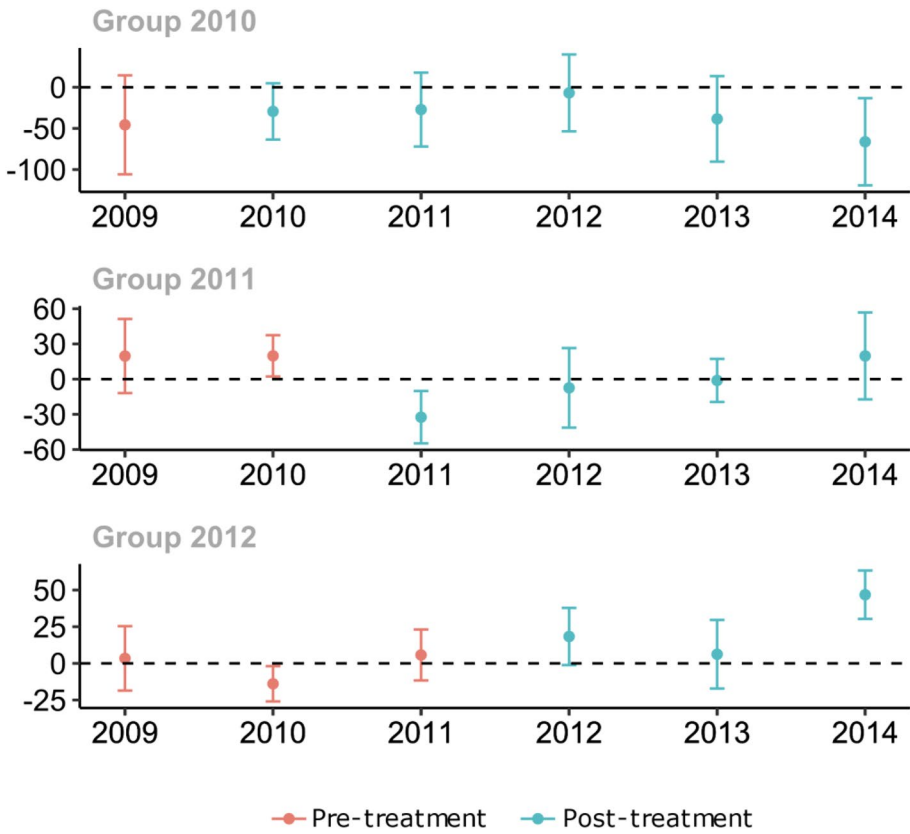
Fig. 3 Group-time average treatment effects for DiD method

The formulas below present the logic of the analysis.

$$R_k^{i,j} = I^i + k \cdot M^i + C^j \cdot \sum_{l=1}^{k} r_l^{i,j}$$

$$H_k^{i,j} = C^j \cdot \sum_{l=1}^{k} h_l^{i,j}$$

where:

i = treatment–comparison pair.

j = category of crime.

k = number of years after installing cameras; k ≥ 1.

K^i = a set of possible numbers of years after installing cameras in the i treatment area; k ∈ K^i

I^i = cost of installing cameras in the itreatment area.

M^i = cost of maintaining cameras for one year in the i treatment area.

C^j = cost of one offence from the jcategory.

$r_k^{i,j}, h_k^{i,j}$ = number of actual and counterfactual crimes (respectively) from the j category in the k year after installation of camera in the i treatment area.

$R_k^{i,j}$ = cumulative actual cost of jcategory crime in the year after installation of cameras in the i treatment area,taking into account the installation and maintenance costs of the cameras for k years.

$H_k^{i,j}$ = cumulative counterfactual costs of crimes from j category in the k year after installation of cameras in the *i* treatment area.

We looked for the year of return on investment in the *i* treatment area for the *j* crime category, i. e., for a year after installing $k_0 \in K^i$, when $\forall \ \forall_{k \geq k_0} H_k^{i,j} > R_k^{i,j}$

Results

In the city of Poznan, between 2006 and 2013, cameras were installed on 106 streets (excluding the cameras installed during periods of one year prior and two years after the intervention). After excluding from our analysis the streets with less than two cameras per street kilometer, eight pairs of treatment areas (with cameras) and comparison areas (without cameras) were selected. The following graph depicts the cumulative costs of actual crime incidents and their counterfactual costs — i.e., what the cost would probably have been, had no cameras been installed (Fig. 4).

