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Review Article

Vacant lot remediation and firearm violence – A meta-analysis and benefit-to-cost evaluation

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HIGHLIGHTS

- Firearm violence is a complex issue and no single policy will resolve it.
- By reducing more than 5% in incidents, vacant lot remediation plays a robust role in controlling firearm violence.
- Cost savings from lowering firearm crimes can recover between 9% and 23% of greening expenses.

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ABSTRACT

Our objectives were to synthesize the early evidence regarding the effect of city-wide vacant-lot remediation programs on firearm violence and to determine what proportion of remediation costs are recovered from reducing firearm violence. Building on our scoping review, we conducted a meta-analysis of before-and-after studies with control groups. We then assumed three hypothetical cities of small, medium, and large populations and performed a probabilistic benefit-to-cost analysis over 30 years.

Eight studies met our eligibility criteria. Interventions included mowing (n = 3), greening (n = 5), and gardening (n = 2), with two studies examining two different interventions. The pooled effect size did not show reduction in firearm violence by mowing vacant lots. However, greening and gardening interventions reduced firearm violence by 5.84% (95% CI: 7.89–3.79%) and 5.34% (95% CI: 7.74–2.93%) respectively. Greening programs were the most cost-effective intervention and cost savings from reducing firearm violence can recover an estimated 8.17% (95% CI: 8.11–8.23%), 10.20% (95% CI: 10.12–10.28%), and 21.06% (95% CI: 20.90–21.23%) of intervention expenses, equating to the net annual per capita costs of $64.53 (95% CI: $64.09–$64.96), $51.88 (95% CI: $51.53–$52.25), and $30.97 (95% CI: $30.73–$31.22) in the small, medium, and large cities respectively.

While vacant lot remediation programs can play a robust role in controlling firearm violence at lower per capita costs than law enforcement polices, cost savings from reducing firearm crimes by itself does not recover all program costs. However, health and environmental benefits of such programs can offset the greening and maintenance costs.

1. Introduction

Despite the declining rate of violent crime since 2000 (Federal Bureau of Investigation, 2020), the United States has considerably higher mortality rates from firearm homicide and suicide compared with other high-income countries (Wintemute, 2015), with a gun homicide rate about 25 times higher in the US (Grinshteyn & Hemenway, 2016). In addition to public health consequences and the familial and community trauma, costs associated with medical and mental health care, work time loss, lost productivity from premature death, and diminished quality of

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life makes firearm violence a huge burden to the US economy. Annual costs from firearm injuries are estimated to be as high as 201 billion in 2020 US Dollar (USD) (Miller, 2012), with medical and work loss costs amounting to 52 billion 2020 USD (Fowler et al., 2015).

Steps to prevent gun violence in the US have primarily focused on legislative efforts, but scientific literature has emerged in the last decade which evaluates the effectiveness of programs that do not depend on state or federal legislation or law enforcement (Branas et al., 2020). A growing number of studies are focusing on the context within which violence occurs and examining place-based interventions in neighborhoods to prevent violence (Branas et al., 2017). Blight remediation of land, which entails the cleaning and greening of vacant parcels, is found in most studies to significantly decrease gun and other forms of violence (Kondo, Andreyeva, et al., 2018). Recent reviews of the impact of urban green space on human health identified multiple mechanisms that may account for such effects, including the impact of increased social interaction and recreation, stronger sense of community, biophilic stress reduction, improved climate modulation, and spaces expressing territorial definition (Shepley et al., 2019; Sivak et al., 2021). Additionally, when it comes to the effect of the physical environment, cleaning and greening of vacant parcels interrupt one of the key mechanisms of firearm violence by remediating spaces that otherwise could be used for hiding, storing, and dumping illegal guns (Branas et al., 2011). A number of older industrial cities in the US, such as Philadelphia, PA (Branas et al., 2011, 2018; Macdonald et al., 2021; Moyer et al., 2019); Youngstown, OH (Kondo et al., 2016); New Orleans, LA (Kondo, Morrison, et al., 2018); Milwaukee, WA (Beam et al., 2020); and Flint, MI (Heinze et al., 2018; Sadler et al., 2017) have initiated vacant lot remediation (e.g., cleaning, mowing, greening, and gardening), which has been shown to reduce violent crime. Similar to many other US cities with rich historical heritages, a common characteristic of these cities is that since the 1960s, post-industrial economic decline, job loss, disinvestment, suburbanization, and population migrations have led to a surge in the number of vacant lots and abandoned structures (Torey & Alison, 2017). In 2011, a group of policy makers proposed the term "legacy cities" to describe municipalities larger than 50,000 people with higher than 20% population loss (Mallach & Brachman, 2013), and this term has since been used to advocate for policies aimed at revitalization. In 2010 census data, more than 60 cities across the US met this definition (Griffin et al., 2015), highlighting the national-level implications of blight remediation efforts for controlling violent crime in general and firearm violence, specifically.

Meanwhile, conventional market-based policies to fund remediation efforts have proved to be unsuccessful as the surplus of blighted vacant lands and structures depresses property values and tax revenues that deter reinvestment (Schilling & Logan, 2008). Documenting tangible benefits of vacant lot remediation efforts and estimating financial savings from such efforts may encourage the engagement of policymakers, residents, and public and private stakeholders.

The goal of this study was to conduct a meta-analysis and quantitatively synthesize existing evidence on the impact of vacant lot remediation on firearm violence; estimate the amount of firearm violence that can be prevented by vacant lot remediation in legacy cities; and perform a benefit-to-cost analysis of vacant lot remediation and maintenance based on estimated firearm violence-prevention effects. The purpose of our benefit-to-cost analysis was to determine what proportion of intervention costs can be recovered just from reductions in firearm violence. Our study excluded self-harms and suicides.

2. Methods

2.1. Meta-analysis

This study builds on our previous scoping review of the impact of urban green space on violent crime in urban environments (Shepley et al., 2019). We followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist in our scoping review. Articles written in English, published since 2000, and covering research in urban areas (not rural or suburban) within the United States were eligible for inclusion. Using the EBSCOhost research platform, a joint search was performed on PsycINFO, Academic Search Premier, and Greenfile. Sociological Abstracts and ProQuest Dissertations and Theses–Global were searched jointly using ProQuest. After multi-step screening of 14,520 articles, we included 45 peer-reviewed articles in the scoping review. Green space in these studies included parks, community gardens, vegetated streets, trees, and developed or undeveloped ground covers. From the 45 peer-reviewed articles, in the current study we included only before-and-after studies with control groups. We excluded cross-sectional studies as it is not possible to assess whether introduction of urban green space contributes to firearm violence or vice versa.

