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Firearm Laws and Illegal Firearm Flow between US States

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Abstract

Background: Considerable variation in firearm legislation exists. Prior studies show an association between stronger state laws and fewer firearm deaths. We hypothesized that firearms would flow from states with weaker laws to states with stronger laws based on proximity and population.

Methods: Crime gun trace data from 2015–2017 was accessed from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) and compared to the count and composition of firearm legislation in 2015 among the contiguous 48 states. Additional independent variables included population, median household income, distance, and presence or absence of a shared border. We used Exponential Random Graph Models to identify predictors of traced firearm transfers between origin and destination states.

Results: After controlling for network structure, firearm laws in origin states were associated with fewer traced firearm transfers (IRR = 0.88; 95%CI: 0.83, 0.93, p<0.001). Conversely, more firearm laws in destination states were associated with more traced firearm transfers (IRR = 1.10; 95%CI: 1.06, 1.15, p<0.001). Larger population at the origin was associated with increased transfers (IRR = 1.38; 95%CI: 1.27, 1.50, p<0.001), as was larger population at the destination state (IRR = 1.45; 95%CI: 1.35, 1.56, p<0.001). Greater distance was associated with fewer

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Erin Andrade contributed to literature search, data interpretation, writing, and critical revision of the manuscript. Mark Hoofnagle contributed to study design, data interpretation, and critical revision of the manuscript. Elinore Kaufman and Mark Seamon assisted with data interpretation and critical revision of the manuscript. Adam R. Pah contributed to study design and data analysis. Christopher N. Morrison contributed to study design, data analysis, and data interpretation.

Conflict of Interest

The authors have no conflicts to declare.

transfers (For each 1,000 kilometers, IRR = 0.35; 95%CI: 0.27, 0.46, p<0.001), and transfers were greater between adjacent states (IRR = 2.49; 95%CI: 1.90, 3.27, p<0.001).

Conclusions: State firearm legislation has a significant impact on gun trafficking even after controlling for network structure. States with stricter firearm legislation are negatively impacted by states with weaker regulations, as crime guns flow from out-of-state.

Level of Evidence: Level III, retrospective epidemiologic

Keywords

firearms; trafficking; gun; legislation; policy

Background

Firearms ended the lives of almost 40,000 people in the United States in 2017, including over 14,000 by homicide.[1] A further 130,000 others were injured.[1] This considerable public health burden is distributed unevenly across the US population, such that the problem contributes substantially to disparities in health between socially advantaged and socially disadvantaged groups. Firearm deaths represent over 11 percent of years of potential life lost among black compared to less than six percent among whites and for black men aged 15 to 34, homicide is the leading cause of death.[2,3]

There is growing evidence that stronger firearm laws can reduce the incidence of firearm injuries and deaths.[4] Studies using composite measures of firearm law strength find states with stronger laws have fewer firearm injuries, fewer firearm suicides, fewer firearm homicides, and fewer mass shooting events. [5–9] Firearm laws regulate how guns may be sold or purchased and who is eligible to own them, and they fall generally into categories of access restrictions from prohibited persons, possession and carry regulations, regulations on dealers and purchasers of firearms, regulations on types of firearms and ammunition, storage laws, “stand your ground laws”, liability/immunity laws and anti-trafficking laws.[10] Many laws currently in effect have been shown to affect firearm mortality but appear to have differential effects on suicide vs homicide and a variable effect on different demographic populations.[11]

These effects on state firearm legislation are further complicated by the potential for interstate commerce, as guns can easily move across state lines despite this commerce being illegal without a federal firearms license.[5,8] Theories from economic and transportation geography predict black markets will emerge to meet demand where supply is artificially restricted,[12] and that these informal sources will originate from locations that are more proximate, more populous, and where supply is greater. With regard to firearms, this suggests that goods will flow from more populous nearby states with fewer restrictions on supply. Some available evidence is consistent with these predictions. The majority of state and federal prisoners who possessed a firearm during a crime obtained the firearm from a family member/friend, or the underground market,[13] in states with restrictive gun laws, over half of guns used in crimes originate out of state, and neighboring states laws have been found to impact the efficacy of laws meant to reduce firearm homicide. [8,14,15] Given the use of illegal firearms in homicides, we must first elucidate how firearm laws impact the availability of illegal firearms within states in order to understand how firearm laws may influence firearm homicide rates.

