



Essays on the Economics of U.S. Firefighting

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Essays on the Economics of U.S. Firefighting

A dissertation presented

by

Joshua Hurwitz

to

The Committee for the PhD in Economics

in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

in the subject of

Economics

Harvard University

Cambridge, Massachusetts

May 2021

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Essays on the Economics of U.S. Firefighting

Abstract

Between 1987 and 2017, the number of annual fire incidents in the US declined by nearly 45 percent, while the number of total career (salaried) firefighters increased by almost 55 percent. This dissertation, which consists of three essays on the economics of U.S. firefighting, is motivated by this stylized fact. The first chapter provides a descriptive analysis of U.S. firefighting trends in recent decades and analyzes potential explanations for the firefighter employment puzzle. The second chapter exploits the employment variation caused by a federal hiring grant called SAFER to study the impact of marginal firefighter employment on fire outcomes. The third chapter details the origins and evolution of fire department involvement in the provision of emergency medical services (EMS), which is shown in the opening chapter to be a likely driver of recent firefighter employment growth. It then reapplies the SAFER grant methodology to analyze the impact of marginal firefighter employment on the incidence of time-sensitive deaths, a critical EMS outcome.

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To my wife, Rachael.

Introduction

Between 1987 and 2017, the number of annual fire incidents in the US declined by nearly 45 percent, while the number of career (salaried) firefighters increased by almost 55 percent. This dissertation, which consists of three essays on the economics of U.S. firefighting, is motivated by this stylized fact.

In the first chapter, I provide a detailed analysis of U.S. firefighting trends in recent decades and analyze potential explanations for the firefighter employment puzzle. I find that the decline in fire incidence has been widespread across the US and has resulted in a proportional decline in casualty loss. Real annual property loss from fire - while more volatile - has also declined by more than 15 percent over the last three decades. I do not find evidence of a significant causal relationship between firefighter employment and fire incidence, nor does it appear that employment growth is associated with compliance to national staffing standards. The growth in career firefighter employment has exceeded most local government employment categories and is associated with rising budget shares towards fire protection. Moreover, the increase in career firefighter rolls does not solely represent substitution for volunteers - intensive growth at a large sample of all-career fire departments exceeded 20 percent over the last three decades. I find that the majority of all-career departments have increased staffing levels since 1987, despite a long-term decline in fire incidence. Suggestive evidence points to the rapid growth of emergency medical service (EMS) provision by fire departments as a likely catalyst for employment growth. After previewing the economics of fire-based EMS, which I explore in detail in the third chapter, I analyze the heterogeneity in firefighter density, employment costs, and average call volumes across a large sample of all-career fire departments. I then provide estimates of breakeven marginal benefit levels per firefighter response to cover employment costs at each department, which serve as a benchmark for the experimental estimates in the subsequent chapters. Under the most conservative

estimates, the average employment cost per firefighter response - pooled across all incident types - is about \$420. Under less generous assumptions, this value can be well over \$1,000.

In the second chapter, I exploit variation in firefighter employment attributable to a federal hiring grant for fire departments called SAFER in order to estimate marginal loss reduction on fire responses. I use a dynamic difference-in-difference (DiD) framework to compare outcomes for treated departments before and after first grant receipt to applicant departments that are denied the grant. During the two-year period following grant receipt, I find that average monthly response times for grant recipients fall by 9.8 seconds on fire responses, and up to 17.7 seconds at the lower end of the confidence interval. I use the empirical relationship between response times and the sources of loss from fire (property and casualty) in the National Fire Incident Reporting System (NFIRS) data to provide estimates of direct economic loss reduction attributable to the grant. I find that grant receipt is associated with property loss reduction of \$204 to \$737 per structure fire response and \$18 to \$200 per non-structure fire response, using the mean response time estimate and the lower end of the confidence interval. While the relationship between response times and fire casualties is less stable, I estimate conservatively that the grant-induced response time improvements could result in \$201 to \$363 of casualty loss reduction per structure fire response and \$41 to \$73 per non-structure fire response. Summing the property and casualty loss estimates suggests total loss reduction of \$405 to \$1,100 per structure fire response and \$59 to \$273 per non-structure fire response. Based on the average call volume at treated departments between 2004 and 2017, I estimate that the direct fire loss reduction for grant recipients is worth between 8 and 25 percent of annualized marginal employment costs. If the response time improvements are distributed equally across the mean relative staffing increase of six firefighters, the results imply that a marginal firefighter in the sample reduces up to \$184 of total loss per structure fire response and up to \$46 per non-structure fire response. While these estimates are useful as a starting point for evaluating current staffing levels, they have limitations as a prescriptive staffing tool and I caution against using them to draw broad policy conclusions.

In the third chapter, I detail the origins and evolution of fire department involvement in the provision of EMS, which is shown in the opening chapter to be a likely driver of firefighter employment growth in recent decades. Despite the prominent role assigned to firefighters in providing these services,

there is a substantial knowledge gap regarding the effectiveness and efficiency of fire-based EMS delivery models. I first provide a brief history of EMS provision in the United States and contextualize the growing involvement of fire departments. I then extend the DiD estimation framework from the previous chapter, again exploiting employment variation from the SAFER hiring grant, to study the impact of marginal firefighter employment on the incidence of time-sensitive deaths. This outcome includes deaths caused by cardiovascular disease, stroke, sepsis, and trauma, all of which are associated with higher survival rates as the time-to-treatment falls. I do not find any evidence that SAFER grant receipt results in a decrease in the incidence of time-sensitive deaths. I use the closing section to unify the findings from this dissertation and describe a path forward for future research.

Chapter 1

The Firefighter Employment Puzzle

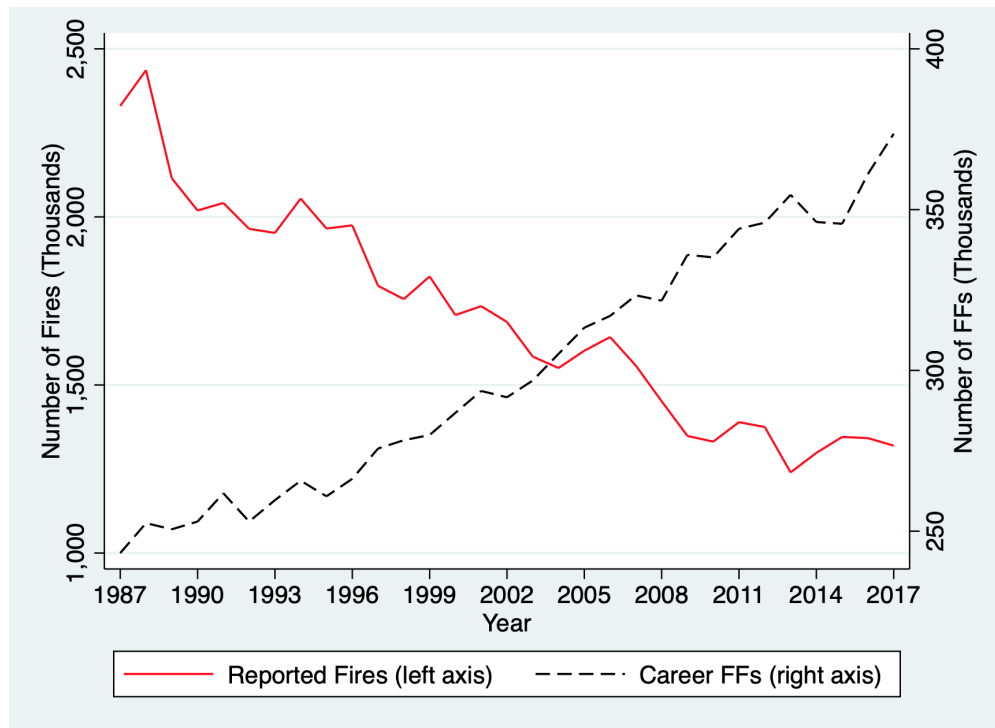
1.1 Introduction

Between 1987 and 2017, the number of annual fire incidents in the United States declined from 2.33 million to 1.32 million - a 43 percent decrease - despite the population growing by more than one third.¹ Over the same period, the number of career (salaried) firefighters rose by 54 percent, from 243,200 to 373,600 (Figure 1.1). On the basis of these trends, several authors - mostly in the popular press - have questioned whether fire protection is an overallocated public good (for example, see Johnson (2001), Keisling (2015), McChesney (2002), Neyfakh (2013), Perry (2015), and Tabarrok (2012)).