From each eligible study we extracted relevant crime rates (number of crimes observed per square mile) for the control group (pre- and post-remediation) and intervention group (pre-remediation). To seek clarification and obtain additional information, we contacted the authors of the original study when necessary. We extracted data using a customized Excel spreadsheet. After gathering all the required data in this spreadsheet, we divided the crime rates of each study by the corresponding observation periods to get the monthly number of crimes observed per square mile. Next, we calculated the post-remediation crime rate for the intervention group by applying the estimated effect size of the intervention to the three crime rates extracted from each study. Using the adjusted effect size, the post-remediation crime rate accounted for the effect of confounding variables included in each study. Using crime rates for the intervention and control groups before and after the remediation, we calculated a difference-in-differences (DID) coefficient for each study. Finally, because the baseline crime rate pre-remediation was different across studies, we normalized our DID coefficients by dividing them by the pre-remediation crime rate in the control group. We repeated the last two steps using the confidence intervals (CIs) reported in each study and calculated CIs and standard errors for our DID coefficients.

We used fixed-effects models in pooling estimates from only two sources, or when Cochran's Q statistic indicated that we could not reject the null hypothesis that all studies evaluated the same effect (Cochran, 1954). Otherwise, we used a random-effects model. To determine the level of heterogeneity between studies we used the I^2 statistic (Higgins et al., 2003). We used the 'metagen' function from the 'meta' package (version 4.18-2) (Balduzzi et al., 2019) in R (version 4.1.0) (R Core Team, 2021).

2.2. Benefit-to-cost analysis

After pooling the effect size for the impact of vacant lot remediation on firearm violence from studies that met inclusion criteria, we performed a benefit-to-cost analysis. We classified cities using size categories commonly used in studies of US legacy cities (Griffin et al., 2015; Mallach & Brachman, 2013; Torey & Alison, 2017) and considered three hypothetical legacy cities of small (fewer than 100,000 residents), medium (between 100,000 and 300,000 residents), and large (more than 300,000 residents) sizes. Performing separate analyses by size was necessary given that such factors as population density, location, and the total area of land to remediate (economy of scale) impact costs and benefits. We estimated representative characteristics of each of our three hypothetical cities using external evidence (national databases and peer-reviewed articles) from a set of legacy cities in the US. We used city-level sample-specific data on land area and crime rate. We constructed cost-related variables (crime and intervention costs) using national-level averages, although the intervention cost is based on sample-specific size and location modifiers.

We selected an analysis period (time horizon) of 30 years, which is the lifecycle commonly expected for urban green infrastructure

(Martineau Geneviève & Samson, 2012; Smetana & Crittenden, 2014). We performed an incremental analysis with no remediation as the base scenario, considering the added costs and benefits of the case scenario in which vacant lots are remediated and maintained. Benefits in the analysis include expenses avoided by reducing firearm violence over the 30-year analysis period. We used the study by McCollister et al. (2010), which estimated the cost to society of individual crimes for policy and program evaluations. McCollister et al. provided an estimate for various components of crime costs, including tangible components (victim costs such as medical expenses, criminal justice system cost, crime career costs such as opportunity costs associated with the perpetrators of crime) and intangible components (victim's pain-and-suffering cost, cost associated with victim's lost productivity and lifetime earnings). Depending on the crime category (unreported incidents, reported incidents leading to criminal court cases, and fatal incidents leading to the loss of life), all or some of these cost components are incurred. Previous studies of vacant lot greening programs, including Philadelphia's return-on-investment analysis by Branas et al. (2016) have used crime costs reported by McCollister et al.

Given the size of city-wide vacant lot remediation projects and resource limitations we assumed that it takes an average of 20 years to remediate all vacant lots. During this 20-year period, reductions in firearm violence is proportional to the ratio of vacant lots that are greened. We assumed that once the remediation program starts, the number of new lots that become vacant each year is cancelled out by the number of vacant lots that are repurposed, keeping the total number of remediable vacant lots unchanged. For example, if in a certain year 100 lots across the city become vacant and eligible for remediation, 100 old vacant lots that were in the remediation program are converted to a parking space or a commercial or residential facility. This assumption is made to account for the fact that city land use pattern is dynamic and changes over time.

We estimated the number of firearm crimes, both reported and unreported, that can be prevented, because nonfatal firearm violence can be about 39% of reported crimes (Planty & Truman, 2013).

We used the following standard equation to calculate the present value of future costs and savings and estimate the benefit-to-cost ratio from a tax-payer perspective (Washington State Institute for Public Policy, 2019):

$$B/C = \sum_{t=1}^{30} \frac{B_t}{(1+i)^t} \Big/ \sum_{t=1}^{30} \frac{C_t}{(1+i)^t} \tag{1}$$

B/C = benefit-to-cost ratio
t = year
B_t = Benefits (cost savings) from firearm violence prevention at year t
C_t = program costs at year t
i = discount rate

The starting year of analysis was assumed to be 2020 and all future costs and benefits were converted to 2020 USD. Given that our estimates for parameters that impact costs and benefits come from data on a sample of legacy cities, we assigned a probability distribution to all variables to account for the extent of uncertainty around their true values. For the discount rate, we followed previous crime-related benefit-cost models (Washington State Institute for Public Policy, 2019) and used a triangular probability density distribution, with the low, modal, and high discount rates of 2%, 3.5%, and 5%, respectively. For other factors, we determined distribution based on the type of each variable, with the γ distribution for costs (e.g., remediation cost and cost of crime), β distribution for variables with non-negative values smaller than 1 (e.g., cost modifiers and percentages), and lognormal distributions for size (e.g., land area), rates (e.g., crime incidents per quire mile), and relative rates (e.g., percent reduction in violent crime) that can theoretically vary from zero to infinity. We used the Method of Moments approach to estimate the parameters of each distribution based either on the mean and standard error from our legacy city sample or from the original study (e.g., we chose parameters of the γ distribution to correspond to the given mean and standard deviation reported in the source publication). When CI or standard errors were not reported, we used a ratio of the mean to estimate the standard error.

After assigning probability distributions, we performed a Monte Carlo simulation with 10,000 iterations to generate a random sample of B/C by sampling from uncertain parameters within each iteration. In addition to the probabilistic analysis, we conducted a deterministic base-case analysis by calculating the B/C using the point estimates (mean) for all variables. Next, we performed a series of deterministic sensitivity analyses by varying the value of each variable within a plausible range and recalculating the B/C and determining the values that will result in a B/C of 1.

