Role of Firearm Ownership on 2001–2016 Trends in U.S. Firearm Suicide Rates

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Abstract

Introduction: In the U.S., state-level household firearm ownership is strongly associated with firearm suicide mortality rates. Whether recent increases in firearm suicide are explained by state-level household firearm ownership rates, and trends, remains unknown.

Methods: Mortality data from the U.S. National Vital Statistics System and an estimate of state-level household firearm ownership rate were used to conduct hierarchical age–period–cohort (random-effects) modeling of firearm suicide mortality between 2001 and 2016. Models were adjusted for individual-level race and sex, and state-level poverty rate, unemployment rate, median household income in U.S. dollars, population density, and elevation.

Results: Between 2001 and 2016, crude national firearm suicide mortality rate increased from 6.8 to 8.0/100,000 and household firearm ownership rate remained relatively stable, at around 40%. Both variables were markedly heterogeneous and correlated at the state level. Age–period–cohort models revealed period effects (affecting people across ages) and cohort effects (affecting specific birth cohorts) underlying recent increases in firearm suicide. Individuals born after 2000 had higher firearm suicide rates than most cohorts born before. A 2001–2006 decreasing period effect was followed, after 2009, by an increasing period effect that peaked in 2015. State-level household firearm ownership rates, and trends, did not explain cohort effects and only minimally explained period effects.

Conclusions: State-level firearm ownership rates largely explain state-level differences in firearm suicide, but only marginally explain recent increases in firearm suicide. Although firearms in the home increase firearm suicide risk, the recent national rise in firearm suicide might be the result of broader, more distal causes of suicide risk.

INTRODUCTION

Suicide mortality risk is highly determined by choice of suicide method. For instance, suicide attempts involving use of a firearm are nearly always lethal and 40 times more lethal than intentional overdoses.[1] Moreover, 90% of attempt survivors do not go on to die by suicide later in life.[2,3] For these reasons, lethality of the suicide methods that people routinely have at hand is a key actionable determinant of long-term survival. Accordingly, lethal means restriction is a leading evidence-based strategy for suicide prevention,[4] largely responsible for recent decreases in global suicide rates.[5]

In the U.S., the country with the highest per-capita prevalence of civilian-owned firearms,[6] the majority of firearm deaths are intentionally self-inflicted and half of suicide deaths involve firearm use.[7] In addition, suicide mortality rates in the U.S. have increased by >30% over the last 2 decades, across all suicide methods, constituting a major public health crisis.[8]

A large body of well-designed studies indicates that firearm ownership is associated with higher risk of death by firearm suicide at the state,[9] household,[10] and individual[11,12] levels, across sociodemographic groups.[12] Accordingly, substantial attention has been directed toward firearm ownership as a salient target for suicide prevention efforts.

Notwithstanding, 2 aspects of the association between firearm ownership and firearm suicide risk in the U.S. remain poorly understood, despite public health and clinical implications (e.g., for guiding preventative policies; developing, implementing, or scaling up preventative interventions; and identifying high-risk sociodemographic groups). First, though evidence from the 1980s and 1990s suggests that declines in firearm ownership rates were directly associated with declines in overall and firearm suicide rates,[13] the role of trends in firearm ownership rates in recent increases in firearm suicide rates has not been explored. Second, decomposing suicide mortality trends across age–period–cohort effects can help identify potential underlying actionable mechanisms. Established age–period–cohort models of suicide in the U.S. indicate that increases in firearm suicide mortality are the result of both period and birth cohort effects,[14] with period effects driving much of the increases in recent years (indicating that suicide mortality is increasing across all ages). However, the extent to which recent trends in firearm ownership rates may have impacted the period and cohort effects underlying recent increases in firearm suicide mortality rate has not been analyzed.

Here, the role of state-level differences and trends in household firearm ownership on recent suicide mortality rates in the U.S. are examined, using hierarchical age–period–cohort (random-effects) models.