In this paper, I seek to unravel this apparent puzzle and provide an economic analysis of recent firefighting trends. I begin by posing and subsequently addressing a series of questions that are critical for contextualizing the patterns in Figure 1.1. Has the decline in fire incidence been a universal phenomenon across the United States or mostly confined to certain geographic areas? Have casualties and property loss from fire declined with incidence, or is there evidence of rising fire severity? Has the growing number of firefighters *caused* the reduction in fire incidence, such as due to expanded prevention efforts? Are the membership increases necessitated by compliance to national staffing

¹Here “fire incidents” corresponds to the total number of reported fires attended by local and municipal fire departments, as estimated by the National Fire Protection Association (Evarts, 2018, 2019; Haynes, 2017). This figure excludes false alarms, but includes fires that are extinguished prior to arrival by the fire department.

Figure 1.1: Number of annual fire incidents and career firefighters in the United States (1987-2017)



This figure shows the total number of annual fire incidents in the US from 1987 to 2017 (left axis), plotted against the total number of career firefighters (right axis). The membership total includes salaried firefighters in both all-career and mixed departments. The fire count excludes false alarms, but includes fires that are extinguished prior to arrival on scene by firefighters. Both are reported in thousands. *Source:* Evarts (2018), Evarts (2019), Haynes (2017).

standards? How has firefighter employment growth compared to other major categories of local government employment and what are the relative budgetary implications? Finally, can this growth be explained by extensive-margin substitution for volunteer firefighters, or have there also been significant employment gains at existing all-career and mostly-career fire departments?²

Using data from the United States Fire Administration, the National Fire Protection Association, the Census of State and Local Governments, and the National Fire Incident Reporting System, I find that the employment puzzle cannot be explained by any of the hypotheses implicit in the set of questions above. The decline in annual fire incidence between 1987 and 2017 was widespread across the US, ranging from 55 percent per capita in the midwest region to 62 percent per capita in the

²A fire department can be classified as all-career, all-volunteer, or mixed, depending on its composition. Mixed departments can be further classified as “mostly-career” or “mostly-volunteer”, depending on which firefighter type comprises the majority of staff.

northeast region. All major fire categories, including structure fires, vehicle fires, and outdoor fires have experienced absolute declines of at least 33 percent. Prominent explanations for these trends include stricter building codes, the increased prevalence of fire-resistant building materials, local mandates requiring sprinkler and alarm installation, improvements in vehicle safety, and declining cigarette consumption (Knight, 2013).

I also find limited evidence that fire severity has significantly increased over the last three decades.³ Between 1987 and 2017, the number of annual civilian deaths and injuries from fire both declined by more than 40 percent, such that the civilian casualty rate per fire has remained very stable. Firefighter deaths and injuries from fire also declined by more than 50 percent, implying a slight decline in casualty risk per fire attended. Total real property loss from fire was more than 15 percent lower in 2017 than in 1987, although the declining loss trend has been relatively volatile. I find that *average* real property loss per fire has increased closely with growth in average real property values. I explain how this finding may be consistent with stable fire intensity, or could also indicate a rise in average fire strength.⁴ Finally, there has been no obvious increase in the incidence rate of major fires, defined as any fire causing more than \$10 million in damage (Badger, 2017). This statistic includes wildfires, even though the firefighters studied in this report are local government employees who are not typically responsible for fighting wildfires.⁵

Many fire departments engage in prevention and awareness activities, safety checks, and inspections, which may directly reduce the occurrence rate of fires (National Fire Protection Association, 2016), similar to the way economists have modeled the relationship between policing and crime.⁶ However, based on three separate pieces of descriptive analysis, I find little support for a significant causal link between firefighter employment and the number of reported fires. First, I show that the

³However, I cannot fully eliminate the possibility that losses would have been more severe had firefighter rolls not grown as sharply.

⁴Some safety agencies have reported that changes in the composition of building materials and household contents have led to higher fire temperatures and growth rates, and increased risk of structural collapse (Stoll, 2013).

⁵Rather, state and federal firefighting agencies handle the majority of wildfire response (National Interagency Coordination Center, 2017). These agencies sometimes contract with municipal fire departments to provide emergency assistance during severe episodes where additional manpower is needed (Morris, 2018).

⁶For example, see Cameron (1998), Nagin (1998), Eck and Maguire (2000), Skogan and Frydl (2004), Levitt and Miles (2006), and Chalfin and McCrary (2017) for extensive summaries of this literature.

decrease in fire incidence was no more severe in jurisdictions with the highest rates of firefighter growth than in those with the lowest. Second, I show that a similar decline has occurred in the United Kingdom, despite a sharply contracting firefighting force; these fire departments also engage in a wide range of preventative activities. Third, I show that the decline in fire incidence is most pronounced for vehicle fires, which are less plausibly preventable by fire department efforts. There is strong evidence that fire prevention efforts aimed at enforcing building codes and increasing proliferation of alarms and sprinklers can have a powerful impact on structure fire incidence rates (Stoll, 2013). However, I find little support in the data for these efforts being highly correlated with firefighter employment.

Firefighting standards and regulations aimed at improving firefighter safety and efficiency have also been introduced during the last three decades. Most notably, in 2001 the National Fire Protection Association (NFPA) passed Standard 1710, which was the first to establish minimum staffing criteria for career firefighters. The standard, although not legally mandated, recommends a minimum of four firefighters per engine on fire calls, and up to six when dealing with high-hazard occupancies. Using incidence-level staffing data on structure fire calls from a large sample of all-career fire departments, I do not find any evidence that the growth in firefighter membership can be explained by an increase in staffing per vehicle. From 2003 to 2017, the average number of firefighters per vehicle actually declined from 3.6 to about 2.8. There was also no change in the average number of vehicles attending structure fires over this period.

I find that firefighter employment and expenditure growth have been *relatively* high as well. Based on Census data, overall growth in fire department membership has outpaced most major areas of local government employment, which has been reflected in rising local budget shares towards fire protection. Between 1987 and 2017, fire department employment grew at nearly the same rate as education employment (the largest category of local government employment), and surpassed growth in the next five largest non-fire employment categories. Fire protection expenditures also outpaced total expenditure growth over this period and rose at the seventh highest compound annual growth rate of any local government spending category. Fire expenditure growth exceeded education, public transportation infrastructure, housing, and public welfare spending and was within 33 basis points of any faster-growing category except for health and social insurance, the latter of which includes

expenditures on firefighter retirement, disability, and unemployment benefits.

Finally, although there has been a 10 percent decline in the number of all-volunteer fire departments over the last three decades and a compensating increase in the number of all-career, mostly-career, and mostly-volunteer departments, the growth in career firefighter rolls cannot be explained by substitution for volunteer firefighters. Intensive growth at a large sample of all-career fire departments, while slower than the aggregate trend, was still greater than 20 percent between 1987 and 2017. Most of this growth occurred prior to the Great Recession. At the individual department level, I observe employment increases at about 60 percent of sampled all-career departments over this period, despite a decline in fire incidence. A significant share of the remaining departments saw minor declines in employment relative to an extreme reduction in fire experience.

Moreover, career firefighter growth at mostly-career departments, which can employ as little as one volunteer to receive this designation, exceeded 70 percent between 1987 and 2017. It is likely that a substantial share of this growth also represents newly-created career firefighter positions, given that volunteers comprise only one-fifth of current membership at these departments and national volunteer rolls have been relatively steady over the last three decades.

So if there are more firefighters and the average firefighter spends significantly less time fighting fires, how do they spend their time? And can increased firefighter employment lead to reduced economic loss in other domains besides firefighting? Based on aggregate NFPA data, fire departments are actually busier than ever in terms of *total* call volume, primarily due to the explosion of emergency medical service (EMS) calls. Between 1987 and 2017, the number of annual EMS calls attended by fire departments increased by nearly 250 percent, from 6.4 million to 22.3 million. Almost two-thirds of total fire department responses were for EMS calls in 2017 (up from 52 percent in 1987), whereas fire incident responses accounted for less than four percent of call volume (down from 19 percent in 1987).⁷ Although incident-level data on EMS calls is only available for a limited subset of departments and years, I provide descriptive evidence that recent career firefighter employment growth has been

⁷False alarm calls (7 percent of 2017 volume), mutual aid calls (4 percent), hazardous materials calls (3 percent), and “other” calls (17 percent) represent relatively small shares of total call volume, but each category also experienced at least a 100 percent increase between 1987 and 2017. Mutual aid responses, while categorized separately from fires, can include out-of-jurisdiction fire incidents for which a department provides additional support.

strongly linked to a department's involvement in EMS delivery.