3. Results

3.1. Meta-analysis

We located eight before-after studies with control groups that met our eligibility criteria. Three of these studies were published after our 2019 scoping review and were uncovered in our manual search for before-after studies. While all types of greenspaces were eligible, all eight studies that met our inclusion criteria examined vacant-lot remediation programs. Additionally, while we did not restrict the location of interventions within the United States, all studies that met our inclusion criteria had examined vacant-lot remediation programs in legacy cities. Interventions included mowing (n = 3), greening (n = 5), and gardening (n = 2), with two studies examining two different interventions. "Mowing" interventions included removal of trash and debris, as well as mowing of all vegetation as frequently as every two weeks. "Greening" interventions included removal of trash and debris, grading the land, planting new grass, planting a small number of trees, installing low wooden perimeter fences, and maintaining the newly treated lots. "Gardening" interventions included grading the soil, planting turfgrass, mowing the lots, and performing additional landscaping such as planting flowers, and in some cases creating vegetable gardens, growing crops or orchards, installing murals, sculptures and painted benches. While within these three groups the interventions were consistent across studies, crime outcomes were not. From each study, we chose the crime outcome most similar in nature to firearm violence. Table 1 summarizes the characteristics of studies included in the meta-analysis and the crime type chosen from each study. The assumption is that the effect of vacant lot remediation on the crime type shown in each row is similar to its effect on firearm violence.

Studies reported average crime rates in different ways, and therefore we used standardized mean difference in pooling effect sizes (Higgins et al., 2019). The pooled results are shown in Fig. 1. The pooled DID effect size does not show reduction in firearm violence by mowing vacant lots (DID −0.0634, 95% CI = −0.1544 to 0.0276). However, it does show a statically significant reduction in firearm violence by greening (DID −0.0584, 95% CI = −0.0789 to −0.0379) and gardening (DID −0.0534, 95% CI = −0.0774 to −0.0293). The heterogeneity between studies was high for mowing ($I^2 = 90\%$), moderate for greening ($I^2 = 54\%$), and small for gardening ($I^2 = 0\%$) interventions. Accordingly, we used a fixed effect model for pooling the effect of gardening interventions and used random effect models for mowing and greening interventions to account for variabilities between studies.

3.2. Benefit-to-cost analysis

The list of legacy cities we used for determining characteristics of our three hypothetical legacy cities, along with corresponding raw data and data sources, are provided in Supplementary data. Our sample included 30 small legacy cities, 20 medium legacy cities, and 10 large legacy

Table 1
Characteristics of studies included in the meta-analysis

Study	Intervention	City	Crime type	Number of lots observed	Mean observation period (months)		Mean number of crimes per lot during the observation period		Unit [b]
					Pre	Post	Pre	Post[a]	
Heinze et al. (2018)	Mowing [c]	Flint, MI	Violent crimes	IG = 216 CG = 446	5	5	IG = 0.36 CG = 0.46	IG = 0.20 CG = 0.40	# of incidents per street segment
Kondo et al.(2018)	Mowing	New Orleans, LA	Violent crimes [d]	IG = 204 CG = 560	30	15	IG = 35.03 CG = 35.15	IG = 20.66 CG = 20.53	# of incidents per square mile
Moyer et al. (2019)	Mowing	Philadelphia, PA	Shootings	IG = 10,440 CG = 9,660	28	22	IG = 33.60 CG = 30.52	IG = 19.98 CG = 19.58	# of incidents per square kilometer
Branas et al. (2011)	Greening	Philadelphia, PA	Gun assaults and gun robberies [e]	IG = 4,436 CG = 13,308	74.16	45.84	IG = 102.04 CG = 95.13	IG = 86.18 CG = 84.29	# of incidents per square mile
Kondo et al. (2016)	Greening	Youngstown, OH	Felony assaults and robberies [f]	IG = 166 CG = 959	22	22	IG = 10.22 CG = 11.42	IG = 13.98 CG = 16.19	# of incidents per square mile
Branas et al. (2018)	Greening	Philadelphia, PA	Gun assaults [g]	IG = 201 CG = 166	18	18	IG = 17.78 CG = 18.42	IG = 17.54 CG = 19.23	# of incidents per square mile
Moyer et al. (2019)	Greening	Philadelphia, PA	Shootings	IG = 12,360 CG = 9,660	28	22	IG = 35.00 CG = 30.52	IG = 21.60 CG = 19.58	# of incidents per square kilometer
Macdonald et al. (2021)	Greening	Philadelphia, PA	Felony assaults and robberies [f]	IG = 4,046 CG = 8,742	24	24	IG = 1.56 CG = 1.56	IG = 1.25 CG = 1.44	# of incidents per square foot
Kondo et al. (2016)	Gardening	Youngstown, OH	Felony assaults and robberies [f]	IG = 77 CG = 959	22	22	IG = 4.74 CG = 5.30	IG = 6.76 CG = 7.51	# of incidents per square mile
Beam et al. (2020)	Gardening	Milwaukee, WI	Violent crimes	IG = 53 CG = 159	7.34	4.32	IG = 3.86 CG = 3.61	IG = 3.21 CG = 3.13	# of incidents per 100 people

Pre = Pre-remediation, Post = Post-remediation, IG = intervention group, CG = control Group

a. We calculated the post-remediation crime rate for the intervention group by applying the reported effect size of the intervention to the crime incidents for the control group (pre and post-mediation) and intervention group (pre-mediation).

b. Since studies reported average crime rates in different ways, in pooling the effect sizes we used standardized mean difference as the summary statistic (Higgins et al., 2019).

c. The study reported that lots received either a greening or mowing treatment, without indicating the number of lots. However, the study indicated the majority of lots did not have additional landscaping and greening features. Accordingly, we classified this study as a mowing intervention.

d. The study reported the rate of violent crime, burglary, domestic disturbance, drug violation, and theft all together. Data provided by Kondo (February 2020) showed that violent crime accounted for about 32% of reported crimes during the observation period.

e. For crime rates and intervention effect size we pooled the values for gun assault and gun robberies reported separately in the study.

f. For crime rates and intervention effect size we pooled the values for felony assault and robbery reported separately in the study.

g. The study reported the rate of all serious crimes (violent and property crimes) together. From 1999 to 2008, in Philadelphia, PA about 6% of all serious crimes were gun assaults (Branas et al., 2011). We multiplied serious crimes by 0.06 to get the number of gun assaults pre- and post-remediation during the observation period.

cities. Table 2 provides analysis parameters and corresponding probability distributions. Detailed descriptions of assumptions are provided in the table notes. For additional details regarding the calculation of benefits and costs please see Supplementary data (Table 2). Using data shown in Supplementary data and Table 2, our estimate is that there are 49,553,419 (95% CI 49,266,952–49,839,886) sq. ft. of remediable vacant land in our small legacy city, 104,684,532 (95% CI 104,077,981–105,291,083) sq. ft. of remediable vacant land in our medium legacy city, and 227,975,167 (95% CI 226,655,863–229,294,472) sq. ft. of remediable vacant land in our large legacy city. Assuming an average lot size of 4713 sq. ft. (Supplementary data), this equates to 10,515 vacant lots in the small legacy city, 22,213 vacant lots in the medium legacy city, and 48,375 vacant lots in the large legacy city.