METHODS

Study Sample

Suicide mortality data from the U.S. National Vital Statistics System were used for the main analysis. Though mortality data are available through 2019, data on firearm ownership by state are available through 2016; thus, the time period of outcome data was matched to the time period of exposure data. Suicide mortality data through 2018 were included in a sensitivity analysis. These data comprise basic clinical and demographic information retrieved from all deaths certificated in the U.S. including immediate and underlying cause/s of death, age, sex (male, female), race (Black or African American, Asian or Pacific Islander, American Indian or Alaska Native, and White), and county of residence.[15] Deaths were designated as attributable to suicide based on ICD-10 underlying cause of death codes X60–X84, Y87.0, and U03, following guidelines from the National Center for Health Statistics.[8] Analyses were further restricted only to firearm suicides among decedents aged 10–84 years, given the lack of firearm suicides prior to age 10 years and unavailability of disaggregated data after age 84 years. State-level population data from the National Center for Health Statistics, including intercensal (1999–2009)[16,17] and postcensal (2010–2018)[18] estimates, were used to calculate unadjusted mortality rates for populations aged 10–84 years.

Measures

To measure state-level household firearm ownership rate, a modification of the factor score developed by the Research and Development Corporation[19] was used. The original household firearm ownership rate score estimates the state-level proportion of adults who live in a household with a firearm annually between 1980 and 2016 and is based on 9 measures: 4 direct measures of household gun ownership from several non-annual representative surveys (the Behavioral Risk Factor Surveillance System, Gallup, the General Social Survey, and Pew Research Center) and 5 indirect measures (male and female proportions of firearm suicides/total suicides, hunting license rate, Guns & Ammo per capita subscribers, and background check rate). In addition, the score includes 3 exogenous factors: indicators of states with laws regulating universal background checks and firearm purchase permits, and 3 time splines (for hunting licenses). A modified estimate of the state-level proportion of adults who live in a household with a firearm (hereafter called household firearm ownership rate) for the 1999–2016 period, excluding the item on firearm suicides/total suicides (which was colinear with the outcome), was calculated using code provided by the Research and Development Corporation and applied in all models. Notably, the original and modified household firearm ownership rate scores were highly correlated (r =0.98, p<0.001).

The following additional state-level covariates[20] were used, with yearly data from 2001 to 2018: proportion of adult population unemployed, retrieved from the U.S. Bureau of Labor Statistics[21]; proportion of families living in poverty, median household income in 2014 U.S. dollars, and population density in people per square mile, all provided by GeoLytics[22]; and mean elevation in feet, retrieved from the U.S. Census.[23] Data from GeoLytics, including

proportion of families living in poverty, population density, and median household income, were not available for Alaska.

Statistical Analysis

First, descriptive analyses of spatiotemporal variation in firearm suicide mortality rates and household firearm ownership in U.S. states between 1999 and 2016 were conducted. Then, age–period–cohort effects were modeled. Age–period–cohort analyses disentangle variation in trends over time related to 3 components: age effects (resulting from factors specific to development stages), period effects (resulting from external factors that impact subjects across age and birth cohort), and cohort effects (resulting from the environmental exposures shared by individuals born into a specific historical context over the life course).[24] The goal was to understand the impact of state-level household firearm ownership on age–period–cohort effect estimates. Hence, hierarchical cross-classified random effect models, which allow for the inclusion of covariates,[25,26] were implemented. All models included individual-level variables for race and sex, and were restricted to the 2001–2016 period and all states excluding Alaska based on covariate information availability. Three models were estimated where age was categorized in 5-year groups and included as a Level-1 variable, and period and cohort were estimated as random intercept effects. For the first model, state was included as a fixed term, given notable differences in firearm suicide rates across states. For the second model, the fixed term for state was excluded and the following state-level covariates were included: poverty rate, unemployment rate, median household income, population density, and mean elevation. For the third model, state-level household firearm ownership rate was added to the set of covariates included in the second model. Of note, household firearm ownership rate was correlated with poverty rate ($r=0.28$, $p<0.001$), unemployment rate ($r=-0.16$, $p<0.001$), and median household income ($r=-0.71$, $p<0.001$) at the state level. State-level household firearm ownership rates remained relatively stable over the study period; variation in household firearm ownership was largely explained by between-state differences (state intraclass correlation coefficient=0.94) rather than betweenperiod differences (period intraclass correlation coefficient=0.13). Hence, household firearm ownership rate was entered in the model categorized in octiles, based on each state's yearly household firearm ownership rate classified relative to the range of rates for all states (excluding Alaska) over the 2001–2016 period. Period and cohort (random) effects were centered to ease interpretation.