Thus focusing solely on fire trends to make assessments about firefighter value potentially overlooks a substantial amount of the economic benefits firefighters provide, particularly in the provision of EMS. Moreover, it is possible that performance improvements due to higher staffing levels, such as faster response times, can still translate to positive net returns in the fire domain, despite the decline in fire incidence. In the second and third chapters of this thesis, I make use of a federal hiring grant called SAFER to estimate net returns on marginal firefighter employment, focusing exclusively on fire outcomes in the second chapter and EMS outcomes in the third chapter.

I close the current chapter by analyzing the substantial heterogeneity in firefighter density, employment costs, and call volumes across a large sample of all-career fire departments. I find that firefighter density averages about 1.7 firefighters per 1,000 citizens, and ranges from less than 1 to more than 6. Firefighter density is positively correlated with average fire incidence in the cross-section, but there is still considerable heterogeneity in fire experience for departments with similar levels of per capita staffing. It does not appear that this equilibrium can be explained (on average) by differences in household income, which has very little explanatory power for relative staffing levels, even after controlling for fire experience and state fixed effects.

I estimate that the average number of annual fire calls attended per firefighter is less than 20 for the median all-career department in my sample; this threshold falls to 11 if restricting just to structure fire calls.⁸ On average, only about 30 and 35 percent (respectively) of these incidents will involve fires that are severe enough to cause any property or casualty loss, based on 2017 NFIRS reporting for this sample. I estimate that the *total* annual call volume per firefighter, which includes fire calls, EMS calls, false alarms, and all other types of incident response, is less than 315 for half of the sample and 570 at the 90th percentile. Under a less conservative estimate, these thresholds fall to 150 and 400, respectively. Based on a 100-shift annual workload, these estimates imply that a firefighter at the median department responds to 1.5 to 3.2 incidents per shift and attends a fire call of any capacity no more than every fifth shift.

⁸The respective 90th percentile estimates are about 35 and 22. These estimates exclude mutual aid provision on fire responses outside of the fire department's jurisdiction.

Finally, I use the average call volume estimates per firefighter at each department, in conjunction with estimates of firefighter compensation, to transition towards the cost-benefit analysis that drives the subsequent chapters of this thesis. For each department in my sample, I estimate the average economic benefit per response that would need to be provided by a marginal firefighter in order to “break even” on total compensation costs. I use these baseline estimates as a point of comparison for the quasi-experimental estimates of marginal firefighter value in the subsequent chapters. I find that under the most conservative assumptions, a marginal firefighter at the average all-career department would need to provide about \$420 of value per response to cover his or her employment costs. This estimate pools across all incident types (e.g. fire, EMS, false alarms) and also makes no adjustment for the majority of fire and EMS calls that do not result in direct economic loss. Restricting call volume to the subset of responses that are life-threatening or expected to result in direct loss increases the average per-response estimate to well over \$1,000. There are some potential limitations of using this type of cost-benefit approach in the firefighting domain and related institutional considerations that I discuss in the context of these estimates.

I reserve my primary discussion of fire-based EMS for the third chapter, but preview here the unique challenge of measuring the economic value of these services and the policy debate regarding the role of firefighters in providing EMS. First, this issue is complicated by the fact that firefighters are not the only provider of emergency medical care, making it difficult to separately identify their contributions. As discussed in Section 1.4.5, many cities use some form of a redundancy model, where a firefighter-staffed fire engine and/or a paramedic-staffed ambulance unit will respond to medical calls. Depending on the type of call and availability of resources, a fire engine unit, ambulance unit, or both may respond. In such cases, the primary goal of firefighters is often to “stop the clock” on time-sensitive medical emergencies that require immediate care, such as heart attacks, strokes, and trauma, by quickly arriving at the scene to provide first response. Because fire stations are located strategically throughout cities for rapid response, and ambulance units may be busy, the idea is that firefighters can often arrive to an emergency first. The separate ambulance unit will then often provide advanced care and transport to the hospital.

This institutional arrangement creates a unique measurement challenge when assessing marginal

firefighter value, but there are also difficulties in cases without this redundancy. Suppose an ideal EMS dataset existed that featured detailed incident-level data, including patient diagnoses and outcomes, and separately documented response times and services provided by firefighters and other providers. Even in this setting, it would be difficult to determine the value-add of a marginal firefighter on a given EMS response. For example, what should be the relevant counterfactual for a medical emergency that is considered time-sensitive, where the victim receives some level of care from a firefighter and ultimately survives the event? Should it always be “death,” and if not, how should that determination be made? Moreover, suppose that firefighters arrive on scene of a time-sensitive emergency, begin providing first response, and one minute later a third-party ambulance takes the patient into care and rushes the patient to the hospital. What is the marginal value of the firefighters’ contribution in this case? Finally, how should we think about the value to a recipient of a firefighter response on an EMS call that turns out to be a non-emergency? Is there any additional benefit created by a faster response time in these cases?

In practice, there is also no such dataset that merges separate accounts of firefighter contributions with those of other providers, so there are many measurement challenges associated with this issue. In the third chapter, I analyze the impact of increased firefighter employment on the incidence of time-sensitive deaths. I also consider how reductions in response time resulting from increased firefighter employment translate to value enhancements on EMS calls. While this analysis necessarily abstracts from some of the nuances mentioned above due to data limitations, it provides a useful starting point for thinking about the bounds on marginal firefighter value on EMS calls.

To the extent that the surge in EMS calls is driving firefighter employment growth, there are also important policy considerations regarding the optimality of this arrangement that are distinct from the value estimates discussed above. A strong efficiency argument can be made for firefighters providing some level of EMS, since fire departments are strategically located for rapid response and the marginal labor cost of attending non-fire calls is very low for an existing firefighter. However, whether it is desirable economically to hire new firefighters on the basis of this need after staffing for an appropriate level of fire coverage, rather than additional emergency medical technicians (EMTs) and paramedics for example, is an important open question. According to the Bureau of Labor Statistics, the median

salaried EMT or paramedic earns about two-thirds of the median career firefighter salary. Moreover, fire engines can cost more than \$500,000, at least seven times as much as the average ambulance, and have a limited lifespan of up to 80,000 miles as a front-line vehicle (Rowe, 2009).⁹ It is not uncommon for a fully-staffed fire engine to arrive at a medical call in addition to at least one ambulance. For example, I find that at least one fire suppression vehicle attends 41 percent of recorded EMS responses in the 2017 National Fire Incident Reporting System data. For half of these responses, the fire department also sends at least one of its own ambulances.¹⁰

Even under models without third-party redundancy, such as where all EMS is provided by cross-trained firefighters or a combination of firefighters and paramedics employed by the fire department, there may still be a rationale for reevaluating how fire department resources are allocated. For example, the Chicago Fire Department houses both firefighters and paramedics. In 2017, EMS calls accounted for nearly 75 percent of call volume, whereas fire calls comprised less than 4 percent. Yet the fire department operated a total of 158 fire trucks and engines, versus just 75 ambulances (plus 10 on standby) (Eng, 2017). For this reason, ambulances were often not available and fire engines were instead sent as first response to medical calls. In cases where patient transport or additional care was needed, the firefighters could only assist the patient(s) until the ambulance arrived. As a result of the ambulance unit shortage, 97 percent of paramedics worked overtime in 2016, resulting in \$14.9 million of overtime pay. Similarly, the New York City Fire Department (FDNY) employed about 11,000 firefighters in its fire unit and 4,000 EMTs/paramedics in its EMS unit in 2018. Base salaries for FDNY EMTs and paramedics were capped at \$51,000 and \$64,000 after five years (respectively), whereas firefighters earned a base of \$110,000 after five years. Yet the EMS unit responded to 1.5 million calls, versus 620,000 calls for the fire unit, nearly half of which were life-threatening medical calls that the EMS unit also attended (Adams Otis, 2019). In general, the 9-1-1 system in many cities is also strained by the large majority of low-acuity calls, and firefighters are often tasked to fill the service gaps (Cannuscio *et al.*, 2016).

There is a critical need for additional research on the optimal organizational structure for a fire

⁹These estimates are based on a 2009 report for the city of San Diego.