Since the pooled effect size for studies covering mowing interventions did not show a statistically significant reduction in firearm violence, we did not perform a benefit-to-cost analysis for mowing interventions.

For greening intervention programs, our pooled DID estimate suggests that over the 30-year analysis period, interventions may prevent 81.60 (95% CI: 81.40–81.79) incidents of firearm violence in the small legacy city, 221.93 (95% CI: 221.38–222.47) incidents in our medium legacy city, and 999.88 (95% CI: 997.41–1002.35) incidents in our large legacy city. Fig. 2 illustrates the probability distribution for the present value of cost savings from reducing these incidents. The present value of costs associated with greening interventions along with corresponding B/Cs are also shown in Fig. 1. Table 3 provides the results of 1-way sensitivity analyses assessing how changes in each variable impact the B/C for each city. The results are presented as relative changes compared to the deterministic B/C calculated using estimated means for

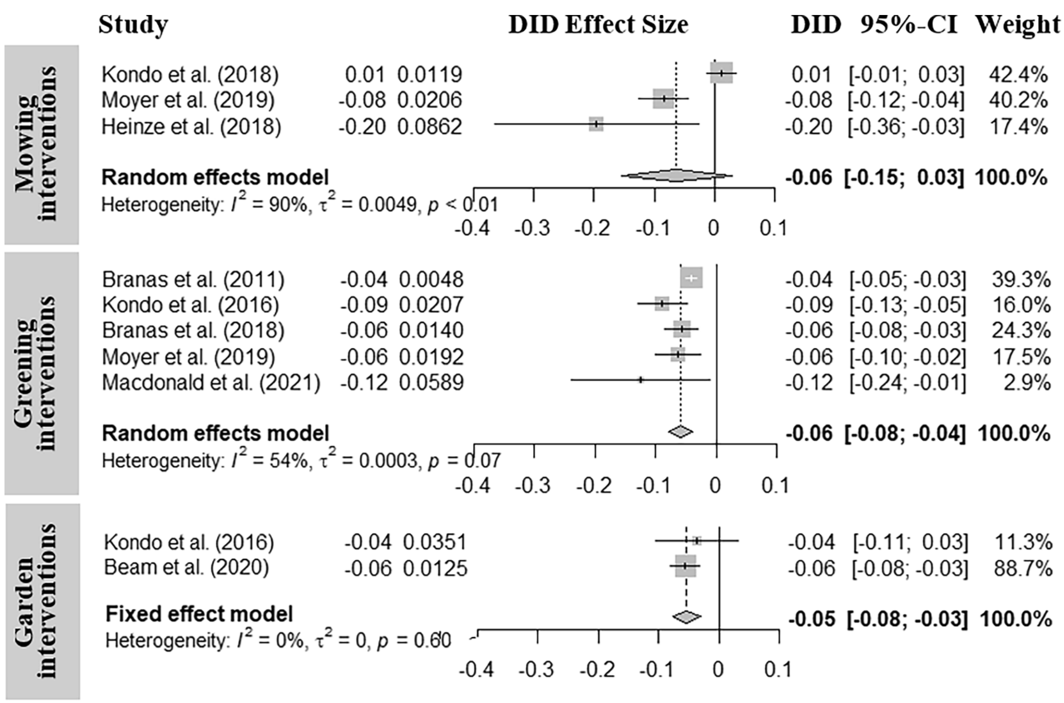

Fig. 1. Effect of vacant lot mowing, greening, and gardening programs on firearm violence. DID effect sizes should be multiplied by 100 to get the estimated percent reduction in firearm violence for remediated lots after intervention compared to control lots before intervention. The diamond symbols represent the pooled estimate and square symbols represent individual study estimates with the size of the square corresponding to their weight in the pooled estimate. Inverse variance weighting is used for pooling.

each variable. We also report the threshold value of each variable that would result in the B/C of 1. For all three cities, results were most sensitive to the location factor and size modifiers, including percent of land that is vacant, percent of remediable vacant lots, and percent of vacant lands eligible for greening. However, for benefits to match costs and have B/C = 1, at least one of these variables would need by be reduced by 94.88%, 91.96%, or 79.85% in small, medium and large cities, respectively.

For gardening interventions, the estimated number of firearm violence incidents prevented over the 30 years of analysis period are 77.71 (95% CI: 77.51–77.91) incidents in the small legacy city, 211.37 (95% CI: 210.82–211.91) incidents in the medium legacy city, and 952.26 (95% CI: 954.72–949.80) incidents in the large legacy city. Given that gardening interventions demand more resources than greening interventions and have a slightly lower pooled effect size than greening programs, we did not perform a benefit-to-cost analysis for gardening interventions.

4. Discussion

Our meta-analysis of three studies examining vacant lot mowing-only interventions in New Orleans, Philadelphia, and Flint provided no evidence of significant reductions in firearm violence. The New Orleans study accounted for more than 42% of the pooled estimate and its non-negative effect size impacted the statistical outcome. As Kondo et al. (2018) discussed, the size of lots and yards and vegetation type in New Orleans may have resulted in a lack of lasting difference in the landscape, thereby diminishing the impact of mowing interventions on violent crime. Nevertheless, while outside the scope of our analysis, Kondo et al. (2018) reported a 6.3% reduction in drug violations around remediated lots. As more studies examine the effect of mowing interventions in different cities, the meta-analysis should be repeated to incorporate and synthesize evidence from other settings.

As for greening and gardening interventions, our meta-analysis found a 5.8% (95% CI: 3.79–7.89%) and 5.3% (95% CI: 7.67–3.04%) reduction in firearm violence respectively, providing evidence that such placed-based interventions can be robust additions to conventional crime prevention policies. For our hypothetical legacy cities, 21 years after beginning the program when all vacant lots across the city would be greened, each year 4.40 (95% CI: 4.39–4.41) incidents in the small legacy city, 11.98 (95% CI: 11.95–12.01) incidents in the medium legacy city, and 53.96 (95% CI: 53.83–54.10) incidents in the large legacy city could be avoided. For gardening interventions, the estimated number of firearm incidents that can be avoided each year are 4.19 (95% CI: 4.18–4.20) incidents in the small legacy city, 11.41 (95% CI: 11.38–11.44) incidents in the medium legacy city, and 51.39 (95% CI: 53.26–51.53) incidents in the large legacy city. Assuming that 2.54% of firearm violence leads to victim's death (Planty & Truman, 2013), for both greening and gardening interventions in a large legacy city, one homicide might be eliminated every 8.5 months.