For each model, the period effect's median odds ratio (MOR) was estimated to quantify the period effect variability that remained unexplained by the other set of variables included in the model. The MOR provides an estimate of the differences between outcomes by Level-2 random effects; an increased MOR for a particular Level-2 effect (i.e., cohort, period) indicates that more of the variation in firearm suicide rates is due to variation in the Level-2 effect. A decrease in the MOR after including a covariate in the model (i.e., state-level firearm ownership by year) indicates that the covariate explained variation in the Level-2 effect. The remaining magnitude of the MOR indicates the amount of variance in the outcome due to the Level-2 effect that is not explained by the covariates. Accordingly, the difference in MOR between the second and third models quantifies the role of state-level

firearm household ownership rate on recent trends and period/cohort effects in firearm suicide mortality.

Data cleaning and descriptive analyses were completed in R, version 4.0.3.[27] Age–period–cohort models were completed in SAS, version 9.4.[28]

Two prespecified sensitivity analyses were conducted. First, the third model was repeated, including the household firearm ownership rate as a continuous variable. Second, capitalizing on the temporal stability of household firearm ownership rate, models were extended through 2018 by carrying forward the 2016 household firearm ownership rate, using 2016–2018 data on firearm suicide mortality rates, poverty rate, unemployment rate, and median household income.

RESULTS

Between 1999 and 2016, U.S. firearm suicide mortality rate for individuals aged 10–84 years increased from 6.8 to 8.0 deaths per 100,000 people as a result of an initial gradual downward trend between 1999 and 2006 followed by an increase between 2007 and 2016 (Figure 1, right axis). National estimates of household firearm ownership rate remained relatively stable over the same period (Figure 1, left axis), indicating that around 40% of adults lived in a household with a firearm.

Figure 2 represents state-level firearm suicide mortality rates and household firearm ownership rates for the whole study period, ranked from lowest to highest: Both variables were notably correlated and substantially heterogeneous across states (r=0.81, p<0.001). States with the highest firearm suicide mortality rates (e.g., Montana, Alaska, or Wyoming) had the highest estimates of household firearm ownership; and states with the lowest firearm suicide mortality rates (e.g., New Jersey or Massachusetts) had the lowest estimates of household firearm ownership.

Appendix Table 1 and Appendix Figure 1 represent the trends over time in firearm suicide rates and household firearm ownership by state. Between 1999 and 2016, firearm suicide rates increased in 41 states, and household firearm ownership rates increased in 28 states.

Recent increases in firearm suicide rates were due to both cohort and period effects. Individuals born after 2000 had higher firearm suicide rates than most cohorts born between 1930 and 2000, with random effect coefficients of around 0.15 (Figure 3). Notably, cohort effects remained unchanged across differently specified models: subtraction and addition of state-level covariates, including household firearm ownership rate, did not account for firearm suicide mortality increases among recently born cohorts.

A decreasing period effect between 2001 and 2006 was followed by a stable period between 2006 and 2009 and a subsequent increasing period effect that peaked, in fully adjusted models, in 2015 with a random effect coefficient of around 0.16 (Figure 4). Inclusion of state-level covariates did modify the variability of period effect estimates. The first model, including only a fixed term for state, yielded a period effect (MOR=1.06). The second model, including state-level poverty rate, unemployment rate, median household

income, population density, and mean elevation resulted on a higher period effect variability (MOR=1.15). Part of the period effect variability could be explained by state-level household firearm ownership rate, as inclusion of this covariate in the third model resulted on a period effect (MOR=1.11).

Results did not change across the 2 pre-specified sensitivity analyses. Inclusion of state-level household firearm ownership rate as a continuous variable resulted in similar cohort and period effects (Appendix Figures 2 and 3), for a period effect (MOR=1.09) in the fully adjusted model including state-level poverty rate, unemployment rate, median household income, mean elevation, population density, and household firearm ownership rate. Extension of the study period from 2001–2016 to 2001–2018 also yielded similar cohort and period effects (Appendix Figures 4 and 5). Again, inclusion of state-level household firearm ownership rate did not lead to variation in cohort effects but reduced the variability of period effect estimates, from a period effect (MOR=1.16) in the model including state-level poverty rate, unemployment rate, median household income, population density, and mean elevation to a period effect (MOR=1.12) following additional inclusion of household firearm ownership rate.