¹⁰In many cases, a third-party medical provider will also be present, but this is not observable in the data.

department in a world with far less fires and far more medical emergencies. One way to approach this problem is to first determine the optimal size of the fire force in a given jurisdiction based on the staffing and resource levels needed to safely achieve a desired response time on fire calls and to handle maximum local fire risks. Many fire departments have mutual aid agreements in place whereby surrounding departments pre-commit to providing additional manpower and resources in the event of severe fires. These arrangements should be a central strategic focus when staffing for tail risks.¹¹ Firefighters could continue providing first response on EMS calls between fires and other emergencies, but these responses would ideally be dispatched exclusively for time-sensitive emergencies, given the high relative cost of operating fire engines. The optimal size of the primary EMS force, which would consist of paramedics, EMTs, and/or cross-trained firefighters in ambulance units, could then be determined based on the remaining need for medical response and the chosen performance targets. After achieving the desired level of fire protection, growth in EMS needs would be supported by an expansion of ambulance units, rather than fire engine units.

The rest of the paper proceeds as follows. In Section 1.2, I briefly describe the data sources used throughout the paper. In Section 1.3, I provide a detailed overview of the U.S. firefighting landscape and describe how it has evolved over recent decades. In Section 1.4, I establish the employment puzzle at the department level and explore potential explanations for recent career firefighter employment growth. In Section 1.5, I provide a descriptive analysis of the heterogeneity in staffing, call volumes, and employment costs for a cross-section of all-career fire departments. I then estimate breakeven marginal benefit targets per firefighter response to benchmark the experimental estimates in the subsequent chapters. In Section 1.6, I provide a closing discussion.

1.2 Data

In the analysis that follows, I make use of four primary sources of data, which I merge based on fire department or government identifier: (1) aggregate fire data from the National Fire Protection

¹¹For example, in September 2018, a series of gas explosions caused more than 100 fires in the Merrimack Valley towns of Massachusetts. As part of a coordinated mutual aid agreement, more than 200 communities across Massachusetts, New Hampshire, and Maine sent fire assets to assist with the emergency (Duval, 2019).

Association (NFPA), (2) descriptive fire department data from the United States Fire Administration (USFA) Fire Department Registry, (3) municipal budget and employment data from the Census of State and Local Governments, and (4) incident-level fire department data from the National Fire Incident Reporting System (NFIRS). I now briefly describe each of these data sources.

1.2.1 NFPA Aggregate Fire Data

The NFPA is a non-profit organization dedicated to eliminating the threat from fire. In addition to publishing codes and standards for the fire community, the NFPA provides research on a wide range of fire-related topics. Many of the aggregate fire trends presented in this paper are compiled from NFPA data.

1.2.2 USFA Fire Department Registry

The USFA Fire Department Registry provides a current cross-section of all identified U.S. fire departments. For each department, it contains information on the headquarters location, the number of fire stations, the number of career and volunteer firefighters, and the organization type (e.g. local, state, federal). The sample accounts for about 92% of aggregate career firefighter membership, as compared to estimates by the National Fire Protection Association.

1.2.3 Census of State and Local Governments

The Census of State and Local Governments provides annual budget and employment data starting in 1957 for a representative sample of governments. Every five years, in the years ending in “2” or “7”, a comprehensive census is obtained. In the intervening years, a smaller sample of government data is collected. For most of the descriptive analysis, I use the census years to create the largest balanced panel for each surveyed government between the years 1987 and 2017.

The Census employment data, contained in the Annual Survey of Public Employment and Payroll (ASPEP), provides the number of full-time employees of each government by occupation type and the total payroll they receive. Fire department employees are classified either as “firefighters” or “other,” which includes paid civilian staff and single-role medical providers employed by the fire department.

Unfortunately, the Census data only accounts for career firefighters, such that time-series data on volunteer firefighters at the department level is unavailable. For this reason, I restrict most of the analysis in this paper to local governments that sponsor all-career fire departments.

The budget data, contained in the Annual Survey of State and Local Government Finances, provides a detailed breakdown of revenues and expenditures by function, including “fire protection” expenditures. Included in this spending category are all EMS-related expenses incurred by fire departments. It does not include, however, spending on medical response that is provided by a separate party outside of the fire department. These expenses are instead grouped with the “health” expenditure category.

1.2.4 National Fire Incident Reporting System (NFIRS)

NFIRS is a standardized incident reporting system used by fire departments across the country to document incident responses. For each response, it contains information on the date, response type (e.g. fire, EMS, false alarm), alarm and arrival times, number of responding firefighters and apparatus, number of civilian and firefighter casualties, and estimates of property damage. The data is available for all recorded fire responses during the years 1980 to 2017. However, for EMS and other response types, the data is limited to 2012-2017.¹²

NFIRS reporting is voluntary at the national level, but many states impose their own reporting requirements (FEMA, 2015). As of 2017, every state reports to NFIRS; however, some states are completely absent from the data in earlier years - particularly before 2003. Moreover, individual fire departments may report in some years, but not others. Finally, there are also obvious cases of under-reporting by some fire departments that do report in a given year, both in terms of the number of incidents documented and the scope of the data that is provided (FEMA, 2011).¹³

¹²The publicly-obtained NFIRS data including EMS events is limited to 2014 at the earliest. I obtained the 2012-2013 EMS-inclusive NFIRS data through a data-sharing agreement with FireCARES. Credit line: *FireCARES: Community Assessment/Response Evaluation System: The content reproduced from the FireCARES Database remains the property of FireCARES and contributing fire departments. The FireCARES team and partners are not responsible for any claims arising from works based on the original Data, Text, Tables, or Figures.*

¹³For example, the number of personnel that are reported as having responded to a given incident is zero in about 19 percent of total incidents in 2017.

Despite these shortcomings, the NFIRS data is estimated by the USFA to account for about 75 percent of annually reported fires and it serves as a primary input for national estimates of fire trends. The data integrity also tends to be more robust for larger departments that employ career firefighters, which is the focus of this paper. For many all-career departments, particularly in states with more explicit reporting requirements, the annual fire incidence trends exhibit a high level of stability going back to the 1980s. In Section 1.4, I show that the trends estimated for the NFIRS samples considered in this paper match very closely with national trends.

1.3 The U.S. Firefighting Landscape

1.3.1 Fire Department Structure and Employment

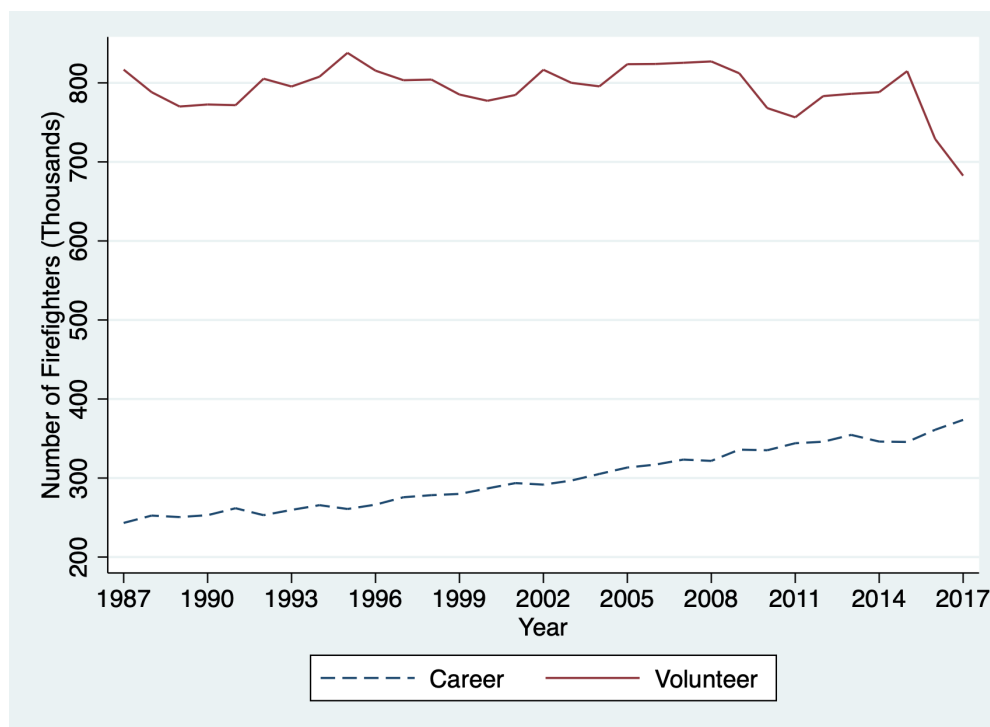
A unique feature of the U.S. firefighting service is that the majority of members are pure volunteers.¹⁴ In 2017, there were 1,056,200 firefighters, of which 682,600 were volunteers and 373,600 were career (salaried) employees.¹⁵ However, between 1987 and 2017, the volunteer share of the firefighting force declined from 77 percent to 65 percent, as the number of career firefighters rose by 54 percent and the number of volunteer firefighters declined by about 16 percent (Figure 1.2). Most of the decline in volunteer membership occurred after 2015; otherwise, volunteer employment has been mostly stable over the last three decades. Importantly, these employment numbers only include firefighters employed by local governments and exclude the minority of firefighters employed by the federal government, state governments, and private employers. As such, the firefighters discussed in this paper are not affiliated with the primary agencies typically responsible for wildfire suppression.