When it comes to the cost of vacant lot greening programs, the large number of vacant lots in most cities might make the city-wide interventions appear to be costly. However, the estimated present value (2020 USD) of the difference between costs and benefits over the 30 years of the analysis period is about $133 million, $284 million, and $545 million for the small, medium, and large legacy cities respectively. These equate to the net annual per capita costs of $64.53 (Fieller's 95% CI: 64.09–64.96), $51.88 (Fieller's 95% CI: 51.53–52.25), and $30.97 (Fieller's 95% CI: 30.73–31.22) in the small, medium, and large cities respectively. In comparison, review of state government finance data released by the U.S. Census Bureau show that each year, a typical local government spends between $347.84 and $372.39 per capita (2020 USD) on law enforcement, a figure that can be up to $586.21 per capita for large cities (Urban Institute, 2017; USAFacts, 2020). As such, given the effectiveness of greening programs in reducing firearm violence by 5.8%, the relative lower costs of such programs would make them appealing investments for most cities.

In terms of benefit-to-cost analysis, our results (Fig. 2) showed that reduction in firearm violence by itself can recover 8.2%, 10.2%, and 21.1% of the citywide greening and maintenance costs in the small,

Table 2
Point estimates of baseline values, parameters of the probability distribution assigned to analysis parameters for probabilistic analysis, and estimated means used for sensitivity analysis.

Analysis parameter	Baseline value (Standard Error)	Estimated mean	Probability distribution
Discount rate	3.50% (±0.01%)	3.50%	Triangular(0.02, 0.035, 0.05)
COST PARAMETERS			
Total land area for small legacy city (sq. mi.)[a]	20.10 (±1.82)	20.02	Lognormal(3.00, 0.01)
Total land area for medium legacy city (sq. mi.)[a]	42.80 (±6.71)	42.29	Lognormal(3.74, 0.02)
Total land area for large legacy city (sq. mi.)[a]	92.93 (±12.88)	92.09	Lognormal(4.52, 0.02)
Percent of land area that is vacant[b]	16.98% (±4.32%)	16.99%	β(12.66, 61.89)
Percent of remediable vacant lots without a structure[c]	68.50% (±7.00%)	68.62%	β(29.48, 13.56)
Percent of vacant lands eligible for greening[d]	76.28% (±7.63%)	76.16%	β(22.96, 7.14)
Clean-up and greening costs (per sq. ft.)[e]	$1.904 (±$0.19)[f]	$1.90	γ(100.00, 0.019)
Annual maintenance costs (per sq. ft.)[g]	$0.162 (±$0.02)[f]	$0.16	γ(100.00, 0.002)
Annual program management costs (per employee)[h]	$90,000 (±$9,000)[f]	$90,045	γ(100.00,900.00)
Cost increase associated with the size of greening intervention[i]	22.22% (±$28.03%)[j]	21.47%	Lognormal (−1.98, 0.95)
Location factor for small legacy city[a]	0.933 (±0.010)	0.933	β(580.85, 41.88)
Location factor for medium legacy city[a]	0.970 (±0.009)	0.97	β(336.86, 10.36)
Location factor for large legacy city[a]	0.989 (±0.008)	0.986	β(191.01, 2.61)
BENEFIT PARAMETERS			
Percent reduction in crime involving firearms (from Fig. 2)	5.84% (±1.05%)	5.73%	Lognormal (−2.68, 0.03)
Annual reported violent crime incidents for small legacy city[a,k]	29.12 (±3.76)	28.88	Lognormal(60.14, 0.48)
Annual reported violent crime incidents for medium legacy city[a,k]	37.38 (±3.97)	37.18	Lognormal(88.75, 0.42)
Annual reported violent crime incidents for large legacy city[a,k]	77.57 (±10.12)	76.91	Lognormal(58.72, 1.32)
Percent of violent crime involving firearms[l]	8.07% (±%0.81)[f]	8.07%	β(91.85, 1046.31)
Percent of firearm violence that is homicide[l]	2.54% (±0.25%)[f]	2.54%	β(97.44, 3739.85)
Percent of nonfatal firearm violence that is not reported[m]	39.00% (±3.90%)[f]	38.94%	β(60.61, 94.80)
Per-offense cost of reported violent crimes involving firearms[n]	$125,994.52 (±$31,498.63)[o]	$126,554.60 $113,102.20	γ(16.00, 7874.66)
Per-offense cost of unreported violent crimes involving firearms[p]	$113,318.54 (±$28,329.64)[o]	$10,560,690.00	γ(16.00, 7082.41)
Per-offense cost of firearm violence that is homicide [q]	$10,575,565.54 (±$2,643,891.39)[o]		γ(16.00, 660972.85)

Construction and maintenance costs are adjusted to 2020 US dollars (quarter 1) using historical construction cost indexes (R.S. Means Engineering Department, 2020). Following the Washington State Institute in the Public Policy Benefit-Cost Model (Washington State Institute for Public Policy, 2019), all other costs are adjusted using implicit price deflator-personal consumption expenditures from Bureau of Economic Analysis, National income and Product Account Tables (U. S. Department of Commerce, Bureau of Economic Analysis, n.d.), Table 1.1.9, Line 2.

Triangular(x,y,z) = triangular distribution with minimum value of ×, mode of y, and maximum value of z. Lognormal(x,y) = lognormal distribution with mean × and standard deviation y for the log-transformed values of the mean. β(x,y) = beta distribution with shape parameter × and scale parameter y. γ(x,y) = gamma distribution with shape parameter × and rate parameter y.

a. See Supplementary data for raw data.

b. We used data from 13 legacy cities for which we had data (see Supplementary data) and assumed that the same ratio applies to our three legacy cities.

c. Greening interventions in studies included in our meta-analysis excluded vacant structures and vacant buildings. We used survey data from Youngstown, Detroit, Gary, and Cleveland (Mallach, 2018) to estimate the ratio of vacant lots without vacant structures and vacant buildings. We assumed the same ratio applies to legacy cities of our study.

d. Vacant lots with insufficient blight and lots that were on existing private or commercial parking lots cannot be remediated (Branas et al., 2018). For the city of Philadelphia, ineligible lots constituted about 10,619 of the city's 44,768 vacant lots (23.72%) (Branas et al., 2018). We assumed the same ratio applied to legacy cities of our study.

e. $1.50 per sq. ft. in 2007 USD for the city of Philadelphia, PA (Birch & Wachter, 2011).

f. Standard error is assumed to be 10% of the point estimate (mean) of the cost.

g. $0.15 per sq. ft. in 2007 USD for the city of Philadelphia, PA (Birch & Wachter, 2011). We assumed lots not in the remediation programs would still require a minimum clean-up that would cost 25% of this amount. As a result, the incremental maintenance cost is 0.112 per sq. ft. in 2007 USD.

h. To cover salary and benefits of each employee in charge of managing and running the program. We assume small, medium, and large legacy cities need teams of three, five, and seven employees to manage the program.

