HEALTH ECONOMICS

Firearms and accidental deaths: Evidence from the aftermath of the Sandy Hook school shooting

Phillip B. Levine[1,2]* and Robin McKnight[1,2]

Exposure to firearms increased substantially after the December 2012 shooting at Sandy Hook Elementary School in Newtown, Connecticut, where 20 children and 6 adults were killed. Gun sales spiked by 3 million, on the basis of the increase in the number of background checks for firearm purchases. Google searches for buying and cleaning guns increased. We used Vital Statistics mortality data to examine whether a spike in accidental firearm deaths occurred at the same time as the greater exposure to firearms. We also assessed whether the increase in these deaths was larger in those states where the spike in gun sales per capita was larger. We find that an additional 60 deaths overall, including 20 children, resulted from unintentional shootings in the immediate aftermath of Sandy Hook.

On 14 December 2012, a shooter entered Sandy Hook Elementary School in Newtown, Connecticut, and killed 20 children and 6 adults. In the aftermath of this event, President Barack Obama spoke forcefully about the need to find ways to reduce the likelihood of such events and made specific proposals to restrict access to guns (*1*, *2*). As we document below, that call for new gun control legislation contributed to a large increase in gun exposure. Americans displayed greater interest in buying new guns and in handling their guns. Indeed, background checks, which are conducted when a gun is sold by a federally licensed firearms dealer, spiked during this period. Using these background-check data as a proxy for gun sales, we estimated that 3 million additional guns were sold in the 5 months after the Sandy Hook incident, beyond the number of sales that would have otherwise occurred.

After Sandy Hook, President Obama called for more research on gun violence, which has been affected since 1997 by changes in funding for the U.S. Centers for Disease Control and Prevention, National Institutes of Health, and other federal agencies (*3*–*5*). Here we take up that charge, focusing specifically on the period after the Sandy Hook school shooting itself.

In particular, we investigated the consequences of the spike in gun exposure after Sandy Hook, focusing on the short-term impact on accidental firearm deaths. Specifically, our analysis asked whether that spike in exposure was associated with a simultaneous spike in the number of these deaths. We went on to consider whether states in which the spike in exposure was larger experienced greater increases in accidental firearm deaths. This approach allowed us to overcome a key empirical challenge that has limited prior research on this topic: the ability to distinguish between the causal effect of exposure to firearms and the effect of other risk factors that are correlated with variation across individuals and over time in exposure to firearms. In much of our analysis, background checks for gun sales served as a proxy for gun exposure.

Greater exposure to guns may plausibly increase the risk of accidents. Previous research has demonstrated that accidental shootings are more likely to occur when there are more guns in the home (*6*), during routine handling of a firearm (*7*), when a gun is not stored properly (*8*), and when people are playing with guns or demonstrating their use (*9*). Children may be particularly at risk.

Gun exposure may increase if new guns are purchased or previously owned guns are removed from storage. Search data available from Google provides suggestive evidence that both forms of exposure increased after Sandy Hook. These data, available from Google Trends, provide an index of relative search frequency for specific search terms over time. Peak search activity for that term, relative to overall search activity, is assigned a value of 100, half that amount is assigned a value of 50, etc. More details on these data, and other data sources, can be found in (*10*).

We examined weekly search volumes for the terms "buy gun" (as in, "where can I buy a gun?") and "clean gun" (as in, "how often should I clean my gun?") in the United States between 2010 and 2014. We hypothesized that individuals whose searches included "buy gun" may be more likely to purchase a new firearm, and individuals whose searches included "clean gun" may be more likely to remove a previously owned gun from storage.