As previewed in the introduction, a fire department can either be classified as all-career, all-volunteer, or mixed, depending on its share of career and volunteer firefighters. Mixed departments can be further classified as “mostly career” or “mostly volunteer,” depending on which firefighter type

¹⁴In some fire departments, volunteers receive partial remuneration for their services, such as property tax deductions, reduced pension credits, and/or a fixed pay rate per call attended. See International Association of Fire Chiefs (2006) for a detailed explanation of permissible benefits to volunteers under the Fair Labor Standards Act.

¹⁵Unless otherwise noted, the aggregate data presented in this section is summarized from National Fire Protection Association data tables and reports, including Evarts (2018), Haynes and Stein (2017), and National Fire Protection Association (2016).

Figure 1.2: *Number of career and volunteer firefighters in the United States (1987-2017)*



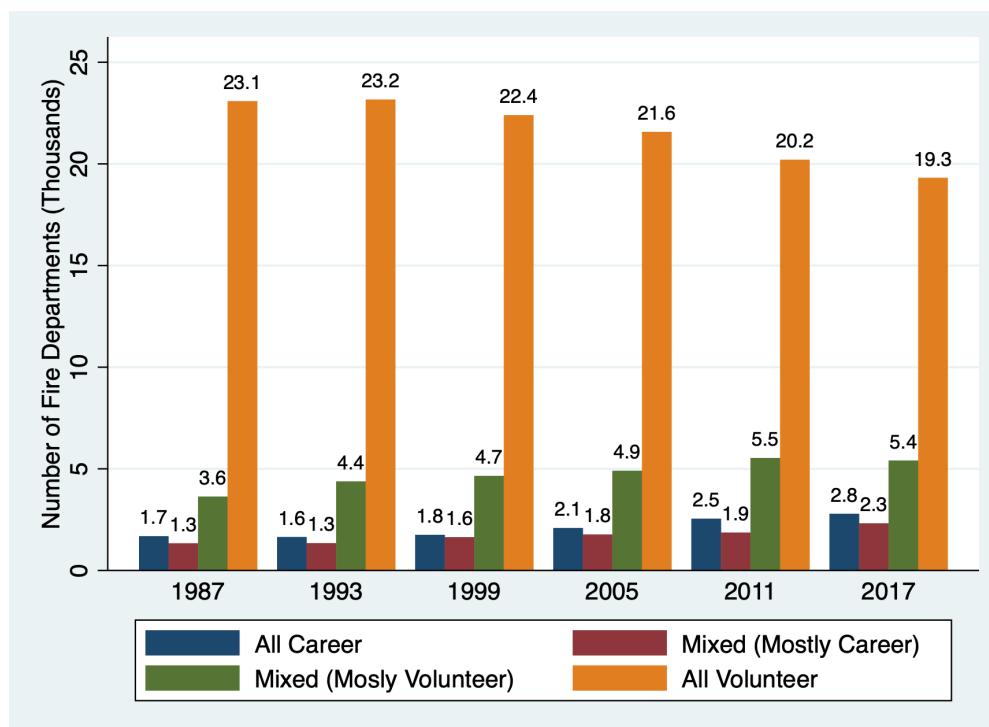
This figure shows the total number of volunteer and career firefighters in the United States (in thousands), from 1987 to 2017. *Source:* National Fire Protection Association.

comprises the majority of staff. Compositional changes have also been occurring at the fire department level in recent decades. Between 1987 and 2017, the number of all-volunteer departments decreased from 23,088 to 19,313, while the number of all-career departments increased from 1,683 to 2,785, and the number of mixed departments increased from 4,970 to 7,721 (Figure 1.3).¹⁶ These trends suggest that some portion of the recent growth in career firefighter rolls has occurred on the extensive margin through replacement or conversion of volunteers, rather than just intensive growth at existing all-career fire departments.

The career share of a municipality's fire department is highly correlated with population size. As seen in Figure 1.4, all-career and mostly-career fire departments accounted for just 9% and 8% of department membership in 2017, but protected 50% and 19% of the population, respectively.

¹⁶ Among the mixed departments, 2,316 employed mostly career firefighters in 2017 (up from 1,335 in 1987) and 5,405 employed mostly volunteers (up from 3,635 in 1987).

Figure 1.3: *Number of fire departments in the United States, by type (1987-2017)*

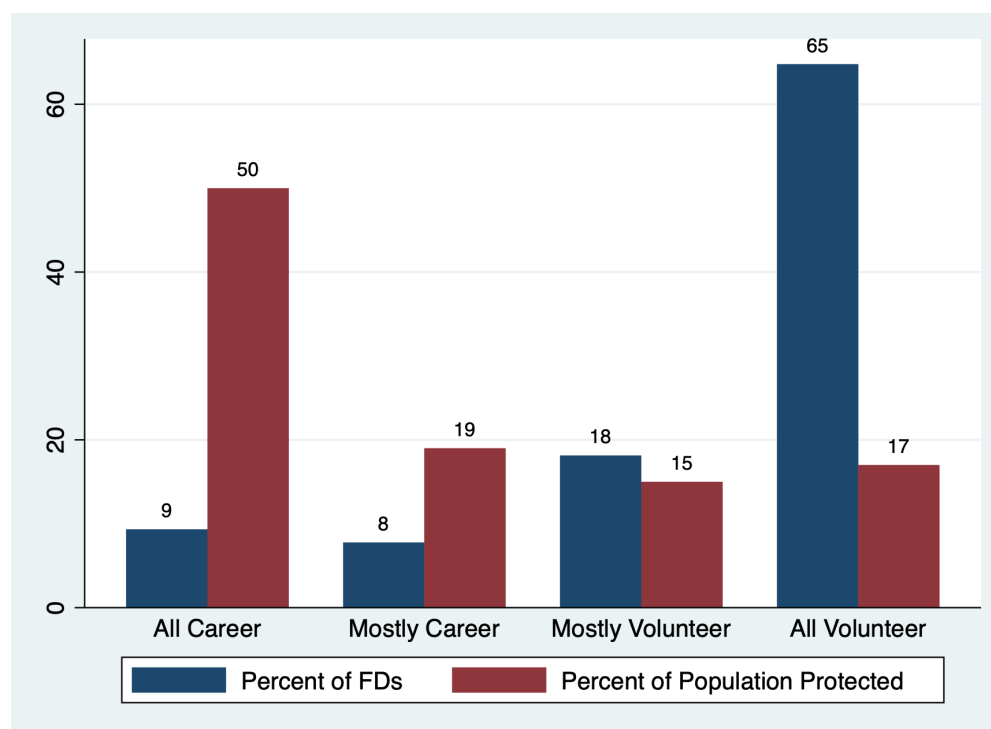


This figure shows the total number of fire departments in the United States from 1987 to 2017, classified by department type. “All-career” departments employ only salaried firefighters, “all-volunteer” departments employ only volunteer firefighters, and “mixed” departments employ a combination of both. *Source:* National Fire Protection Association.

Alternatively, all-volunteer fire departments accounted for almost two-thirds of departments, but were almost exclusively concentrated in municipalities with less than 10,000 citizens. Nearly 50 percent of U.S. fire departments protect populations with 2,500 or less citizens, and almost 95 percent of these departments are all-volunteer.

Figure 1.5 shows how career fire department employment has evolved relative to other major categories of local government employment over the last three decades using the ASPEP data. The first two bars for each employment category show the number of full-time-equivalent employees in 1987 and 2017 (in 100,000s), respectively. The third bar provides the comprehensive annual growth rate (CAGR) over this three-decade period. The “fire” category here includes both career (salaried) firefighters and non-firefighting employees who work at fire departments; it does not include any

Figure 1.4: *Fire department distribution and population coverage in 2017*



This figure shows the share of U.S. fire departments represented by each department type (blue bars), as well as the share of the population protected by each (red bars). *Source:* Evarts and Stein (2020).