DISCUSSION

Between 1999 and 2018, firearm suicide mortality rates increased in the U.S. nationally and in 41 of 50 states owing to cohort and period effects: Firearm suicide risk increased disproportionately (1) among recently born cohorts in comparison with all birth cohorts since 1930 and (2) across age groups and birth cohorts, after 2009. The proportion of people who lived in a household with a firearm, however, remained relatively stable at around 40%, increasing in 28 states between 1999 and 2016. These findings indicate that state-level household firearm ownership rates and trends could explain a proportion of period effects but appeared unrelated to cohort effects in firearm suicide mortality, which has important implications for prevention efforts.

State-level household firearm ownership rates were spatially correlated with state-level firearm suicide mortality rates. State-level household firearm ownership rates also partially explained the recent increase in firearm suicide risk over time across age groups and birth cohorts (e.g., the period effect). Both findings are in line with a large body of literature examining the ecological association between firearm ownership and suicide mortality[9–11,29,30] and serve to highlight the importance of firearm ownership as a determinant of access to lethal means for people experiencing a suicidal crisis.[31] Reducing the availability of highly prevalent lethal means[32,33] in general and of firearms[34–38] in particular has proven effective at lowering method-specific and overall suicide mortality rates in several high-income countries.[24–29]

In the U.S., where rapid reductions in the overall level of firearm ownership are unlikely given the entrenched historical, political, social, and legal climate (sometimes referred to as "gun culture"[39–41]), clinical and legislative efforts to reduce access to firearms during suicidal crises might focus on more proximal determinants of firearm suicide, such as method for firearm storage[42,43] or individual interventions for at-risk individuals including

lethal means counseling.[31] Policy efforts such as red flag laws, which allow court petitions to temporarily prohibit firearm purchase and possession to individuals deemed dangerous to self or others, have broad public support and are associated with modest reductions in firearm suicide rates.[44]

A substantial proportion of the period effect in firearm suicide mortality, however, could not be explained by rates and trends in household firearm ownership. There was a notable increase in firearm suicide mortality risk among recent birth cohorts, in line with recent research,[45] and consistent with recent increases in depression and suicidal behaviors among U.S. adolescents and young adults.[48–50] State-level firearm ownership rate and trends did not modify this cohort effect. This is in keeping with evidence indicating that suicide mortality increased recently in the U.S. across sociodemographic groups, birth cohorts, and methods—in fact, recent increases in suicide mortality in the U.S. were starker for non-firearm than firearm suicide,[8] leading to the observation that the proportion of suicides involving use of a firearm has decreased slightly because of faster increases in other suicide methods. Taken together, this evidence points to broader, more distal factors, such as consequences of the opioid overdose epidemic,[45] downstream consequences of the 2008 recession,[46] or a general decline in social connectedness.[47]

Importantly, this finding should not lead to an underestimation of the importance of access to firearms as an actionable public health target for reducing suicide risk, because firearm ownership rates mediate the relationship between distal social factors and firearm suicide mortality risk. Although recent stable firearm ownership rates do not seem to have had a role in contemporary risk increases among young individuals, a large body of evidence links variations in firearm availability to variations in firearm suicide risk, especially among youth. Recent reports,[51] indicating that firearm purchases have increased markedly during the initial phases of the coronavirus disease 2019 (COVID-19) pandemic, should be cause for concern over its potential contribution to longer-term trends in suicide mortality rates.

Limitations

This study has potential limitations. First, suicides may be under-reported owing to certification errors.[52] Second, the original estimate of state-level household firearm ownership rate was recalculated, after excluding an item measuring the proportion of suicides involving a firearm to prevent collinearity with the outcome. Notably, the original and the modified estimated rates were very highly correlated. Third, the ecological nature of the associations somewhat hinders interpretation. Future studies should examine the role of firearm ownership on suicide using more granular spatial units or at the individual level. Fourth, as data did not include information on firearm ownership after 2016, sensitivity analyses extending results through 2018 rely on the assumption that household firearm ownership rate remained stable between 2016 and 2018. This assumption, however, is reasonable according to recent surveys.[53,54] Fifth, the moderating role of certain specific firearm access variables that may be associated with firearm suicide risk, such as ownership of multiple firearms or of particular types of firearms,[55] proportion of first-time firearm buyers,[11] or firearm storage practices,[43] could not be explored. Although evidence strongly indicated that firearm ownership increases firearm suicide risk regardless of number or type

of firearms owned and of storage practices,[56,57] future research should examine the role of these variables on recent increases in suicide mortality. Last, the analysis also did not examine state firearm policies that may contribute to the reported associations.