Curves illustrate that the cumulative counterfactual cost does not intersect the actual cost curve for the eight areas, jointly. Moreover, fitted linear regression models show that the curves are divergent. Thus, considering the three categories of crime in the study period, the CCTV system appears to be cost-ineffective, in general. The yearly and cumulative costs, divided into components, show that the counterfactual costs are smaller than the actual costs in all the years (Fig. 5). However, the difference decreases over time.

Considering the treatment-comparison pairs separately, the comparison revealed that the CCTV system was cost-effective in only one of the eight treatment areas (Szpitalna, see Fig. 6) and close to cost-effective in three areas (Szamarzewskiego, Polna, and Rybaki). The graphs show remarkable variation between areas in terms of cost-effectiveness (the difference between actual and counterfactual costs): in some graphs, the curves converge, while in others they diverge.

Fig. 4 Cumulative actual CCTV system and crime costs and counterfactual crime costs in treatment areas in the City of Poznan (in USD); dashed lines present fitted linear regression model ($\beta_{actual} \approx 0.70$, $\beta_{counterfactual} \approx 0.49$; slopesdiffer with significance $p = 0.001$)
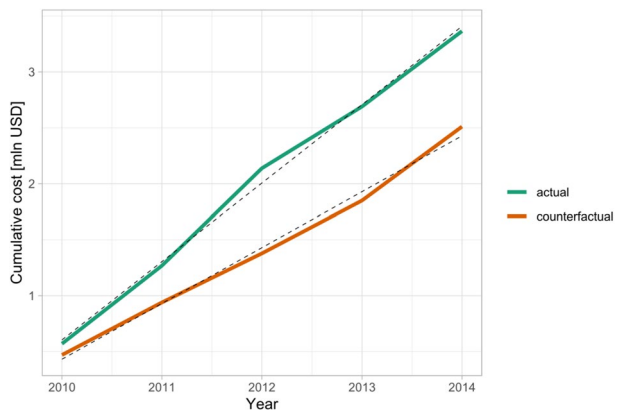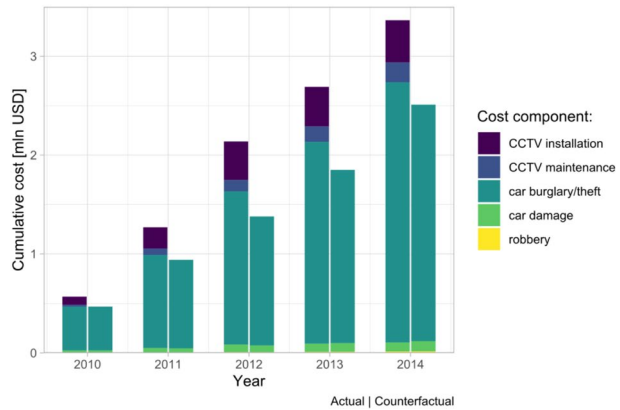
Fig. 5 Actual crime and CCTV system costs and counterfactual crime costs in all treatment areas in Poznan compared
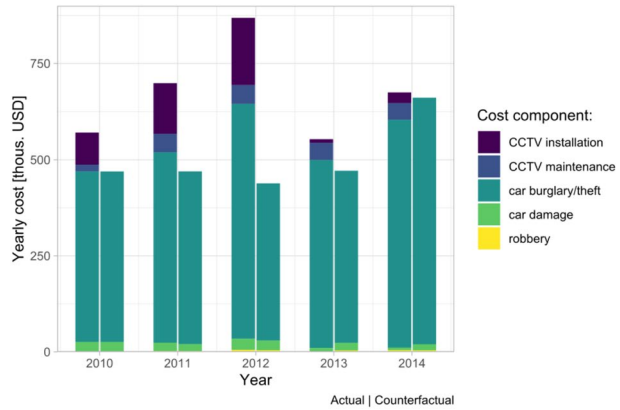

a) yearly

b) cumulatively

When cost-effectiveness was analyzed for all the treatment areas jointly, the difference between the cumulative actual and counterfactual costs peaked in 2013 and descended in 2014 (Fig. 7).