i. Between 1999 and 2008, in Philadelphia about 7.8 million sq. ft. of vacant lots were greened (Birch & Wachter, 2011). Economies of scale imply that costs for other cities are higher than those of Philadelphia at the beginning of the greening program. We used size modifier (R.S. Means Engineering Department, 2020) and assumed that at year one, costs are 1.22 times higher than those of Philadelphia, but as the program grows cities manage to lower the costs and at year 20, the costs will be similar to the cost reported for Philadelphia, PA.

j. We assumed that 95% upper and lower CIs were away from the mean by half of the mean value and then calculated the standard error from CIs.
k. Using data included in supplemental material, we divided the number of incidents in the last three years by three times the city land area and then used mixed effect models to pool crime rates (number of incidents per sq. mi. per year) for each city size.
l. We pooled the last three years of available data from a report on firearm violence by the U.S. Department of Justice (Planty & Truman, 2013).
m. From the special report by the U.S. Department of Justice (Planty & Truman, 2013).
n. $107,020 in 2008 USD for aggravated assaults (McCollister et al., 2010), including tangible (crime victim cost, criminal justice system cost, crime career cost) and intangible (pain-and-suffering cost and cost associated with the risk of death) costs.
o. Standard error is assumed to be 25% of the point estimate (mean) of the cost.
p. $96,253 in 2008 USD (McCollister et al., 2010). Includes tangible and intangible costs minus criminal justice system costs and crime career costs.
q. $8,982,907 in 2008 USD for murders (McCollister et al., 2010), including tangible and intangible costs.

medium, and large legacy cities respectively. Thus, there is preliminary evidence that the return on investment improves as the city size increases. In other words, while the cost of remediation increases with the size of the city, the opportunity to reduce firearm violence is greater (cost savings grow at a higher rate than remediation costs). Moreover, evidence exists that urban greenspace may reduce other types of violent (Kondo et al., 2016) and non-violent crimes, including property crime (Kuo & Sullivan, 2001), burglary (Branas et al., 2011, 2018), vandalism (Branas et al., 2011), disorderly conduct (Branas et al., 2011), and drug violations (Kondo, Morrison, et al., 2018). A strong body of evidence also suggests that urban greenspaces improve such health outcomes as immune function (Kuo, 2015), mortality, attention, mood, and physical activity (Kondo, Fluehr, et al., 2018), heart rate and blood lead levels (Sivak et al., 2021), and increase tax revenue for cities by enhancing property value (Heckert & Mennis, 2012). They also provide essential ecosystems services such as reducing non-point source stormwater runoff and the heat island effect (Wolf et al., 2020). While more studies with rigorous methodologies are needed to generalize the findings, it is probable that the financial return from investments in vacant lot remediation programs considerably improves if we account for cost savings from overall crime reduction and improvement in other outcomes listed above. More importantly, when such placed-based interventions are implemented in conjunction with conventional crime prevention policies, their synergistic effects could augment the impact of individual programs, resulting in further financial returns. Finally, in some neighborhoods, vacant lot remediation programs engage community groups that often volunteer or are paid for mowing trash removal, and maintenance work (Heinze et al., 2018) which lowers the intervention costs.

A purely fiscal approach in assessing vacant lot remediation programs poses the risk of leaving out their potential unintended consequences. Compared to housing development projects or building parks and recreational facilities, remediating vacant lots is fast, inexpensive, and scalable, however it may pose the threat of gentrification (Branas et al., 2016). Especially in low-income communities, neighborhood greening interventions have shown to increase the potential of gentrification in the long-term by attracting wealthier residents and displacing existing populations (Curran & Hamilton, 2012; Lee & Newman, 2021;

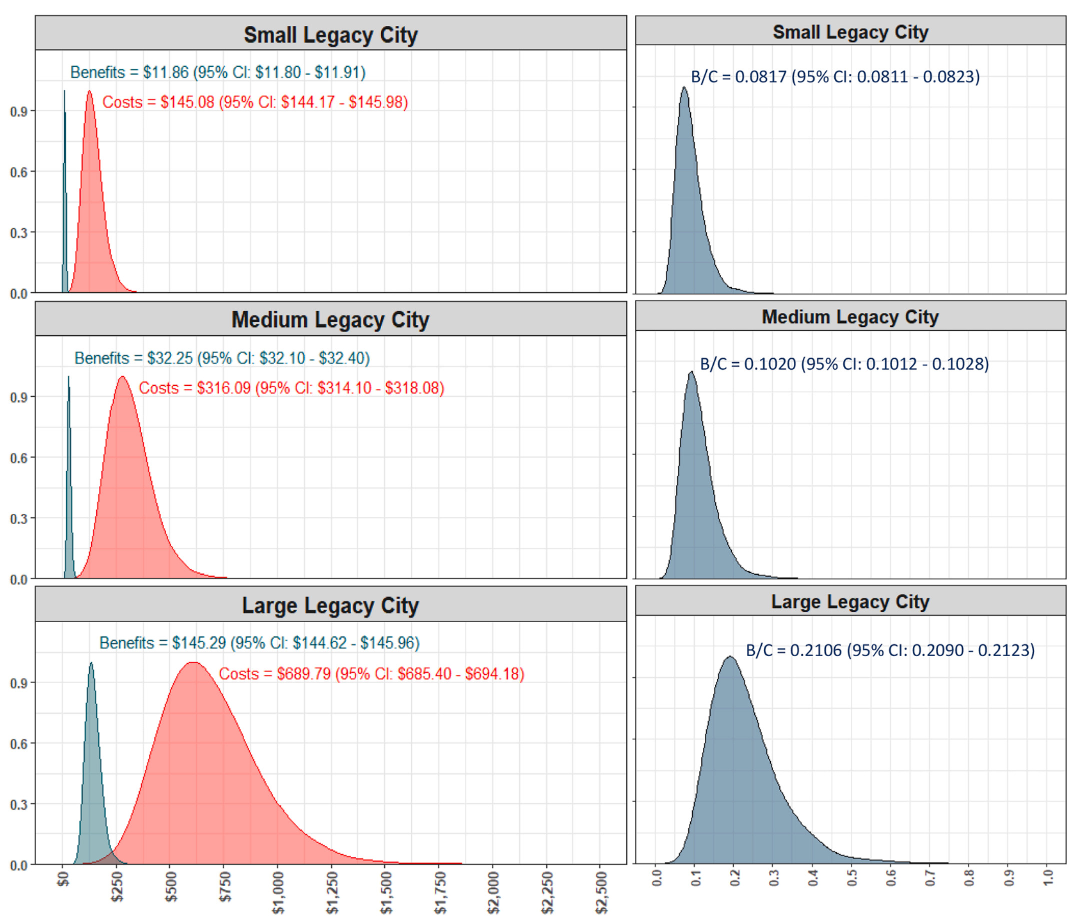

Fig. 2. Monte Carlo simulations results. Values in parentheses represent standard errors of the estimated means. Given the difference in the sample size, estimate for large and medium legacy cities exhibits higher variance. For mean B/C we divided the estimated mean of benefits by the estimated mean of costs and calculated Fieller's 95% CIs for the ratio of the means (Fieller, 1940), using the 'mratios' package (version 1.4.2) (Djira et al., 2020) in R.