In sum, firearm violence contributes substantially to the public health burden and to disparities in health outcomes in the US, and the interstate flow of firearms has the potential to disrupt the effectiveness of state firearms laws ability to reduce firearm violence. The aim of this study was to examine associations between state firearm laws and the flow of illegal firearms between states. We hypothesized that firearms would flow from states with weaker laws to states with stronger laws based on proximity and population.

Methods

2.1. Study Setting

This cross-sectional study used data for the 48 contiguous US states. We excluded the non-contiguous states of Alaska and Hawaii because firearm transfers to and from these states are likely to differ from transfers between other US states. We excluded the District of Columbia and other US territories because firearm laws data were not available for these locations.

2.2. Data

We obtained data from four sources: traced firearm transfers from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF)[16]; state firearm laws from the Boston University State Firearm Laws Database[17]; population estimates from Centers for Disease Control and Prevention Web-based Injury Statistics Query and Reporting System (CDC WISQARS)[1]; and state demographic characteristics from the United States Census Bureau.[18]

The dependent variable was traced firearm transfers. We defined this variable as the state-level count of firearms that were recovered by law enforcement after being used or suspected to be used in a crime and were originally purchased in another state.

The main independent measure was the count and composition of firearm laws for the 48 states in 2015, as provided in the Boston University State Firearm Laws Database.[10,19] An important methodological concern for firearm research is that laws are often highly correlated within states, and it can be difficult to isolate the effect of any one individual law.[4,20] To address this problem, we calculated the total count of laws per state (out of 133 total laws in the database) and the proportion of this total within each of seven categories: background checks, buyer laws, concealed carry laws, dealer laws, firearm trafficking laws, prohibitions against high-risk persons, and "other" laws. We selected these categories for inclusion based on prior evidence that laws within these categories are associated with firearm injury and mortality,[4] because they represented a substantial proportion of all state firearm laws, or because they could theoretically affect interstate firearm transfers.

Additional independent variables were the population size and annual median household income for US states for 2015. State geographic relationships were captured in two ways: the distance between state centroids (the geometric center), and the presence or absence of a shared border. We anticipated that traced firearm transfers would be less common over greater distances, and more common over shared borders.[21]

2.5. Statistical Analyses

We employed successively more sophisticated models to approximate the factors that are influencing gun trafficking in the US. We initially used linear regression of state anti-trafficking laws on exported crime guns per population. Then to assess for collinearity of firearm laws, we performed a regression of all state firearm laws on exported crime guns per population. The geographic structure of these data violate the assumptions of standard regression models, making results of these models unreliable.[22] To appropriately incorporate the geographic relationships between exposures and outcomes, we used Exponential Random Graph Models (ERGM), fitted using the *statnet* package in R, to identify predictors of traced firearm transfers between origin and destination states.[23,24] ERGM is a statistical analytic method that accounts for the dependencies that commonly arise in network data and which violate assumptions of standard regression models.[22] We specified that the traced firearm transfer data was a valued and directed network with a Poisson reference distribution, meaning that the cell values for the 48 × 48 matrix of traced firearm transfers were continuous, that the values followed a Poisson distribution, and that the flow from one state to another could differ from the flow in the opposite direction.[25] To then account for the effects of distance, firearm laws, and population characteristics, we added the distance between states, adjacency, firearm laws, population size, and median household income. Finally, we considered six network variables[A] that could account for relationships between the outcome and the exposure. The ERGM results yield incidence rate ratios (IRRs) for changes in traced firearm transfers relative to 1-unit increases in the independent variable. At each step, we assessed model fit by inspecting the parameter estimates for the included variables, the Akaike Information Criterion (AIC), the Bayesian Information Criterion (BIC). We also calculated the potential scale reduction factor (PSRF) for two Markov chain Monte Carlo simulations from different initial values. The PSRF is a quantitative measure of convergence for iterative simulations such as EGRM.[26] We retained included network variables when they were significant at $p < 0.05$ and reduced the AIC, the BIC, and the PSRF.