Cameras in treatment areas were installed in different years, so it is possible to see how crime costs evolved x years before the intervention, i.e., installation of the first camera, and x years after the intervention (crime costs and camera installation and maintenance). Figure 8 shows the median costs for each year in a treatment area and the median costs within pre-intervention (68,328 USD) and post-intervention (75,649 USD) periods. Statistics are for medians, due to the small amount of available data, particularly at the beginning and end of the graph.

Discussion and implications for policy and research

CCTV has become a mainstream crime prevention method in public spaces. In this section, we assess the CCTV cost-effectiveness in Poznan, Poland, and discuss existing difficulties in measuring and providing lessons for the implementation of CCTV systems. These
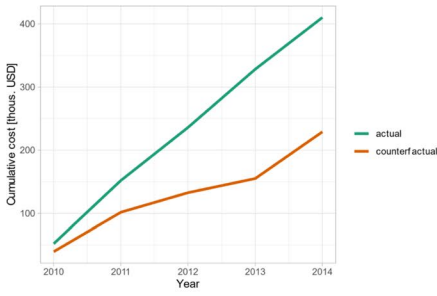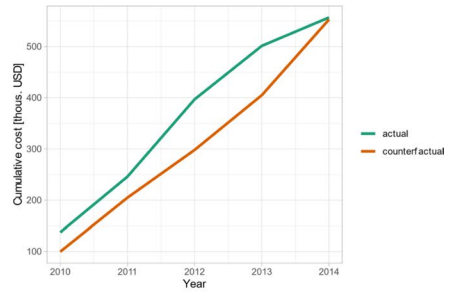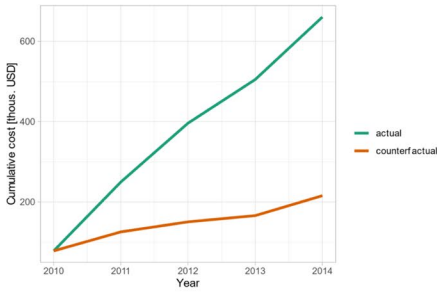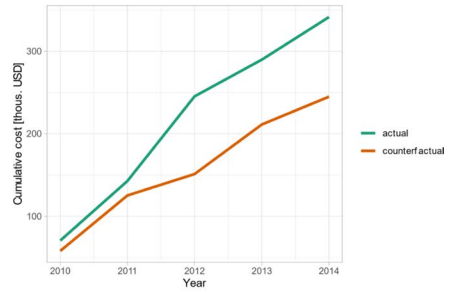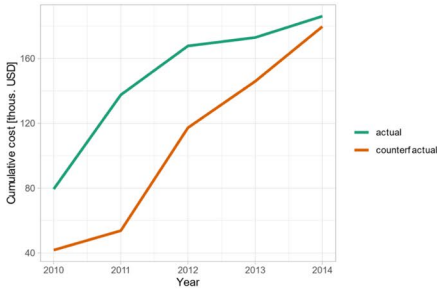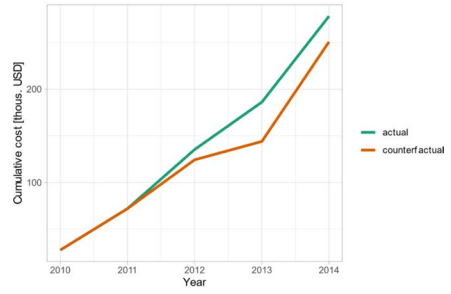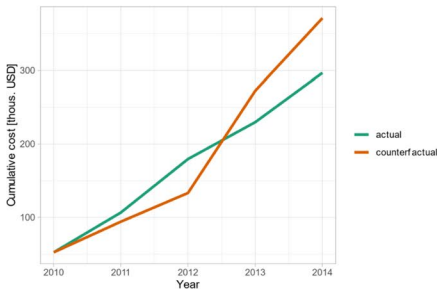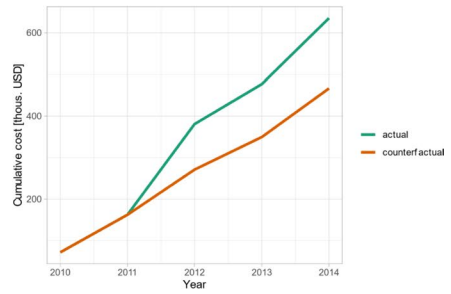