Figure 1 shows that the frequency of these searches spiked immediately after the Sandy Hook school shooting. We define the "post–Sandy Hook window" as the December 2012 through April 2013 period. That window emerges from our subsequent analysis of background checks and from the timing of the policy debate that took place immediately after Sandy Hook. Five

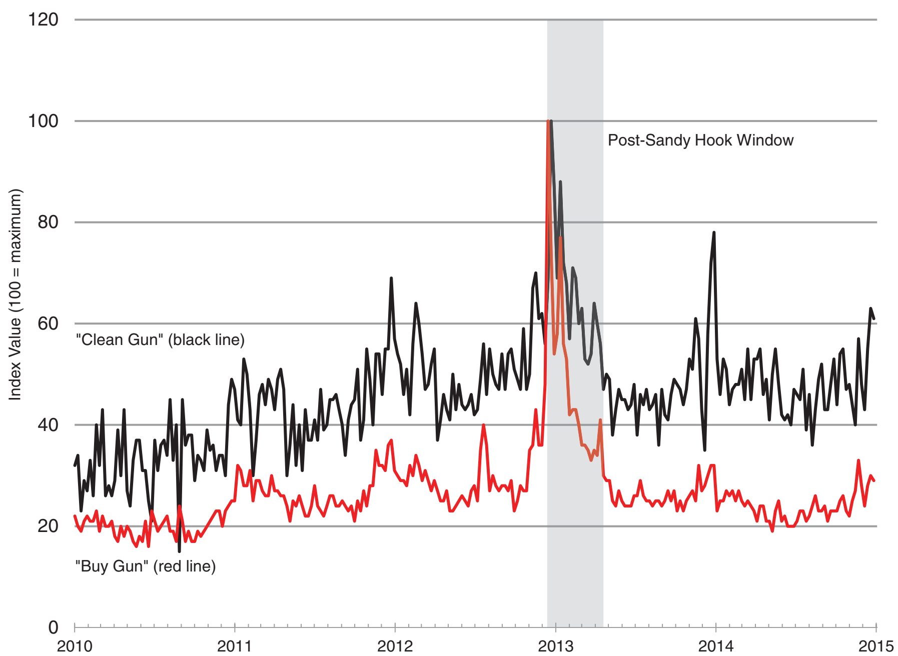

Fig. 1. Relative frequency of weekly Google searches that included the terms "clean gun" and "buy gun" between 2010 and 2014. This graph uses data from Google Trends (http://trends.google.com/) to track weekly patterns in search activity that included each set of words. The week with maximum search volume is indexed to equal 100 and values below 100 reflect relative search activity in proportion to the week with the maximum value.

[1]Department of Economics, Wellesley College, Wellesley, MA 02481, USA. [2]National Bureau of Economic Research, Cambridge, MA 02138, USA.
*Corresponding author. Email: plevine@wellesley.edu

days after the shooting, President Obama spoke publicly about the need for new gun control legislation. He suggested specific legislative changes on 16 January 2013 and discussed the proposed legislation in his 12 February 2013 State of the Union address. Search activity related to buying and cleaning guns spiked immediately after each of these events. Congress debated these changes until the legislation was voted down on 17 April 2013, at which point this search activity ebbed and returned to pre–Sandy Hook levels. The correlation coefficient between these two search terms is 0.72, indicating a strong positive relationship between the two types of gun exposure.

We also documented an increase in gun exposure using data from the National Instant Criminal Background Check System (NICS), focusing on the 2008 through 2015 period surrounding the Sandy Hook shooting. Briefly, the NICS data provide the number of background checks performed on individuals seeking to purchase a gun through a licensed dealer, which we use as a proxy for the number of firearm sales (we use the terms gun and firearm interchangeably for convenience, although all of our data represent total firearm sales). When detrended, these data are highly correlated with the Google Trends data on "buy gun" (correlation coefficient = 0.71) described earlier. Background checks also have been previously shown to be strongly correlated with other measures of firearm sales, including tax revenue from firearm sales, per capita gun ownership, and the net total of guns manufactured, imported, and exported (*11*–*13*).

Moreover, estimates obtained from the NICS data are strongly consistent with the findings of a recent study of complete handgun transaction records from California's Department of Justice, which found that 26,000 additional handguns were sold in that state in the 6 weeks after Sandy Hook (*14*). Using NICS data, we estimated that 33,000 additional handguns were sold in California in December and January of 2012–2013. Interestingly, although the NICS data do not provide any information about buyers, the California transaction records suggest that 59% of the additional purchases in response to Sandy Hook were made by first-time firearm buyers.

