OBSERVATION: BRIEF RESEARCH REPORT

Fatal Firearm Incidents Before and After Australia's 1996 National Firearms Agreement Banning Semiautomatic Rifles

Background: In 1996, after the Port Arthur massacre in Tasmania, the National Firearms Agreement was enacted across Australia. Provisions included uniform gun registration, repudiation of self-defense as a legitimate reason to hold a firearm licence, locked storage, a ban on private gun sales and civilian ownership of semiautomatic rifles and pump-action shotguns, and standardized penalties (1). Two buyback programs and 26 uncompensated amnesties between 1996 and 2015 resulted in the surrender of 1 038 089 illicit firearms (2).

An analysis of firearm deaths between 1979 and 2013 showed that 13 mass shootings (homicides in which at least 5 persons died, not including the perpetrator) took place in the 18 years preceding and including the Port Arthur massacre; none has occurred in the 22 years since (3). Many believe that these data indicate that gun law reforms effectively stopped firearm massacres. However, others contend that this interpretation is unwise because of the rarity of these events compared with more common incidents in which fewer than 5 persons died (4).

Objective: To test the null hypothesis that the rate of mass shootings remained unchanged after introduction of the National Firearms Agreement.

Methods: We modeled the occurrence of mass shootings over time by using a rare events model in which occurrences in nonoverlapping intervals are independent Poisson random variables. Different intervals may have different intensities or rates. The expected value in each interval is the product of the rate and length of the interval.

The period before legislation was defined as January 1979 to June 1996 (210 months); the period after legislation was defined as July 1996 to February 2018 (260 months). We considered a constant rate model where the rate of mass shootings was assumed to remain constant over the entire period and a (2-period) changepoint model where the rate differed between these periods. A likelihood ratio test was used to compare the goodness of fit between the models.

We calculated the *P* value associated with the likelihood ratio test by using standard asymptotic theory and through simulation by using a parametric bootstrap method. As a sensitivity analysis, we recomputed the asymptotic *P* value to determine how it would change if another shooting had taken place in February 2018. An additional sensitivity analysis accounted for possible dependence over time (a mass shooting at 1 time may increase the chances of another in a subsequent short period) by using a test based on scan statistics (5). We obtained (unadjusted) *P* values for the maximal scan statistic at a range of window sizes and obtained a multiplicity-adjusted *P* value based on the smallest of these. Full details of this test and the simulation are available in the

Figure 1. Summary of statistics.

Variable	Months, *n*	Mass Shootings, *n*	Expected Mass Shootings Under Constant Rare Events Model
Before legislation*	210	13	$\frac{13}{210+260} \times 210 \approx 5.809$
After legislation†	260	0	$\frac{13}{210+260} \times 260 \approx 7.191$

LR test comparing constant and changepoint model fits:

Asymptotic (actual data)

$$LR = \left[\frac{e^{-13}13^{13}}{13!}\frac{e^{-0}0^{0}}{0!}\right] \Big/ \left[\frac{e^{-5.809}5.809^{13}}{13!}\frac{e^{-7.191}7.191^{0}}{0!}\right] \approx 35313.9$$

$$P = P\,(\chi^2_1 \geq 2log_e\,(35313.9) \approx 20.95) \approx 4.7 \times 10^{-6}$$

Asymptotic (perturbed data)

$$LR = \left[\frac{e^{-13}13^{13}}{13!}\frac{e^{-1}1^{1}}{1!}\right] \Big/ \left[\frac{e^{-6.255}6.255^{13}}{13!}\frac{e^{-7.745}7.745^{1}}{1!}\right] \approx 1741.9$$

$$P = P\,(\chi^2_1 \geq 2log_e\,(1741.9) \approx 14.93) \approx 1.1 \times 10^{-4}$$

Bootstrap resampling‡

$$P = 137/20 \text{ million} = 6.9 \times 10^{-6}$$

Reported *P* values are 2-sided. The constant model assumes that the rate of mass shootings remains constant across the full period; the changepoint model assumes that the rate differs between the before and after periods. LR = likelihood ratio.
* January 1979 to June 1996.
† July 1996 to February 2018.
‡ Based on 20 million simulations; R code (R Project for Statistical Computing) is provided in the **Supplement** (available at Annals.org).

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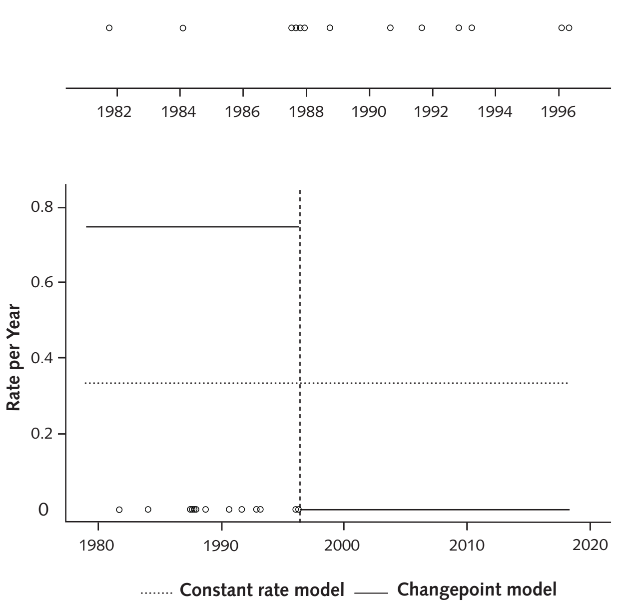
Figure 2. Mass shootings.



Open circles indicate mass shootings. **Top.** Occurrences of mass shootings, 1979–1996. **Bottom.** Estimated rate of mass shootings per year under 2 different models. Our statistical test compared the constant rate and changepoint models, rejecting the former in favor of the latter. The vertical dashed line indicates the change at June 1996.

Supplement (available at Annals.org). The range of window sizes used was between 1 and 18 months, suggested by the 2 most significant sizes of 7 and 16 months (**Supplement**).

Results: Under the standard Poisson process model (**Figure 1**), strong evidence indicates a structural change in 1996. A (conservative, 2-sided) likelihood ratio test for a changepoint in a Poisson process model gives a *P* value of less than 0.001, which is strong evidence to reject the null hypothesis that the rate of mass shootings did not change after the legislation (**Figure 2**). Perturbing the data with an extra shooting again gives a *P* value of less than 0.001. A follow-up goodness-of-fit test designed to detect excessive clumping gives a *P* value of 0.095, which indicates that the Poisson model is a good fit in this sense; the degree of clumping in the data is not dramatic enough to reject the Poisson process model.

Before 1996, approximately 3 mass shootings took place every 4 years. Had they continued at this rate, approximately 16 incidents (SD, 4) would have been expected since then by February 2018.

Discussion: Without a 22-year randomized controlled trial assigning only parts of a national population to live under the National Firearms Agreement, establishing a definitive causal connection between this legislation and the 22-year absence of mass firearm homicides is not possible. However, a standard rare events model provides strong evidence against the hypothesis that this prolonged absence simply reflects a continuation of a preexisting pattern of rare events.

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Disclaimer: Dr. Chapman was a member of the Australian Coalition for Gun Control, which advocates for firearm law reform, between 1993 and 1996. Mr. Alpers runs GunPolicy.org, a global nonpartisan clearinghouse for firearm-related data.

Disclosures: Disclosures can be viewed at www.acponline.org/authors/icmje/ConflictOfInterestForms.do?msNum=M18-0503.

Reproducible Research Statement: *Study protocol, statistical code, and data set:* See the **Supplement** (available at Annals.org).

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