Fig. 6 Actual crime and CCTV system costs and counterfactual crime costs in all treatment areas in Poznan compared cumulatively
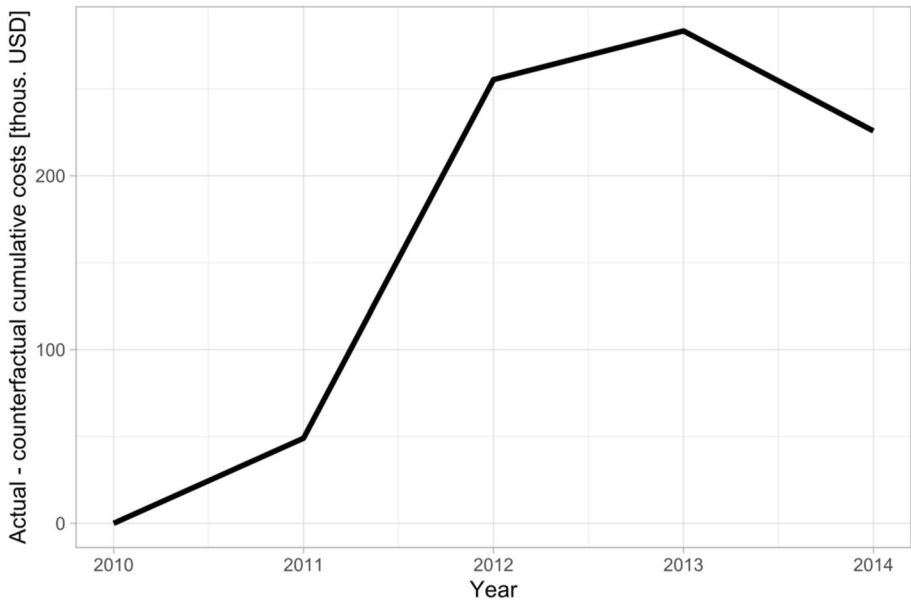
Fig. 7 Difference between the cumulative actual and counterfactual costs in all treatmentareas in Poznan
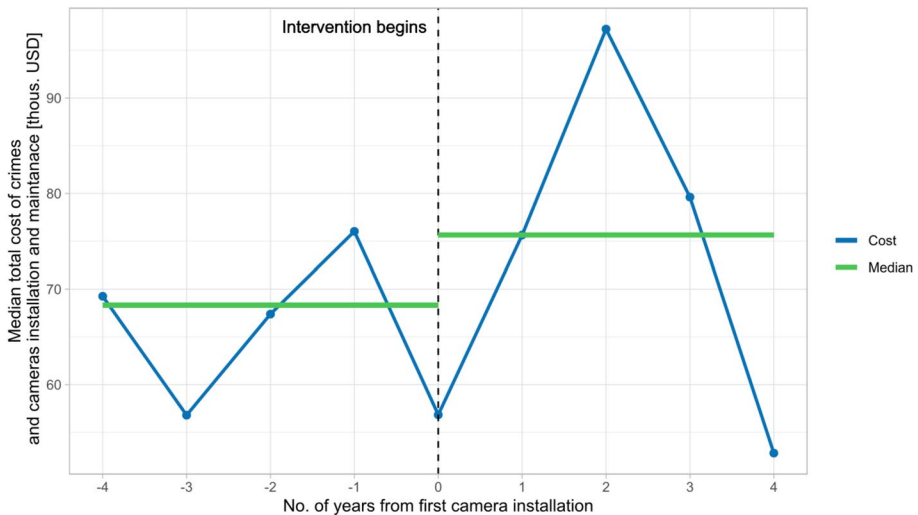

Fig. 8 Costs of crimes and cameras installation and maintenance in relation to the installation of the first camera

issues are particularly crucial, as further development of CCTV is claimed to be necessary for tackling crime (Skogan, 2019), and evidence-based public policies are advocated. However, such efforts are inseparably connected with the allocation of resources obtained by the municipalities from taxpayers' money. Besides directional assumptions, reliable empirical data on cost-effectiveness are needed. Data analytics, like the ones presented in

this article, can form the basis of a broader evidence-based policy-making framework, and regular evaluation of any interventions can inform future policy-making decisions.