2.6. Sensitivity Analyses

We conducted additional analyses to ensure that the parameter estimates were not artefacts of model or variable specification. Specifically, we constructed models in which the dependent and independent variables were untransformed, and another in which we withheld the “other” laws category as a referent instead of the concealed carry laws. We specified additional analyses using traced firearm transfers for 2015, 2016 and 2017 separately, to ensure that firearm law implementation preceded firearm transfers. Two chains of the Markov chain Monte Carlo failed to converge when the dependent measure was not square root transformed, as assessed by visual inspection and by PSRF. When the independent

[A]Individual heterogeneity (different states have different propensities to interact), mutuality (transfers from state *i* to state *j* are more likely if there are transfers from state *j* to state *i*), over-dispersion (variance is greater than the mean), transitivity (tendency to form triangles between connected states), triadic closure (overall number of triangles), and zero inflation (excess origin-destination dyads with no connection).

measures were not square root transformed, results were similar to the main models but the AIC, BIC and PSRF were slightly larger. Selecting a different referent did not materially affect results or model diagnostics.

Results

The ATF traced a total of 178,712 interstate firearms transfers between the 48 contiguous US states for 2015 to 2017. The largest volume of transfers was from Arizona to California (5,518 firearms), Indiana to Illinois (4,147 firearms), and Nevada to California (3,778 firearms), as shown in Figure 1. Of the 2,304 state-to-state directions, 2,130 had at least one traced firearm transfer. Figure 1 depicts the traced firearm transfers as a network graph. State node size corresponds to the total number of laws active in that state in 2015, and line thickness indicates the number of firearms transferred from origin states to destination states.

The 48 included states had an average of 26.2 (19.6%) of the 133 available firearm laws active in 2015, of which 16.8% were prohibitions against high-risk persons, 23.5% were concealed carry laws, and 39.7% were categorized as “other” laws (Table 1). The states with the largest total number of laws were California (102 laws), Massachusetts (101 laws), and Connecticut (85 laws).

Both the scatterplot of total firearm transfers from origin states and counts of firearm laws and the scatterplot of total firearm transfers from origin states and counts of trafficking laws show an apparent negative association (Figure 2A and 2B), which suggests collinearity between trafficking laws and firearm laws overall. The inflection point occurs at a lower law count when limiting the analysis to trafficking legislation. In the initial bivariate Poisson model, additional firearm laws in origin states were associated with fewer firearm exports to other states (Table 2, Model 1). The best fitting ERGM included three network variables (individual heterogeneity, mutuality, and over-dispersion) (Table 2, Model 2). Individual heterogeneity refers to the fact that one state can interact differently with multiple states modified for example by interstates creating trade routes. Mutuality means that states have reciprocal relationships and are more likely to export to states from which they receive imports. Over-dispersion is defined as variance being greater than the mean. After controlling for these aspects of network structure, firearm laws in origin states were associated with fewer exports (IRR = 0.88; 95%CI: 0.83, 0.93, $p<0.001$). Conversely, more firearm laws in destination states were associated with more imports (IRR = 1.10; 95%CI: 1.06, 1.15, $p<0.001$). Larger population at the origin was associated with increased exports (IRR = 1.38; 95%CI: 1.27, 1.50, $p<0.001$), similarly larger population at the destination state was associated with increased imports (IRR = 1.45; 95%CI: 1.35, 1.56, $p<0.001$). Greater distance was also associated with fewer firearm transfers (For each 1,000 kilometers, IRR = 0.35; 95%CI: 0.27, 0.46, $p<0.001$), and transfers were greater between adjacent states (IRR = 2.49; 95%CI: 1.90, 3.27, $p<0.001$).

The final model (Table 2, Model 3) included the firearm law composition variables. Additional firearm laws at origins were related to fewer firearm exports and these associations were strongest where laws were composed of more buyer laws (IRR = 0.90;

95%CI: 0.83, 0.96, p=0.003). Additional firearm laws at destinations were related to more firearm imports particularly where laws were composed of more background check laws (IRR = 1.2; 95%CI: 1.07, 1.2, p<0.001). Model 3 was a poorer fit than Model 2.