Table 3
Results of the sensitivity analysis.

Parameter	B/C When Changed by −10%	B/C When Changed by +10%	Change Required to Have B/C = 1 Absolute change (relative change) from baseline
Small Legacy City (deterministic B/C using estimated means 0.084)[a]			
Discount Rate	0.085	0.083	No feasible solution exists (0.093)
Total land area for small legacy cities (sq. mi.)	0.083	0.084	No feasible solution exists (0.087)
Percent of land area that is vacant	0.093	0.076	−16.12% (−94.88%)
Percent of remediable vacant lots without a structure	0.093	0.076	−65.10% (−94.88%)
Percent of vacant lands eligible for greening	0.093	0.076	−72.26% (−94.88%)
Clean-up and greening costs (per sq. ft.)	0.088	0.08	No feasible solution exists (0.155)
Annual maintenance costs (per sq. ft.)	0.088	0.08	No feasible solution exists (0.169)
Annual program management costs (per employee)	0.084	0.083	No feasible solution exists (0.087)
Cost increase associated with the size of greening intervention	0.084	0.083	No feasible solution exists (0.090)
Location factor for small legacy cities	0.093	0.076	−0.89 (−94.88%)
Percent reduction in crime involving firearms	0.075	0.092	+62.66% (+1,093.67%)
Annual reported violent crime incidents for small legacy cities	0.075	0.092	+315.84 (+1,093.67%)
Percent of violent crime involving firearms	0.075	0.092	+88.21% (+1,093.67%)
Percent of firearm violence that is homicide	0.079	0.089	+48.38% (+1,904.15%)
Percent of nonfatal firearm violence that is not reported	0.082	0.086	+58.87% (+150.98%)
Per-offense cost of reported violent crimes involving firearms	0.082	0.086	+$5,109,240.13 (+4,037.18%)
Per-offense cost of unreported violent crimes involving firearms	0.082	0.085	+$7,993,740.85 (+7,067.71%)
Per-offense cost of firearm violence that is homicide	0.079	0.089	+$201,091,236.34 (+1,904.15%)
Medium Legacy City (deterministic B/C using estimated means 0.105)[a]			
Discount Rate	0.106	0.103	No feasible solution exists (0.117)
Total land area for medium legacy cities (sq. mi.)	0.104	0.105	No feasible solution exists (0.107)
Percent of land area that is vacant	0.116	0.095	−15.62% (−91.96%)
Percent of remediable vacant lots without a structure	0.116	0.095	−63.10% (−91.96%)
Percent of vacant lands eligible for greening	0.116	0.095	−70.03% (−91.96%)
Clean-up and greening costs (per sq. ft.)	0.11	0.1	No feasible solution exists (0.195)
Annual maintenance costs (per sq. ft.)	0.11	0.099	No feasible solution exists (0.213)
Annual program management costs (per employee)	0.107	0.106	No feasible solution exists (0.112)
Cost increase associated with the size of greening intervention	0.105	0.104	No feasible solution exists (0.107)
Location factor for medium legacy cities	0.116	0.095	−0.89 (−91.96%)
Percent reduction in crime involving firearms	0.094	0.115	+49.06% (+856.32%)
Annual reported violent crime incidents for medium legacy cities	0.094	0.115	+318.37 (+856.32%)
Percent of violent crime involving firearms	0.094	0.115	+69.07% (+856.32%)
Percent of firearm violence that is homicide	0.099	0.111	+37.88% (+1,490.91%)
Percent of nonfatal firearm violence that is not reported	0.102	0.107	+58.31% (+149.53%)
Per-offense cost of reported violent crimes involving firearms	0.102	0.107	+$4,000,432.00 (+3,161.03%)
Per-offense cost of unreported violent crimes involving firearms	0.103	0.106	+$6,258,937.89 (+5,533.88%)
Per-offense cost of firearm violence that is homicide	0.099	0.111	+$157,450,415.88 (+1,490.91%)
Large Legacy City (deterministic B/C using estimated means 0.215)[a]			
Discount Rate	0.217	0.212	No feasible solution exists (0.240)
Total land area for large legacy cities (sq. mi.)	0.214	0.215	No feasible solution exists (0.219)
Percent of land area that is vacant	0.238	0.196	−13.57% (−79.85%)
Percent of remediable vacant lots without a structure	0.238	0.196	−54.80% (−79.85%)
Percent of vacant lands eligible for greening	0.238	0.196	−60.82% (−79.85%)
Clean-up and greening costs (per sq. ft.)	0.225	0.205	No feasible solution exists (0.404)
Annual maintenance costs (per sq. ft.)	0.233	0.207	No feasible solution exists (0.443)
	0.227	0.204	No feasible solution exists (0.219)

(continued on next page)

Table 3 (*continued*)

Parameter	B/C When Changed by −10%	B/C When Changed by +10%	Change Required to Have B/C = 1 Absolute change (relative change) from baseline
Annual program management costs (per employee)			
Cost increase associated with the size of greening intervention	0.215	0.214	No feasible solution exists (0.230)
Location factor for large legacy cities	0.238	0.196	−0.79 (−79.85%)
Percent reduction in crime involving firearms	0.193	0.236	+20.94% (+365.46%)
Annual reported violent crime incidents for large legacy cities	0.193	0.236	+281.09 (+365.46%)
Percent of violent crime involving firearms	0.193	0.236	+29.48% (+365.46%)
Percent of firearm violence that is homicide	0.203	0.227	+16.17% (+636.29%)
Percent of nonfatal firearm violence that is not reported	0.209	0.221	+55.03% (+141.13%)
Per-offense cost of reported violent crimes involving firearms	0.213	0.225	+$1,707,311.25 (+1,349.07%)
Per-offense cost of unreported violent crimes involving firearms	0.212	0.218	+$2,671,200.29 (+2,361.76%)
Per-offense cost of firearm violence that is homicide	0.203	0.227	+$67,196,970.10 (+636.29%)

For this analysis, we used estimated means from 10,000 Monte Carlo simulations as shown in Table 2. For some variables no value resulted in B/C = 1. For example, in the small legacy city, the highest B/C that can be achieved by reducing clean-up and greening costs to $0 is 0.141. For these variables, the value in parentheses shows the highest B/C that can be achieved.

a. Results are slightly deferent from those shown in Fig. 2 and reported throughout the text due to rounding effects.