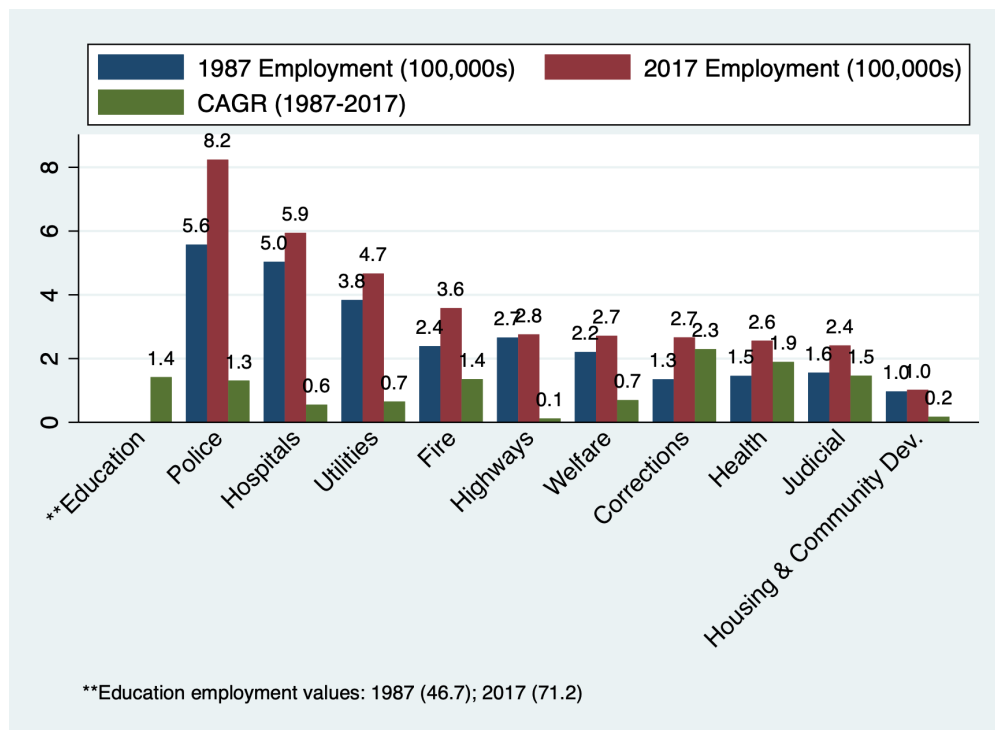
volunteers.¹⁷ In 2017, fire protection represented the fifth largest major category of local government employment, behind only education, police, hospitals, and utilities (water, gas, electric, and mass public transit). If this figure were to include volunteer firefighters, the fire category could be as high as the second largest employment group, depending on how volunteer employment is converted to “full-time equivalents.”

The figure also shows that fire protection employment grew faster (1.36% CAGR) than any larger employment category, except for education, which grew at a very similar rate (1.42%).¹⁸ Smaller

¹⁷There is a discrepancy between the firefighter employment numbers presented in Figures 1.1 and 1.2, which derive from the National Fire Protection Association (NFPA), and those shown in Figure 1.5, which are taken from the ASPEP. For example, the NFPA estimates that there were 373,600 career firefighters in 2017, whereas the ASPEP records 324,574 firefighters (and 358,307 total fire department employees). As discussed in subsequent sections, the time trends for each data source look mostly similar.

¹⁸The results are nearly identical (qualitatively) if the “fire” category is further restricted just to employees classified as “firefighters.” The CAGR for this group is 1.27%, which is almost exactly equal to the growth rate for police (1.31%).

Figure 1.5: Local government employment (1987, 2017) and real CAGR (1987-2017), by function



For each employment category, this figure shows 1987 and 2017 employment levels (in 100,000s of full-time-equivalent employees), as well as the comprehensive annual growth rate (CAGR) over this three-decade period. The education employment bars have been removed to maintain visual clarity. The "fire" category includes both firefighters and full-time non-firefighting employees of fire departments. *Source:* U.S. Census Bureau Annual Survey of Public Employment and Payroll.

employment categories with high growth rates include corrections (2.3%), health (1.9%), and judicial (1.5%). The health category includes salaried EMTs and paramedics who are not employed by the fire department. As previewed in the introduction, one hypothesis for recent career firefighter growth is their involvement in providing emergency medical care. Similar steady growth in the health employment category may be consistent with the rising demand for these services. On the other hand, employment in highways and public transportation infrastructure, public welfare, and housing development experienced very little growth over the last three decades.

The extent to which a fire department is involved with emergency medical service (EMS) delivery is also increasing in population size, and thus the career share of employees. Table 1.1 shows that 38 percent of all fire departments provide no EMS, 45 percent provide Basic Life Support (BLS), and 17

percent provide Advanced Life Support (ALS).¹⁹ However, nearly 90 percent of fire departments that protect at least 25,000 citizens provide some form of EMS, and the majority of these departments are all-career in membership (Evarts and Stein, 2020). In Section 1.4.5, I provide additional analysis on fire-based EMS; the third chapter of this thesis deals exclusively with this topic.

Table 1.1: *EMS delivery by protected population size (2016-2018)*

Population Protected	Departments (#)	No EMS (%)	BLS (%)	ALS (%)
1,000,000 or more	15	0	0	100
500,000 to 999,999	43	0	26	74
250,000 to 499,999	66	2	27	72
100,000 to 249,999	288	3	34	63
50,000 to 99,999	559	6	39	55
25,000 to 49,999	1,321	17	37	46
10,000 to 24,999	3,511	27	42	32
5,000 to 9,999	4,283	38	43	19
2,500 to 4,999	5,378	41	47	12
Under 2,500	14,242	45	49	6
Nationwide	29,705	38	45	17

For each protected population size, this table shows the total number of fire departments in service, and the share of these departments providing no emergency medical service (EMS), Basic Life Support (BLS), or Advanced Life Support (ALS). *Source:* Evarts and Stein (2020).

1.3.2 Fire Experience and Call Volume

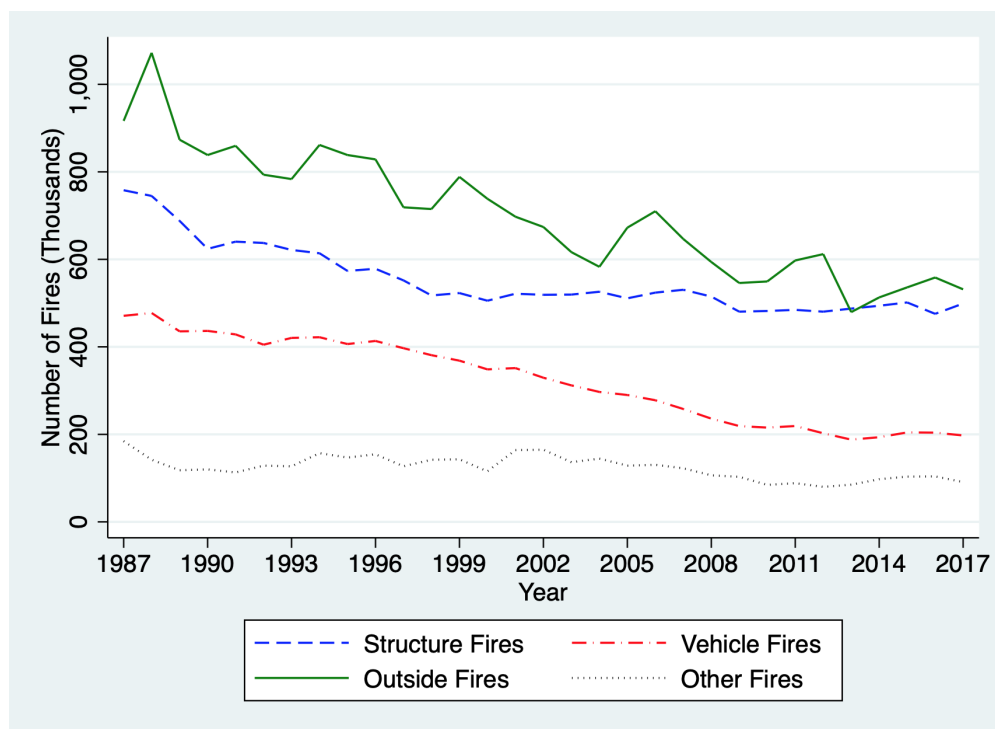
In terms of fire experience, the number of annual fires in the US declined by 43 percent between 1987 and 2017, from 2.33 million to 1.32 million.²⁰ This aggregate change implies a reduction from 78 annual fire calls for the average fire department to 44 fire calls, when allocating total incidence equally across career and volunteer departments. Average call volumes tend to be higher at urban, all-career departments that serve larger populations, but the fire trends are similar. For a sample of 777 all-career departments that serve a population of least 20,000 and have available NFIRS data, I find that the average fire call volume declined from 509 in 1987 to 319 in 2017. This reduction in incidence has

¹⁹BLS involves the basic first steps in stabilizing a patient, whereas ALS involves more advanced resuscitation and management procedures. Only professionals trained in ALS are able to administer emergency drugs and invasive treatments.