Figure 2 shows the pattern over time in the level of gun sales, as proxied by background checks, after adjusting for seasonality and trends. Each point on the line represents the deviation from expected sales. These data show that the spike in sales emerged immediately after the Sandy Hook shooting. Sales increased right away, peaked in January 2013, and remained substantially above trend through April of that year. These results, along with the timing of the public discussion about gun control legislation described earlier, led us to define the 5-month post–Sandy Hook window that is the focus of our analysis. No systematic offsetting declines in sales are evident in subsequent months, indicating that these increases do not reflect short-term substitution in the timing of sales. In total, 3 million additional guns—949 for every 100,000 people in the United States (the 2013 U.S. population was 316 million)—were sold during this window. Taken together, these results, along with our analysis of Google Trends data, show that exposure to firearms increased substantially in the post–Sandy Hook window.

The bars in Fig. 2 represent the deviation from the expected number of children per capita who died as the result of an accidental shooting over successive December-through-April windows. The data for this analysis are drawn from the Vital Statistics system, which includes every recorded death in the United States. We used population data from the Surveillance, Epidemiology, and End Results (SEER) program at the National Cancer Institute to convert death counts to rates per 100,000 population. The results provide visual evidence of a spike in accidental firearm deaths to children exactly at the time of the increase in gun sales after Sandy Hook. Although detrended accidental deaths per capita exhibit variability from year to year, no positive spike of that magnitude is observed in any other period. This is the pattern we would expect to see if those who purchase guns (and perhaps those who remove guns from storage) are more likely to succumb to accidents until those guns are stored in a safer environment.

We formalized these visual perceptions in our econometric analysis, separately examining accidental firearm deaths at all ages: among children (ages 0 to 14) and among adults (ages 15 and over). We first estimate the following equation

$$DeathRate_{my} = \beta_0 + \beta_1 SandyHook_{my} + \varphi_m + \varphi_y + \varepsilon_{my}$$

where $DeathRate_{my}$ is the rate of accidental firearm deaths in the United States per 100,000 population in month m and year y and $SandyHook_{my}$ represents an indicator variable for the post–Sandy Hook window. Our regressions include a full set of year fixed effects (φ_y) to control for trends and month fixed effects (φ_m) to control for seasonal patterns. β_0 is the intercept and ε is the residual in this specification; the coefficient of interest is β_1. If $\beta_1 > 0$, this would indicate that, after controlling for trends and seasonal fluctuations, the number of accidental firearm deaths per capita increased during the period after Sandy Hook.

Table 1 presents the results of this analysis. The panel "Descriptive statistics" presents descriptive statistics of deaths and population size for the relevant age groups that are useful for reference purposes. The "National data, 2008–2015, ordinary least squares" panel shows the results of the analysis described above. Our results indicate that there were an additional 0.0036 monthly

Table 1. Estimated impact of Sandy Hook and gun-sales spikes on the number of monthly accidental firearm deaths per 100,000 population, by age. Each column shows the impact for a different age group, and each panel uses a different level of data aggregation or estimation method. Standard errors are reported in parentheses and, for state-level data, are clustered at the state level. The implied number of additional accidental firearm deaths for all ages may not equal the sum of the additional deaths for the two separate age groups as a result of rounding error. Regressions using national data include 96 monthly observations, and regressions using state-level data include 4512 month observations by state. **P* < 0.10; ***P* < 0.05; ****P* < 0.01.