Why Does CCTV Surveillance Monitoring Require Evaluation?

CCTV surveillance is, as a rule, viewed positively worldwide. Over the last 25 years, CCTV monitoring as a measure for crime prevention and improving security has become a common practice in many places. In Poland, as in many other countries, CCTV is supported by the local authorities, promoted via media, and is largely welcomed by the general public. Despite some criticism of the potential privacy violations, and doubts concerning the actual impact on crime prevention, the number of cameras in Polish cities continues to increase. Local governments build their CCTV surveillance systems independently, applying different technologies and various organizational schemes. Poland's case can serve as an interesting example, as CCTV developed from a diffusion of a security technologies first tested in other countries. Despite 20 years of experience in using CCTV in Poland, its implementation is still based on assumptions and inertia, but not on evidence. CCTV's effectiveness and cost-effectiveness are taken for granted, and its implementation is constantly pushed by experts, regardless of the importance of the local context. Therefore, local authorities face hard choices.

On one hand, local authorities are under public pressure to use CCTV. On the other hand, they do not have the tools to assess CCTV economically. It is noteworthy that cost-effectiveness can be measured in absolute or relative terms. In the latter analysis, the costs and benefits of a CCTV surveillance system are not fully weighed, yet the costs of alternative measures are taken as a reference (Gill & Spriggs, 2005). Furthermore, the decision on whether or not to implement a CCTV system does not necessarily rely solely on cost-effectiveness. Other issues, such as an inclination to strengthen the subjective sense of security of the citizens, may take prominence in the local authorities' decision-making process. Nevertheless, implementation should be a conscious choice.

What Are the Lessons from Evaluating CCTV Surveillance Monitoring in Poland?

Measuring cost-effectiveness, although considered to be a robust measure for evaluating public policies, is in practice difficult, due to multiple complications. First, access to crime data and their reliability varies significantly among countries. Data on crimes and on CCTV cameras are, in principle, available in Poland, although they are not always easy to access. Moreover, although police data are relatively available, their quality is limited. Changes in crime classifications, in database structures, and in data aggregation can impact analyses. In terms of data on camera location and costs, there are significant differences between cities. Second, measurement is difficult due to timing: there is a coincidence between the development of CCTV systems and a general decrease in Poland's crime levels after 2005. However, there is no evidence of a *causal* relationship between CCTV and decreased crime rates. Yet this coincidence has effectively been treated as handy proof of CCTV's measured utility. Third, our analysis provides specific evidence, but it does rely on several assumptions and simplifications. These cannot be easily solved, and the absence of available data can discourage municipalities from efforts to evaluate the cost-effectiveness of CCTV, since the results cannot rely on a unified methodology, and cannot offer clear results.

However, this research shows that, despite the limitations in terms of data availability and quality, calculations can be performed and provide evidence to the cost-effectiveness of CCTV systems. Nevertheless, city-to-city comparisons in terms of cost-effectiveness, although they would be informative, would be difficult to conduct in reality. Due to limitations in terms of data and local conditions, one-city analyses appear to be more feasible.

Implications for Further Research

Our research results suggest that CCTV may be profitable in one location and unprofitable in another. Further explorative analysis could focus on detecting land use characteristics and crime categories that correlate with cost-effectiveness. Such analyses would be instrumental in the optimal localization of cameras. It could also be practical from the municipalities' perspective. This study has limitations in several respects, and further studies could contribute to a more comprehensive approach to evaluating CCTV surveillance monitoring. First, although the three categories of crime considered in our analysis are known for their susceptibility to CCTV surveillance, the cameras' deterrent effect also applies to other crime categories. Thus, the actual effect, in terms of cost-effectiveness, may prove to be more significant if other categories of crime and social costs and benefits are included in the analysis. Second, the effect of the specific location of the cameras, in areas of higher crime rates, requires attention in future studies, due to the aforementioned street selection issue (see "Selection of Treatment and Comparison Areas," above). Third, the crime costs applied in this study have been simplified. Thus, more precise data or a combination of different types of data could improve our understanding of CCTV's preventive effect.

Data Availability Data are available from authors upon request.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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