²⁰On a population-weighted basis, this equates to a 58 percent drop, from 9.6 annual fires per one thousand citizens to 4.1 fires.

been consistent across fire types, with annual structure fires falling by 34 percent, vehicle fires by 58 percent, outside fires by 42 percent and all other fires by 51 percent (Figure 1.6).²¹ These trends have also been robust across broad geographic regions. Figure 1.7 shows that population-weighted declines in fire incidence have ranged between 55 percent and 62 percent in the South, Northeast, Midwest, and West.

Figure 1.6: *Number of annual fire incidents, by type (1987-2017)*

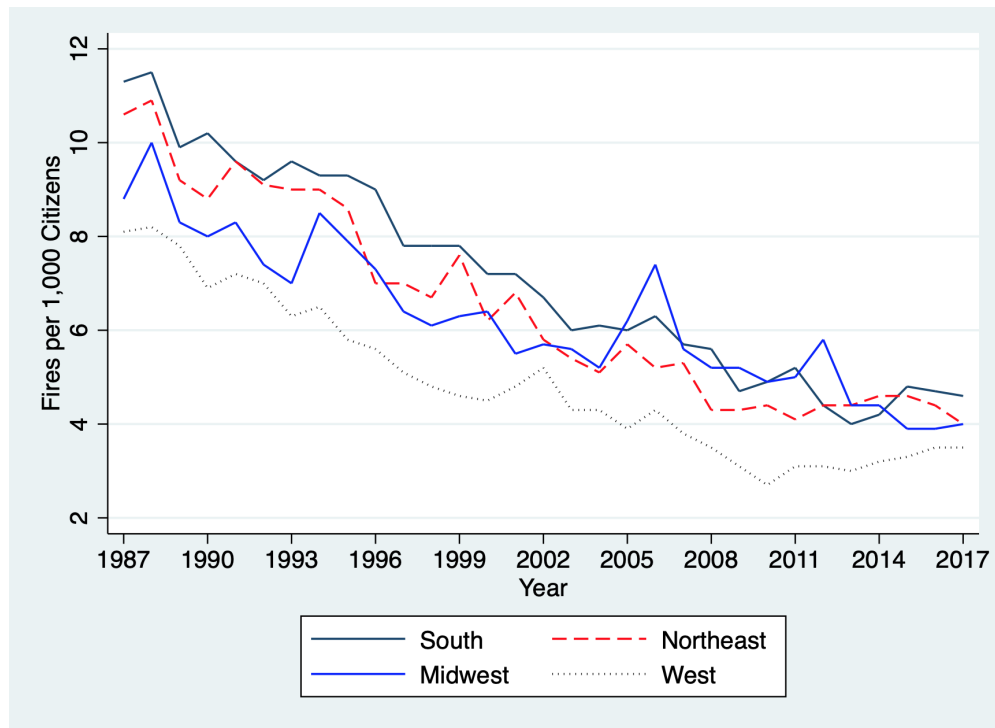


Outside fires include fires outside of structures, brush fires, grass fires, forest fires, and rubbish fires. *Source:* Ahrens (2017), Haynes (2017), and Evarts (2018).

Despite the sharp decline in fire incidents across the US, the total number of calls received by fire departments has nearly tripled over the last three decades. In 2017, fire departments responded to 34.7 million calls, implying an average total call volume of 1,163 per department. In 1987, the average call volume was only about 411. This call growth has been driven in large part by EMS calls, which more than tripled from 6.4 million in 1987 to 22.3 million in 2017 (Figure 1.8). EMS calls now account for nearly two-thirds of all fire department activity, whereas fire calls represent only 4 percent. All other

²¹Outside fires include fires outside of structures, brush fires, grass fires, forest fires, and rubbish fires.

Figure 1.7: Number of annual fire incidents per 1,000 citizens, by region (1987-2017)



Source: Karter (2013) and Evarts (2018).

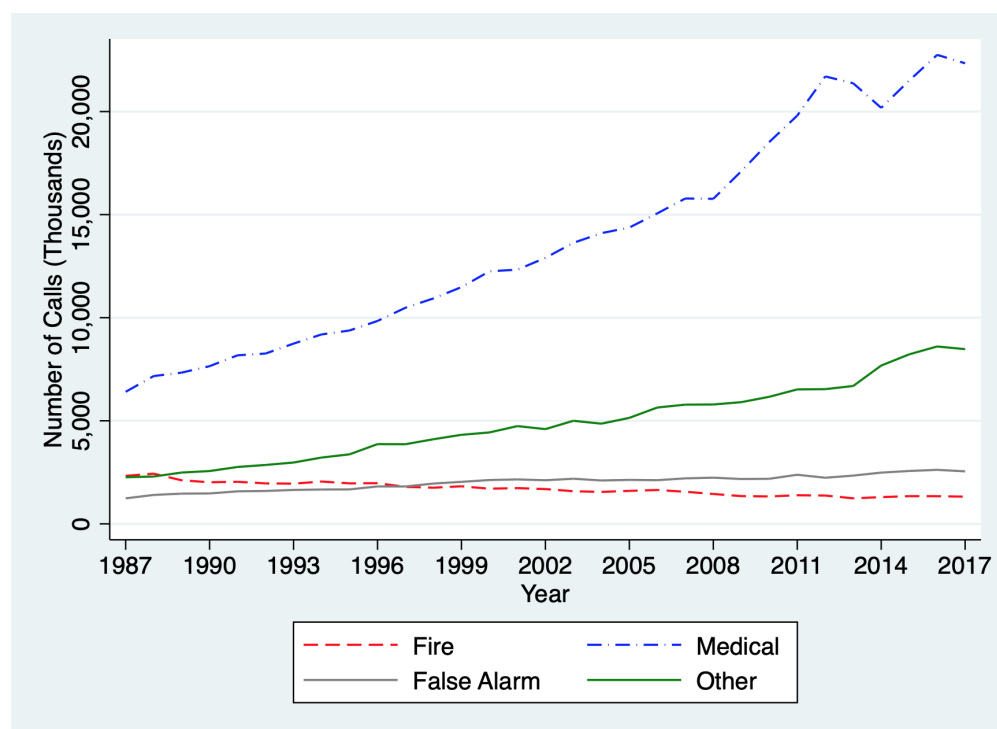
response categories also experienced considerable growth between 1987 and 2017, as false alarm calls rose from 1.2 million to 2.5 million (7% of call volume), mutual aid calls rose from 0.43 million to 1.4 million (4% of call volume), and all other calls rose from 1.8 million to 7.1 million (19% of call volume).²² As discussed further in Section 1.4.5, the surging EMS call burden shown in Figure 1.8 provides a compelling potential explanation for the growth in career firefighter membership.

1.3.3 Fire Protection Expenditures

Local fire departments can be funded through a variety of mechanisms, including government transfers, special fire district revenues, user fees, federal grants, and fundraising efforts. This section will focus on fire protection expenditures funded directly by local government entities. In 2017, direct fire

²²“Mutual aid” calls refer to aid responses outside of a department’s jurisdiction that are typically enacted automatically based on prearranged agreements. Many of these responses will typically be for backup on fire incidents, but are categorized separately. The “other” calls category includes hazardous conditions and materials calls, overpressure rupture calls, service calls, good intent calls, and severe weather calls. Mutual aid calls are included in the “other” category in Figure 1.8.