CONCLUSIONS

Recent increases in firearm suicide mortality were due to both cohort and period effects: Individuals born after 2000 had higher suicide rates than most 1930–2000 birth cohorts and firearm suicide risk increased after 2009 across age groups and birth cohorts. State-level firearm ownership rates, which remained relatively stable over the last 2 decades, largely explain state-level differences in firearm suicide but only marginally explain recent increases in firearm suicide: State-level firearm ownership rates, and trends, did not explain cohort effects and only minimally explained period effects. Although firearms in the home increase the risk of firearm suicide, the recent national rise in firearm suicide may also involve increases in other threats to health, including consequences of the opioid overdose epidemic,[45] downstream consequences of the 2008 recession,[46] or a general decline in social connectedness.[47] Minimizing the risks due to firearm ownership remains an important part of suicide prevention, but other efforts targeting broader, more distal causes of suicide risk are also urgently needed.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

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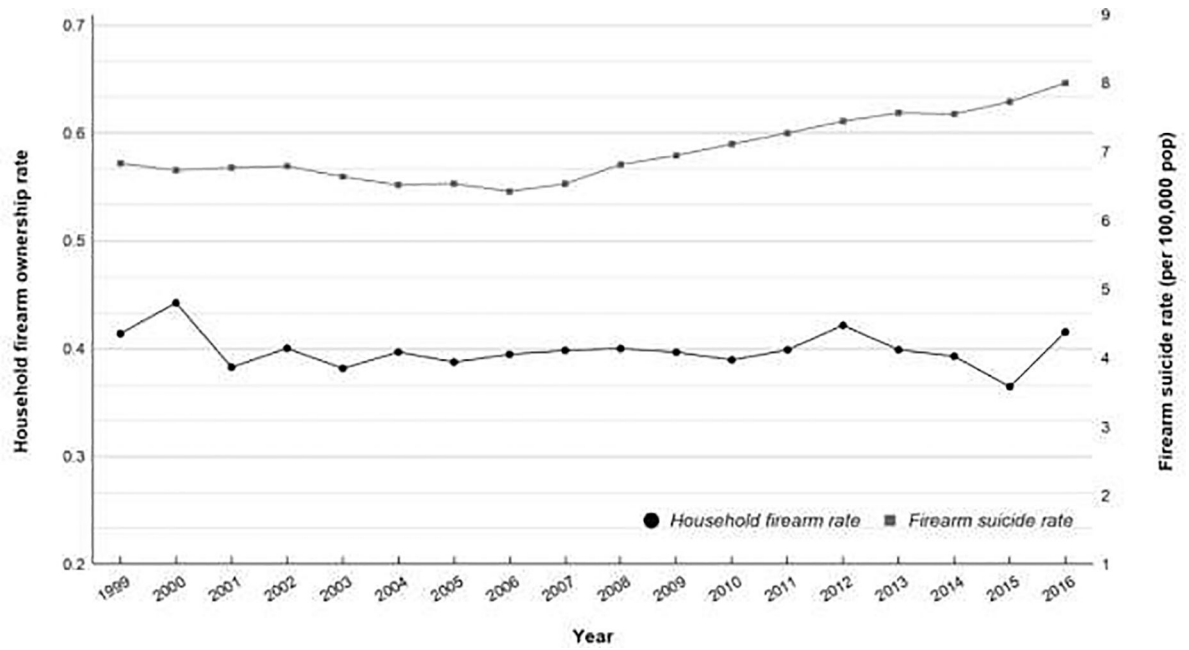
Figure 1.
Proportion of adults who live in a household with a firearm (left axis) and firearm suicide
mortality rate (right axis) in the U.S., 1999–2016, by year.