	All ages	Children (ages 0 to 14)	Adults (ages 15+)
Descriptive statistics			
Average number of accidental firearm deaths in a 5-month window	210	28	182
2013 population (in millions)	316	61	255
National data, 2008–2015, ordinary least squares			
Impact of Sandy Hook	0.0036*** (0.0013)	0.0058*** (0.0021)	0.0031* (0.0016)
Implied number of additional accidental firearm deaths	57	18	40
National data, 2008–2015, instrumental variables			
Impact of 1000 gun sales per 100,000 population	0.019*** (0.006)	0.030*** (0.010)	0.016** (0.007)
Implied number of additional accidental firearm deaths	57	17	39
State data, 2008–2015, instrumental variables			
Impact of 1000 gun sales per 100,000 population	0.022** (0.010)	0.038** (0.018)	0.018* (0.010)
Implied number of additional accidental firearm deaths	66	22	43

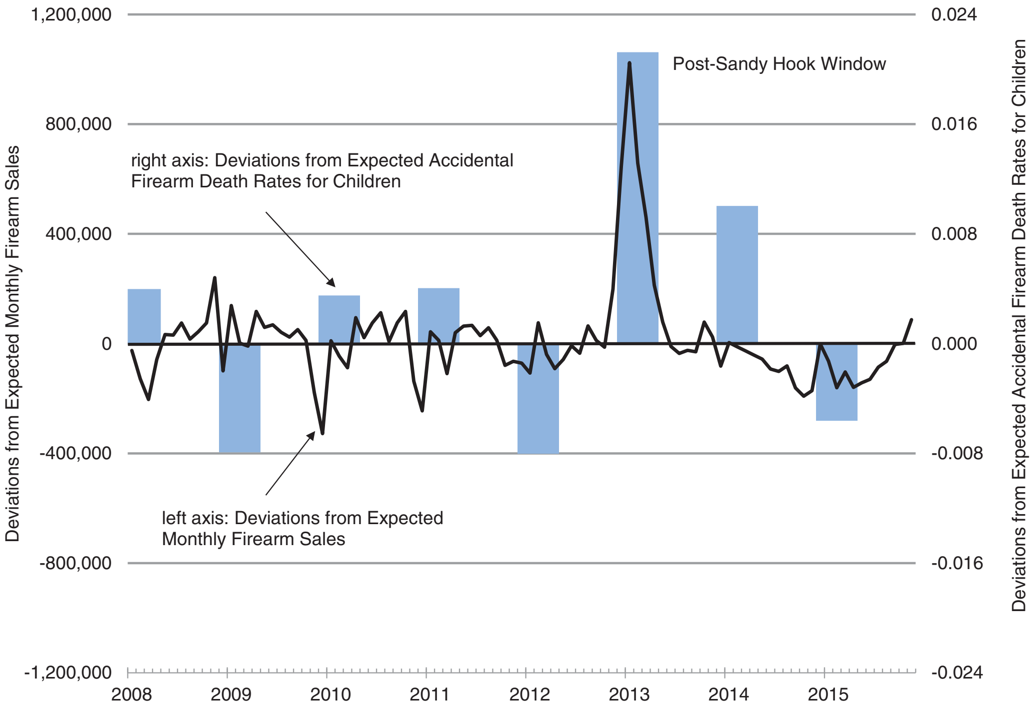

Fig. 2. Seasonally adjusted, detrended monthly firearm sales and accidental firearm death rates per 100,000 children (ages 0 to 14) between December and April. Firearm sales data are proxied by NICS data on background checks conducted when a firearm is purchased from a registered dealer. The accidental firearm death rate is calculated from Vital Statistics mortality data and SEER population data. The post–Sandy Hook window is defined to be December 2012 through April 2013.