Sensitivity analyses, including using firearm transfer data from 2016 and 2017, were substantively similar to the main model presented here.

Discussion

This study indicates that the discrepancy in firearm legislation between states correlates with the flow of guns. In origin states, more firearm laws are associated with fewer traced firearm transfers, i.e. fewer exports. This was true in both our initial model using Poisson regression and with ERGM. In destination states, more firearm laws are associated with more traced firearm transfers, i.e. more imports. When examining specific types of firearm statutes, buyer laws, such as, age restrictions, de facto gun registration through recordkeeping requirements, permit to purchase, and waiting periods, were associated with fewer exports from origin states. The use of ERGM improves our understanding of the network of illegal crime gun flow across the US. The major patterns that emerge from this network show that guns move from southeastern states with weaker gun laws into states with stricter firearm laws in the northeast; into Illinois from neighboring states, and into California from western states and Texas. States that were closer together or shared a border had more traced firearm transfers.

There is a growing body of literature that shows that stricter state laws decrease the proportion of guns used in crime that are from that state. Many of these studies look at specific legislation or specific regions. Webster et al. found that cities with mandatory registration and licensing laws had fewer guns from in-state that were used in crimes; however, this effect was dampened if neighboring states had weaker laws.[14] The implementation of a Virginia law limiting firearm purchases to one per month was associated with decreased traced firearms from Virginia in crimes nationwide.[27] When considering the impact of specific law types rather than composite measures, evidence is strongest for universal background checks.[4] Studies have shown universal background checks to be associated with lower state homicide rates.[28,29] Our study strengthens the evidence for the effect of buyer laws in reducing traced firearm transfers. While prior studies show a correlation between specific types of state firearm laws and decreased firearm homicides,[30,31] this analysis suggests that that relationship may be confounded by the laws of neighboring states through exported crime guns.

Only two prior studies have utilized nationwide data to analyze the relationship between state firearm legislation and gun trafficking.[32,33] Even after controlling for network structure, our results confirm the pattern observed in both of these studies, which showed that guns move from states with less stringent legislation to states with more stringent legislation. It has been suggested that the impact of comprehensive firearm legislation may be greater than that of any individual law in reducing gun violence.[34] In the study by Coates et al, the strongest relationship between trafficking and legislation occurs at a relatively high level of legislation.[33] This helps to explain why our initial ERGM model looking at law count rather than law type provides a better fit for the data. However, the negative association of law count and traced firearm transfers occurred at a lower law count when specifically looking at trafficking laws rather than all firearm legislation. While states have sole jurisdiction over firearm legislation within their borders, they are still impacted by the laws of neighboring states. The burden of stricter gun laws shifts the market toward obtaining guns in less stringent states. This suggests that gun laws are effective in decreasing illegal trafficking as traffickers buy more frequently in states with fewer laws where purchasing is less difficult as demonstrated by higher gun exports in states with fewer laws. Further analyses are needed to determine how the flow of trafficked firearms relates to state firearm homicide rates.

This study has several limitations. First, as a cross-sectional study, we cannot test for causality between gun legislation and trafficking. Second, we cannot assess the impact of the variation in enforcement of legislation. Third, only the contiguous 48 states were included so trafficked guns from Hawaii, Alaska, or international sources are not included in the network analysis. Fourth, this model does not take into account changes in the number of firearm laws during the study period as related to traces because the number of firearm traces has independently doubled in the last five years making such a trend analysis difficult. Finally, ATF traces of crime guns are an imperfect proxy for gun trafficking as they include guns that legally crossed state lines when people move between states. However, this is likely a very small percentage of guns used in crimes and unlikely to affect the analysis.

Conclusion

In conclusion, we have shown that state firearm legislation has a significant impact on gun trafficking even after controlling for network structure. States with stricter firearm legislation are negatively impacted by the weaker regulations in other states, as crime guns are trafficked from out-of-state.