Notes: Household firearm rate represents the average proportion of adults living in
households with a firearm. Firearm suicide rates are restricted to population aged 10−84
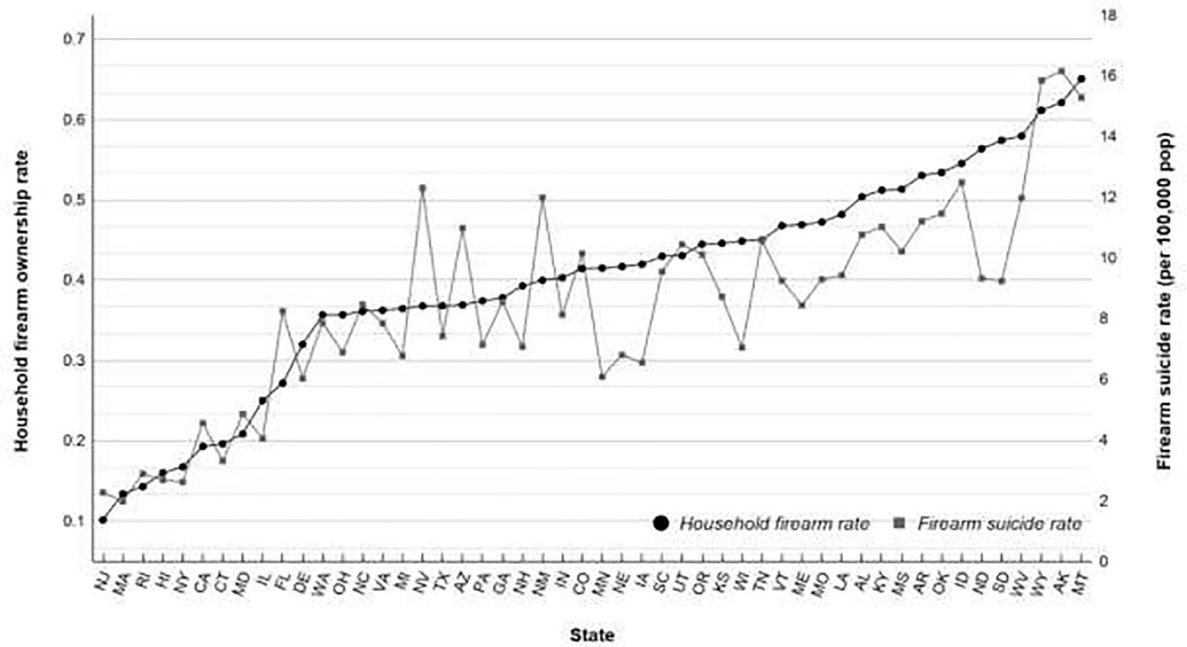years.

Figure 2.
Proportion of adults who live in a household with a firearm (left axis) and firearm suicide mortality rate (right axis) in the U.S., 1999–2016, by state.

Notes: Household firearm rate represents the average proportion of adults living in households with a firearm. Firearm suicide rates are restricted to population aged 10–84 years.
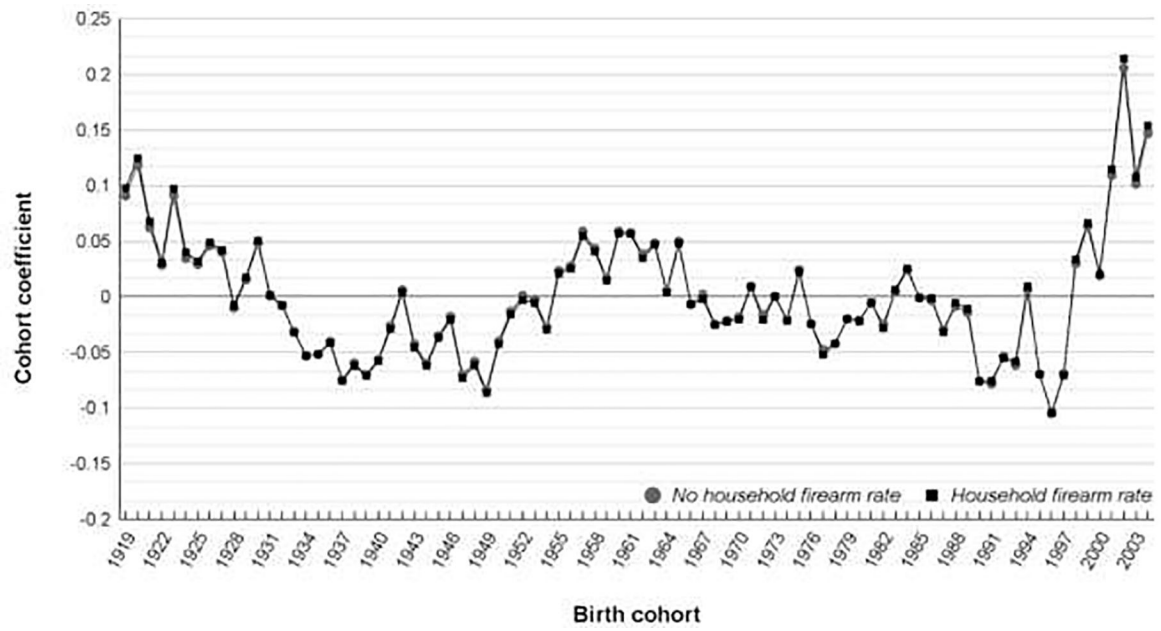
Figure 3.
Cohort effects on firearm suicide in the U.S. from 2001 to 2016, from hierarchical ageperiod-cohort models adjusted by individual-level age, sex, and race and state-level annual poverty rate, annual unemployment rate, annual median household income in 2014 U.S. dollars, population density, and median elevation.