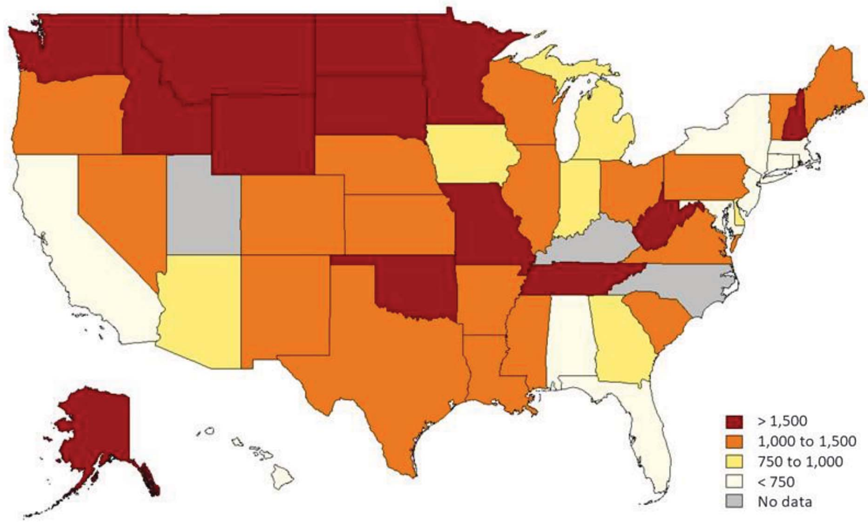

Fig. 3. Variation across states in the increase in firearm sales per 100,000 population in the post–Sandy Hook period. See notes to Fig. 2 for more details regarding the data. The spike in sales in each state is estimated as the seasonally adjusted and detrended increase in background checks in the months within the Sandy Hook window. The legend numbers represent the increase in firearm sales per 100,000 population.

deaths per 100,000 population overall, including an additional 0.0058 monthly deaths per 100,000 children and 0.0031 monthly deaths per 100,000 adults. The estimates for all deaths and for those of children are statistically significant at the 1% level. The estimates for adults are significant at the 10% level. This and all subsequent hypothesis tests represent two-tailed Student's t tests. With a 2013 population of 61 million children and 256 million adults and a 5-month period of increased firearm sales, these results imply 57 additional accidental firearm deaths in total (0.0036 × 3160 × 5, which represents monthly impact on the death rate × total population in 100,000s × number of months in post–Sandy Hook window), including 18 additional deaths among children (0.0058 × 610 × 5). These findings represent a 27% increase in such deaths overall, relative to an average 5-month period, and a 64% increase among children.

The analysis presented in the "National data, 2008–2015, instrumental variables" panel of Table 1 uses the same data, but in an instrumental variables framework. In this framework, we first created a predicted gun "sales rate" (thousands of guns sold per 100,000 population) using the following regression equation:

$$SalesRate_{my} = \delta_0 + \delta_1 SandyHook_{my} + \xi_m + \xi_y + v_{my}$$

This equation includes the same set of month and year fixed effects (ξ_m, and ξ_y) as before, but the dependent variable is now the sales rate, which serves as a proxy for gun exposure. The δ_1 indicates the extent to which the sales rate changed during the post-Sandy Hook window (δ_0 is the intercept and v is the residual). We then use the predicted sales rate (indicated with a "hat" above *SalesRate*) from that equation to estimate the following model (again, with fixed effects θ_m and θ_y, intercept γ_0 and residual u):

$$DeathRate_{my} = \gamma_0 + \gamma_1 \widehat{SalesRate}_{my} + \theta_m + \theta_y + u_{my}$$

This provides an estimate (γ_1) of the relationship between the gun sales rate ($SalesRate_{my}$) and the accidental firearm death rate ($DeathRate_{my}$). This model incorporates the assumption that the mortality rate would not have diverged from its normal seasonal and yearly patterns during this 5-month period if not for the increased firearm exposure that occurred during that time.

The results of this analysis are shown in the "National data, 2008–2015, instrumental variables" panel of Table 1. They indicate that an additional 1000 gun sales per 100,000 population were associated with 0.019 additional accidental gun deaths per 100,000 population overall and 0.030 and 0.016 for children and adults, respectively. These estimates are statistically significant at the 1% level overall and for children and at the 5% level for adults. With an actual increase in sales of 949 per 100,000 population in the aftermath of Sandy Hook, this translates into 57 additional deaths in the total population (0.019 × 0.949 × 3160, which represents impact of a 1000 additional gun sales per 100,000 population on the death rate × the size of the estimated sales increase × the total population in 100,000s), including 17 additional deaths among children (0.030 × 0.949 × 610) and 39 additional deaths among adults (0.016 × 0.949 × 2560).