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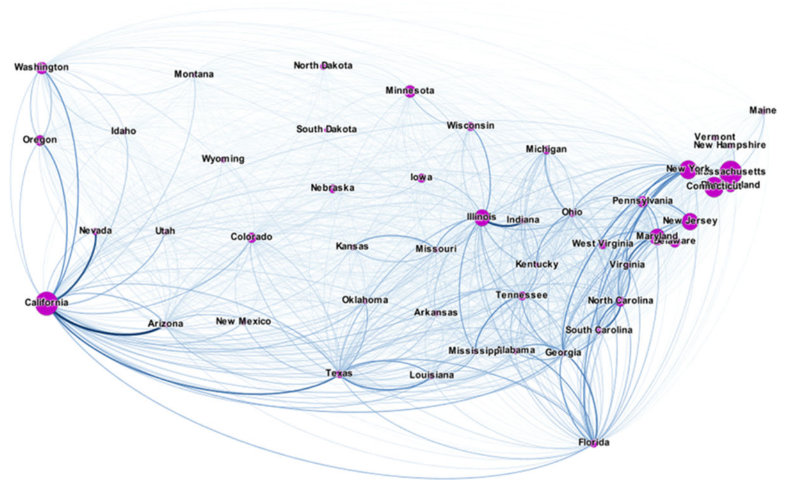

Figure 1.

Network graph of firearm traces 2015–2017. Node size (purple circle) is total law count. Edge size (line thickness) is proportionate to the number of firearms traced. Edge direction is clockwise (i.e. clockwise line from a node indicates firearms traced from origin state to the destination state where the crime was committed).

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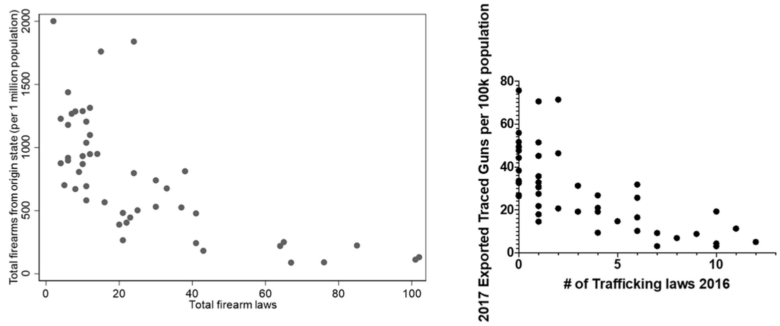

Figure 2.

A. Scatterplot for total exported traced guns from each state per 1 million population for 2015–2017 and total count of firearm laws for 2015 (n=48)

B. Scatterplot for total exported traced guns from each state per 100,000 population for 2017 and total count of trafficking firearm laws for 2016 (n=48)

Table 1.

Descriptive statistics for 48 US states (nodes). Data and variable descriptions for firearm laws extracted from McClenathan, Pahn, and Siegel with permission.[10]

Variable	Description	Median	(Interquartile	Range)
Population	Total resident population, 2015	4,764,852	1,990,650	7,776,672
Income	Annual median household income (US$), 2015	54,027	48,997	61,053
Firearm laws				
Count	Sum of the total count of laws from all categories	15.5	9.5	35.0
Background checks (%)	% of laws that establish requirements and procedures for firearm dealers to perform background checks on prospective firearm purchasers	0.0	0.0	10.7
Buyer laws (%)	% of laws that firearm purchasers must obey in order to obtain a firearm	3.3	0.0	9.2
Concealed carry laws (%)	% of laws that outline the process that individuals must undergo to obtain a concealed carry permit in their state	18.3	7.9	34.8
Dealer laws (%)	% of laws that establish rules for anyone in the business of selling, lending, or trading firearms	1.7	0.0	12.5
Firearm trafficking laws (%)	% of laws that prohibit the sale of firearms with the intent to re-sell them, ban straw purchases, or require gun technology that helps trace firearms or ensure that a gun can be operated only by its owner	0.0	0.0	3.8
Prohibitions against high-risk persons (%)	% of laws that prevent individuals with a history of crime, substance use, or mental health issues from possessing firearms	11.0	4.9	25.0
Other laws (%)	% of other laws, including regulations on ammunition, assault weapons and large-capacity ammunition magazines. Also includes the absence of stand your ground laws, laws granting states preemption, and laws providing immunity from prosecution	44.6	23.5	50.0

Table 2.