Notes: Firearm suicide rates are restricted to population aged 10–84 years. The cohort coefficient can be interpreted as the average increase in the suicide rate for each birth cohort over the lifecourse, compared to the mean across all cohorts.
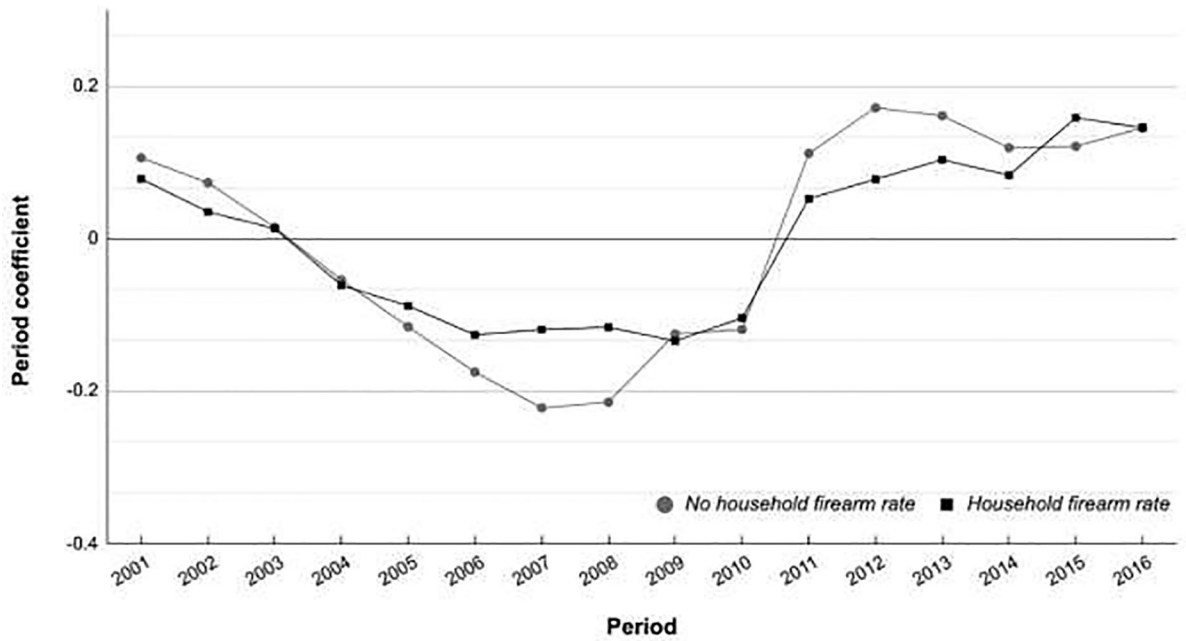
Figure 4.
Period effects on firearm suicide in the U.S. from 2001 to 2016, from hierarchical ageperiod-cohort models adjusted by individual-level age, sex, and race and state-level annual poverty rate, annual unemployment rate, annual median household income in 2014 U.S. dollars, population density, and median elevation.

Notes: Firearm suicide rates are restricted to population aged 10–84 years. The period coefficient can be interpreted as the average increase in the suicide rate for each period compared to the mean across all periods.