We extended this approach to estimate the relationship between gun exposure and accidental firearm deaths using state-level observations of the same data sets (*15*). First, we detrended and deseasonalized the state-level sales data, as we did earlier using national data, and calculated the additional gun sales in each state in the 5-month window after Sandy Hook. As presented in Fig. 3, the results show considerable heterogeneity in the impact of Sandy Hook on firearm sales per 100,000 population across states, ranging from zero in Maryland to 2500 guns per 100,000 residents in New Hampshire.

In Fig. 4, we separated states into those whose gun sales rates rose by more or less than 1000 guns per 100,000 population and display the December-through-April rate of accidental firearm deaths among children between 2008 and 2015. This figure mimics the bars in Fig. 2, except that we distinguish between states with relatively high– and low–sales rate increases. The results show that the spike in children's deaths after Sandy Hook was, indeed, concentrated in those states with larger increases in per capita gun sales.

We formalized this analysis using an instrumental variables strategy. We predicted state-level increases in gun sales using two variables: (i) the same indicator variable for the Sandy Hook period that we used in the national data analysis and (ii) the interaction between the Sandy Hook indicator and the share of the electorate in each state that voted for Barack Obama in 2012. The first variable captures the average increase across all states in the rate of gun sales in the post–Sandy Hook window. The second variable captures the differential impact of Sandy Hook on gun sales across states. Prior research has shown that state voting patterns in presidential elections are correlated with the prevalence of voter concerns about gun control legislation (*13*). States that more strongly supported Barack Obama experienced smaller increases in gun sales (correlation coefficient = –0.63).

We used the predicted variation in state gun-sales increases as the key independent variable in a multivariate regression in which the dependent variable is the accidental firearm death rate for each age group. This model also controls for state-specific month and year indicator variables. The key assumption of this model is that the share of Obama voters in a state did not impact that state's accidental firearm mortality rate during this 5-month period, except through its impact on gun exposure in that state during that period. The advantage of using this predicted variation in state gun sales, rather than actual variation, is that it abstracts from any other variation in gun exposure that is unrelated to gun-policy concerns in the aftermath of Sandy Hook, but might also have an impact on accidental firearm deaths. More details about this regression model are available in (*10*).

The "State data, 2008–2015, instrumental variables" panel of Table 1 reports results from this analysis. We estimate that 1000 additional gun sales per 100,000 population is associated with 0.022 accidental firearm deaths per 100,000 population. The effect among children and adults is 0.038 and 0.018, respectively. These results are statistically significant at the 5% level overall and for children and at the 10% level for adults. The estimates from this model imply that additional gun exposure after Sandy Hook led to the accidental shooting deaths of 66 people, including 22 children.

We caution against interpreting our results as representing a direct link between the greater gun sales and these additional deaths. Gun sales represent a proxy for gun exposure in our analysis; they are correlated with an increased interest in firearms, even among current gun owners, as shown in our Google Trends analysis. We cannot determine the extent to which the impact is driven by sales or greater exposure to existing guns.

An important attribute of this analysis is the ability to plausibly distinguish causation from simple correlation. Simple comparisons of trends over time, for instance, indicate a negative correlation between gun sales and accidental gun deaths. Such comparisons, though, do not account for the presence of other trends that confound these statistics. The methodology we implemented enables us to abstract from these confounding factors. The focus on spikes in gun sales, whose timing may be considered random, enables us to introduce techniques that simulate an experiment. Unless it happened to be the case that something else occurred that caused an increase in accidental firearm deaths at exactly the same time as Sandy Hook and in those locations where the gun-exposure spikes were largest, our approach will have generated causal estimates.