Wolch et al., 2014). City-wide vacant lot greening programs could result in crime- and health-related improvements that could influence city-level gentrification and wealth disparities. Although in Philadelphia, PA, researchers found no evidence of increase in property taxes after implementation of greening interventions (Branas et al., 2011, 2018), fear of increase in taxes or potential gentrification can diminish the involvement of residents in greening efforts and hinder the success of remediation programs (Stewart et al., 2019). Fiscal policies, such as freezing property tax rates for existing residents may help deter gentrification (Lee & Newman, 2021) and, as Branas et al. (2018) noted, this strategy has shown to be effective in curtailing displacement due to gentrification in Philadelphia, PA. City-wide greening programs can take several years, and equitable distribution of vacant lot greening efforts might reduce potential gentrification effects.

In terms of benefit-to-cost analysis, our results are in contrast with findings of the 2016 study of the city of Philadelphia (Branas et al., 2016), which found that for every dollar spent on vacant lot remediation return, is $333 over post-treatment period of 46 months. This is despite the fact that we used the same assumptions as Branas et al. (2016) for estimating both intervention costs (Birch & Wachter, 2011) and crime costs (McCollister et al., 2010). There are several reasons our results might differ. First, Branas et al. examined 4436 out of 54,000 vacant lots, while our study entails greening all vacant lots, translating to higher greening and maintenance costs. Second, our remediation costs are higher as we incorporated a size modifier to account for increased cost at the beginning of the greening program due to economies of scale. Third, our analysis assumes that it takes 20 years to remediate all vacant lots and fully achieve the estimated 5.8% reduction in firearm violence. With a discount rate of 3.5% and using Eq. (1), $1 saved 21 and 30 years (end of our analysis period) in the future are worth $0.5 and $0.36 at present time, respectively. Greening costs incurred closer to the present time are discounted to a lesser extent than savings, and affects our B/C. Fourthly, as Supplementary data shows, the City of Philadelphia has the highest incidence of violent crimes in our sample of legacy cities, with crime incidents 2.2 times higher than the average number of incidents for the other nine large legacy cities. A higher number of incidents translates to a higher number of crimes that can be prevented by remediation. We believe our benefit-to-cost analysis may be more applicable outside the City of Philadelphia given that we pooled results from multiple studies and conducted long-term analyses of city-wide cleaning programs.

Nevertheless, our study is subject to limitations. First, given the complexity and multi-year nature of city-wide vacant lot remediation efforts, the credible sources of evidence on this topic are very limited. This is reflected in the small number of eligible studies included in our meta-analysis. Because our three legacy cities represent average characteristics of a sample of legacy cities (Supplementary data), our conclusions are not transferable to individual cities in the sample. Future studies should focus on conducting a city-level benefit-to-cost analysis. Additionally, while we incorporated size and location modifiers for adjusting costs, generalizing the results must be done with caution.

Second, our analysis can be subject to publication bias. In other words, studies that did not report statistically significant differences between the control and intervention groups may have been less likely to be published than those that found a significant difference. However, the New Orleans study (Kondo, Morrison, et al., 2018) included in the meta-analysis did not have significant results. The fact that all existing studies on the relationship between vacant-lot remediation and violent crime have been conducted by the same research group as the New Orleans study, we can argue that publication bias is not a strong threat to the internal validity of our study as other potential insignificant results would have been reported as well. Nevertheless, when it comes to internal validity, the limitation of studies included in the analysis apply to ours as well. For example, five (Beam et al., 2020; Branas et al., 2011; Heinze et al., 2018; Kondo et al., 2016; Kondo, Morrison, et al., 2018) of the original eight studies used a quasi-experimental design. The quasi-experimental design allowed reasonable estimates of the true changes in crime as a result of vacant lot remediation (Branas et al., 2016), and these studies controlled for important confounding variables such as population density, income, residential stability, and unemployment. However, vacant lot assignments to a treatment versus control group were not randomized.

Finally, our model is limited by the assumptions noted in Table 1 and Table 2. For example, while we were able to obtain official crime data for our sample of legacy cities (Supplementary data), the most recent reliable reference (Planty & Truman, 2013) we found for calculating firearm-related incidents only had data up to 2011. Due to lack of reliable references, we also assumed that each incident of firearm violence only has one victim. Similarly, reliable data on lot vacancies in legacy cities were limited. As a result, it is possible that we overestimated or underestimated benefits or costs. Despite these important limitations, our sensitivity analysis (Table 3) showed that unless there are substantial deviations from the estimated mean values of our analysis variables, benefits are always lower than remediation costs. More importantly, the methodology of our approach can be used by other investigators to quantify changes in benefits and costs as a result of changes in input parameters.

Overall, given the limited number of credible sources of evidence in the literature, our study remains a proof-of-concept example for the application of objective benefit-to-cost assessments of city-wide greening interventions with a probabilistic framework. In practice, cities are likely to implement more than one type of vacant-lot remediation program, for example greening in conjunction with commercial or residential developments on vacant lots. Future studies could examine the combined effect of such remediation programs and assess their benefit-to-cost outcomes.

5. Conclusions

A growing number of studies are examining the role of place-based interventions, including cleaning and greening of vacant lots, in fighting crime and violence. When it comes to a specific form of crime, firearm violence, our meta-analysis showed that by 5.8% (95 CI: 3.79–7.89%) and 5.3% (95 CI: 7.67–3.04%) reduction in such incidents respectively, greening and gardening interventions can play a robust role in controlling crimes. On the other hand, given the large number of vacant lots in most legacy cities, planning and implementing city-wide remediation programs are highly resource-intensive and time-consuming. Our estimate showed that greening and maintaining all vacant lots can cost up to $145 million, $316 million, and $690 million for a typical small, medium, and large legacy city, respectively. We found that cost savings from lowering firearm crimes can recover 8.9%, 11.2%, and 23.2% of these costs in the small, medium, and large legacy cities, respectively.

This finding does not indicate a lack of cost-effectiveness of vacant-lot greening programs as we only assessed returns from reductions in firearm violence. City-wide greening efforts are shown to be associated with improvements in a wide range of environmental and health-related outcomes. It is likely that cost savings from these outcomes would offset the greening and maintenance costs. Overall, given the limited number of credible sources of evidence in the literature, our study serves as a proof-of-concept examination of early evidence. As more studies document the full benefits of urban greening programs, the broader return-on-investment from such programs can be investigated. As we have demonstrated, it is important that future return-on-investment evaluations are performed with full characterization of uncertainty in the evidence.

CRediT authorship contribution statement

Hessam Sadatsafavi: Methodology, Investigation, Formal analysis, Validation, Writing - original draft, Data curation. **Naomi A. Sachs:** Conceptualization, Writing - review & editing. **Mardelle M. Shepley:** Conceptualization, Writing - review & editing. **Michelle C. Kondo:** Writing - review & editing, Data curation. **Ruth A. Barankevich:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2021.104281.

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