Exponential random graph model for counts of traced firearm transfers for 2015–2017 from origin states to destination states. Dependent variable, node characteristics and edge characteristics square root transformed. Bolded estimates have $p < 0.05$. Incidence rate ratios are abbreviated IRR. Confidence intervals are abbreviated CI.

	Model 1				Model 2				Model 3			
	IRR	(95%	CI)	p-value	IRR	(95%	CI)	p-value	IRR	(95%	CI)	p-value
Origin State												
Population (1 million)	**1.659**	**1.569**	**1.755**	**<0.001**	**1.378**	**1.268**	**1.498**	**<0.001**	**1.428**	**1.298**	**1.570**	**<0.001**
Median household income ($10,000)					1.009	0.614	1.660	0.971	0.537	0.277	1.038	0.064
Firearm laws												
Count	**0.891**	**0.840**	**0.946**	**<0.001**	**0.879**	**0.834**	**0.926**	**<0.001**	**0.885**	**0.813**	**0.963**	**0.005**
Background checks (%)	0.964	0.921	1.009	0.113					1.043	0.962	1.131	0.309
Buyer laws (%)	**0.925**	**0.872**	**0.980**	**0.009**					**0.895**	**0.832**	**0.962**	**0.003**
Concealed carry laws [referent]	0.994	0.956	1.034	0.757					1.000			
Dealer laws (%)	1.021	0.954	1.094	0.545					1.037	0.984	1.092	0.176
Firearm trafficking laws (%)	**1.073**	**1.025**	**1.124**	**0.002**					**1.077**	**1.008**	**1.149**	**0.027**
Prohibitions against high-risk persons (%)									0.999	0.953	1.046	0.954
Other laws (%)	0.962	0.917	1.009	0.115					1.021	0.960	1.084	0.511
Destination State												
Population (1 million)					**1.452**	**1.353**	**1.558**	**<0.001**	**1.515**	**1.391**	**1.650**	**<0.001**
Median household income ($10,000)					0.790	0.505	1.237	0.303	0.610	0.343	1.084	0.092
Firearm laws												
Count					**1.104**	**1.057**	**1.152**	**<0.001**	**1.081**	**1.009**	**1.159**	**0.027**
Background checks (%)									**1.155**	**1.074**	**1.241**	**<0.001**
Buyer laws (%)									0.981	0.909	1.060	0.634
Concealed carry laws [referent]									1.000			
Dealer laws (%)									**0.906**	**0.857**	**0.958**	**0.001**
Firearm trafficking laws (%)									1.070	0.999	1.145	0.052
Prohibitions against high risk persons (%)									1.032	0.981	1.086	0.228
Other laws (%)									1.032	0.967	1.101	0.340
Geographic Characteristics												

	Model 1				Model 2				Model 3			
	IRR	**(95%**	**CI)**	**p-value**	**IRR**	**(95%**	**CI)**	**p-value**	**IRR**	**(95%**	**CI)**	**p-value**
Distance (1,000 kms)					**0.349**	**0.269**	**0.455**	**<0.001**	**0.290**	**0.220**	**0.383**	**<0.001**
Adjacent					**2.494**	**1.903**	**3.268**	**<0.001**	**2.625**	**1.956**	**3.523**	**<0.001**
Network Structure												
Individual heterogeneity					**1.656**	**1.173**	**2.337**	**0.004**	**2.100**	**1.589**	**2.775**	**<0.001**
Mutuality					**2.212**	**1.727**	**2.833**	**<0.001**	**1.801**	**1.225**	**2.649**	**0.003**
Over-dispersion					**0.003**	**0.001**	**0.012**	**<0.001**	**0.005**	**0.001**	**0.029**	**<0.001**
Diagnostics												
Akaike Information Criterion	*−970*				*−1767*				*−1790*			
Bayesian Information Criterion	*−918*				*−1698*				*−1652*			
Potential Scale Reduction Factor	*1.380*				*1.150*				*1.430*			