There are several limitations that need to be taken into consideration in evaluating the results of our analysis. First, Vital Statistics mortality

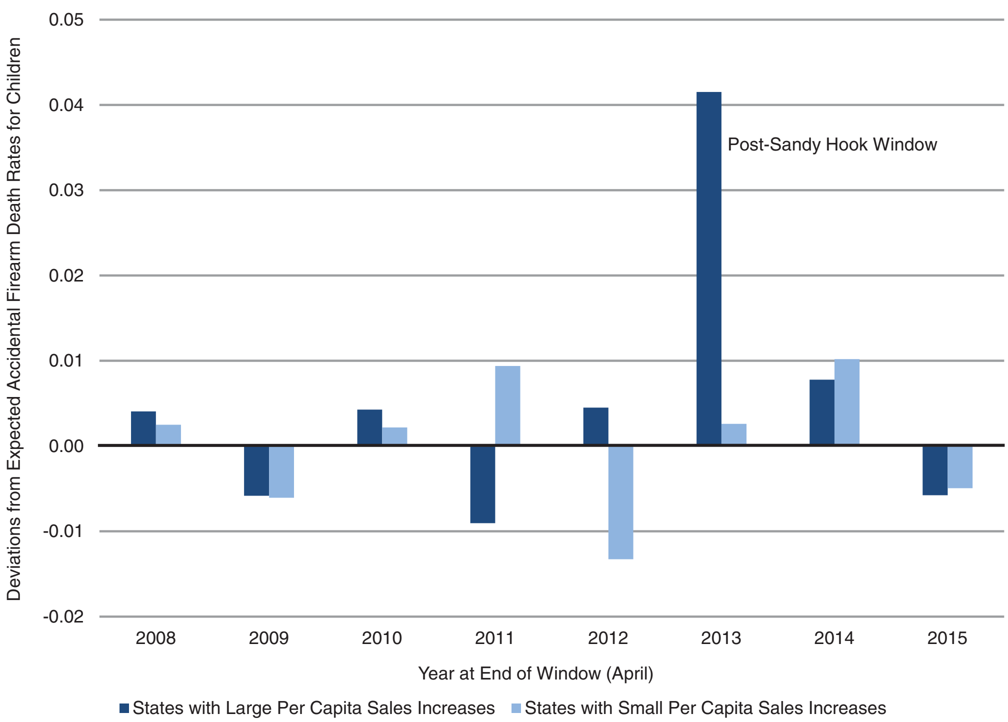

Fig. 4. Deviations from expected accidental firearm death rates per 100,000 children (ages 0 to 14) between December and April for states with large and small post–Sandy Hook increases in gun sales rates. See notes to Fig. 2 for more details regarding the data. A large (small) increase in gun sales is defined to be greater (lesser) than 1000 additional guns sold per 100,000 population.

data are known to understate accidental firearm deaths (*16*). Mismeasurement in the Vital Statistics data, however, will bias our results only if it is systematically associated with the spikes in gun sales, which is unlikely.

A second limitation is that we observe only those unintentional firearm injuries that result in death, and our estimates therefore provide a lower bound on the public health consequences of spikes in gun exposure. Prior research demonstrates that the majority of unintentional firearm injuries do not result in death (*17*, *18*).

A third limitation is that our reported analysis has focused only on accidental firearm deaths, ignoring the potential impact on firearm-related suicides and homicides. Individuals who responded to concerns about gun control by purchasing or handling a firearm are unlikely to be motivated by an intention to kill themselves or others with those guns. We have also examined these mortality outcomes and found no systematic effect of the spike in gun sales. This finding is consistent with prior research that analyzed the short-term impact of increased firearm purchases due to local gun shows on homicides and suicides and found no evidence of impacts on those outcomes (*19*).

A fourth limitation is that our empirical approach does not allow us to identify any long-term impact of firearm purchases. The presence of more firearms in society may alter the likelihood of accidental deaths (or other outcomes) at any point in time, but we are only able to identify the short-term impact.

Taken as a whole, our analysis provides evidence indicating that the spike in gun exposure that followed the Sandy Hook school shooting increased the incidence of accidental firearm deaths, particularly among children. Our findings support the recommendations of the American College of Preventive Medicine, which include safe gun-storage laws and physician counseling of their patients about approaches that can help reduce deaths associated with the accidental discharge of a firearm (*20*).

REFERENCES AND NOTES

1. A. Altman, "Obama takes a first step on gun control after Sandy Hook." *TIME*, 19 December 2012; http://swampland.time.com/2012/12/19/obama-takes-a-first-step-on-gun-control-after-sandy-hook/.
2. "What's in Obama's gun control proposal," *New York Times*, 16 January 2013; www.nytimes.com/interactive/2013/01/16/us/obama-gun-control-proposal.html.
3. E. Underwood, *Science* **339**, 381–382 (2013).
4. D. E. Stark, N. H. Shah, *JAMA* **317**, 84–85 (2017).
5. A. L. Kellermann, F. P. Rivara, *JAMA* **309**, 549–550 (2013).
6. D. J. Wiebe, *Accid. Anal. Prev.* **35**, 711–716 (2003).
7. N. Sinauer, J. L. Annest, J. A. Mercy, *JAMA* **275**, 1740–1743 (1996).
8. M. Miller, D. Azrael, D. Hemenway, M. Vriniotis, *Accid. Anal. Prev.* **37**, 661–667 (2005).
9. G. J. Wintemute, S. P. Teret, J. F. Kraus, M. A. Wright, G. Bradfield, *JAMA* **257**, 3107–3109 (1987).
10. See supplementary materials.
11. M. Lang, *Econ. J. (London)* **123**, 1085–1099 (2013).
12. M. Lang, *South. Econ. J.* **83**, 45–68 (2016).
13. E. Depetris-Chauvin, *J. Public Econ.* **130**, 66–79 (2015).
14. D. M. Studdert, Y. Zhang, J. A. Rodden, R. J. Hyndman, G. J. Wintemute, *Ann. Intern. Med.* **166**, 698–706 (2017).
15. National Center for Health Statistics. Mortality File with All County Geographical Information, 2008–2015, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. See www.cdc.gov/rdc for more details.
16. C. Barber, D. Hemenway, *Accid. Anal. Prev.* **43**, 724–731 (2011).
17. J. L. Annest, J. A. Mercy, D. R. Gibson, G. W. Ryan, *JAMA* **273**, 1749–1754 (1995).
18. K. A. Fowler, L. L. Dahlberg, T. Haileyesus, C. Gutierrez, S. Bacon, *Pediatrics* **140**, e20163486 (2017).
19. M. Duggan, R. Hjalmarsson, B. A. Jacob, *Rev. Econ. Stat.* **93**, 786–799 (2011).
20. B. L. Strong, S. B. Ballard, W. Braund, *Am. J. Prev. Med.* **51**, 1084–1089 (2016).

ACKNOWLEDGMENTS

We are grateful to D. Azrael, C. Barber, M. Fan, D. Fetter, D. Hemenway, R. McClure, M. Miller, K. Park, and D. Sichel for helpful conversations and seminar participants at Wellesley College and Dartmouth College for their comments. All publicly available data sources and programs used to generate the results reported in this paper are available at doi: 10.7910/DVN/EVLKBN. Mortality data containing state identifiers, which we use in part of our analysis, are restricted, but can be obtained for research purposes from the U.S. Centers for Disease Control and Prevention (www.cdc.gov/rdc). All components of this research project were carried out equally by the two authors; neither author has a conflict of interest in the conduct of this research. No external funding was used to support this research.

SUPPLEMENTARY MATERIALS

www.sciencemag.org/content/358/6368/1324/suppl/DC1
Materials and Methods
Figs. S1 to S4
References (*21*–*24*)

23 May 2017; accepted 20 October 2017
10.1126/science.aan8179

Science

Firearms and accidental deaths: Evidence from the aftermath of the Sandy Hook school shooting

Phillip B. Levine and Robin McKnight

Science **358** (6368), 1324-1328.
DOI: 10.1126/science.aan8179

One cause of accidental deaths
The number of accidental deaths involving a firearm might be expected to correlate with the number of firearms, but claims that a causal relationship exists have not been persuasive (see the Policy Forum by Cook and Donohue). The 2012 mass shooting at an elementary school in the eastern United States resulted in the deaths of 20 children. Levine and McKnight used the random timing of this event and the subsequent increase in gun purchases (as recorded by an increased number of background checks) to show that the increased exposure to guns resulted in ~60 accidental deaths.
Science, this issue p. 1324 see also p. 1259