Figure 1.8: Number and type of fire department calls (1987-2017)



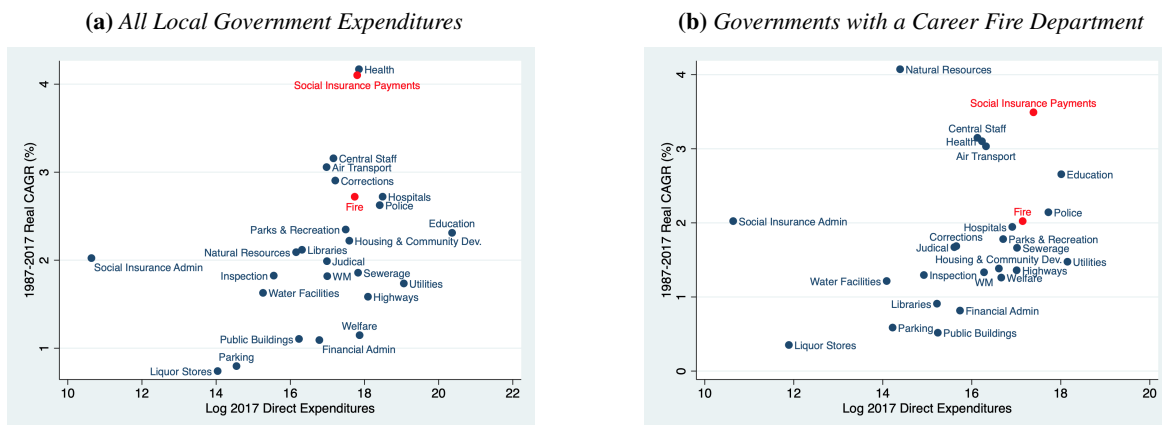
This figure shows the distribution of fire department calls from 1987 to 2017. “Other” calls include hazardous conditions and materials calls, overpressure rupture calls, service calls, good intent calls, severe weather calls, and mutual aid calls. Mutual aid refers to aid responses outside of a department’s jurisdiction that are typically enacted automatically based on prearranged agreements. *Source:* National Fire Protection Association.

protection expenditures from local governments amounted to about \$50.5 billion, or nearly 3 percent of total direct expenditures.

Figure 1.9 uses data from the Annual Survey of State and Local Government Finances to plot the 2017 magnitudes (in logs) of different direct spending categories for local governments relative to their real compound annual growth rates (CAGRs) from 1987 to 2017. Panel (a) accounts for all direct local government expenditures, including those deriving from counties, municipalities, townships, special districts, and school districts. The figure shows that fire protection expenditures (highlighted in red) are currently the tenth largest major spending category across local governments and the seventh fastest-growing expenditure function over the last three decades. Notably, the real CAGR for fire protection expenditures (2.72%) is within 33 basis points of any faster-growing category, except for social

insurance payments (4.1%) and health (4.17%).²³ The social insurance marker is also highlighted red to indicate that a non-trivial portion of these expenditures represent retirement, disability, and workers' compensation benefits paid out to firefighters. Another takeaway from the figure is that fire protection expenditures have grown slightly faster than police expenditures (2.63% CAGR), and considerably faster than education (2.3% CAGR), housing and community development (2.2%), highways and transportation infrastructure (1.6% CAGR), and public welfare (1.15%) expenditures. The gap between police expenditure growth and outlays associated with human capital development, social assistance, and infrastructure improvements has been heavily scrutinized in recent political discourse. To the extent that this debate is centered around the marginal economic value of public funds, in addition to racial and social justice, this figure motivates fire protection expenditures as another important area for analysis.

Figure 1.9: Local government direct expenditures (2017) vs. real CAGRs (1987-2017)



For each local government expenditure function, this figure plots 2017 direct expenditures (in logs) against the real comprehensive annual growth rate (CAGR) from 1987 to 2017. The scatter in Panel (a) accounts for all local government direct expenditures; the scatter in Panel (b) is restricted to local governments identified in the Census data that sponsor all-career fire departments. I also restrict the Panel (b) sample to government entities with a population of at least 1,000 and with balanced Census data in the 5-year increments between 1987 and 2017 (N = 1,640). *Source:* Author's calculations from the U.S. Census of State and Local Government Finances.

Panel (b) of Figure 1.9 restricts the analysis sample to county, municipal, and township governments that represent a population of at least 1,000 and help support an all-career fire department - the primary

²³The health category includes the provision of non-hospital services for the conservation and improvement of public health, including ambulance and emergency medical services provided outside of the fire department. Any medical services provided directly by the fire department are included in fire protection expenditures.

domain of interest in this paper.²⁴ The qualitative results are similar to those in Panel (a) except that for this sample, fire protection represents an even more substantial share of aggregate expenditures (5.3%), behind only utilities (14.4%), education (12.5%), police (9.4%), and social insurance payments (6.7%).²⁵ While fire protection is also still among the ten fastest-growing spending categories between 1987 and 2017, its real CAGR (2.02%) falls 70 basis points lower than in Panel (a) and is exceeded by the growth rates for police (2.14%) and education (2.66%). Nevertheless, fire protection spending for this group still outpaces total direct spending (1.91% CAGR).

1.4 The Firefighter Employment Puzzle

The aggregate trends in Figure 1.1 present a puzzle to the extent that a decline in the presumed demand for firefighters (i.e. the number of fires) is being met by an increasing supply of firefighters, especially given that firefighter employment growth has also exceeded most other major areas of local government employment. However, there are several alternative explanations for these aggregate patterns that I work through in this section. First, I assess whether these trends can be explained by endogeneity or volunteer substitution. Then I consider other potential drivers for firefighter employment growth besides fire incidence, including rising fire severity, adherence to national staffing standards, and the rapid increase in EMS calls.

1.4.1 Endogeneity

One possible explanation for Figure 1.1 is that the growth in career firefighter rolls has *caused* the decline in fire incidence. Almost all fire departments engage in some variety of preventative activities, such as code inspections and educational outreach, and fire authorities often emphasize risk reduction as an important, underserved need (National Fire Protection Association, 2016). The recent growth in career firefighter membership may have expanded the supply of fire prevention efforts, which

²⁴For a government entity to be included in the sample, I also require sample balance in each five-year interval of the Census data between 1987 and 2017. The resulting sample of 1,640 governments represents 82 percent of firefighters and 69 percent of fire departments, as estimated from the USFA Fire Department Registry.

²⁵The utilities category combines water, gas, electric, and mass public transit utilities.

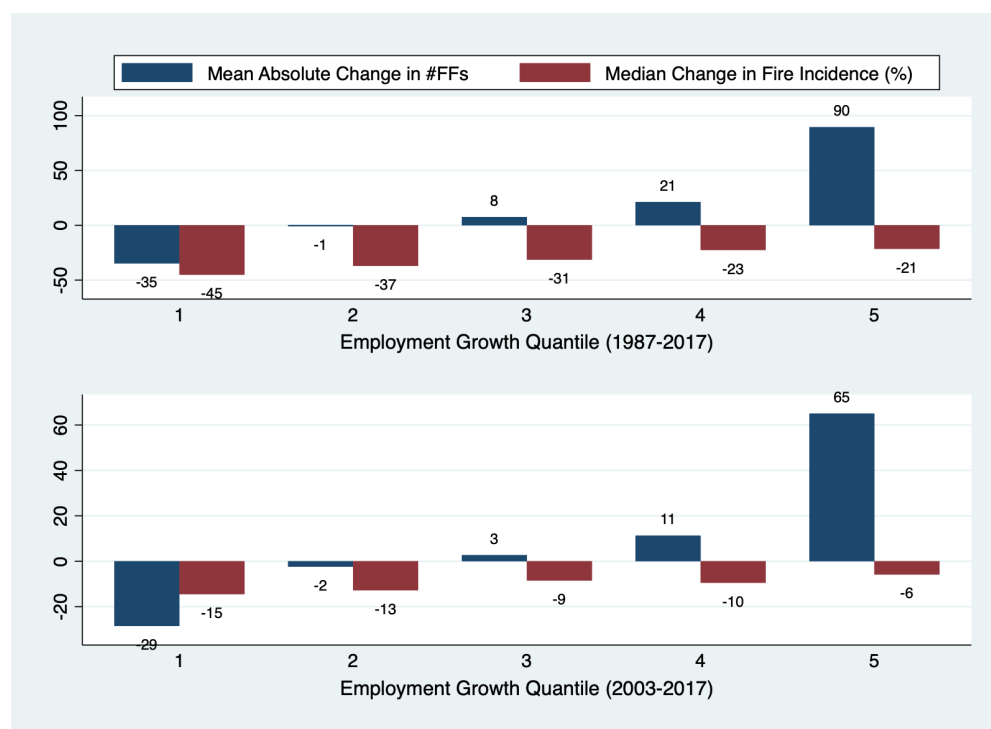
endogenously lowered the occurrence rate of fires. However, to the extent that these activities are conducted by fire inspectors, rather than firefighters, this explanation would not account for the trends in Figure 1.1. More importantly, there are many other drivers commonly attributed to the decline in fire incidence, including stricter building codes, the proliferation of alarms and sprinklers, and improvements in vehicle safety.

I offer three pieces of descriptive evidence against the hypothesis that career firefighter employment growth endogenously lowered fire incidence. First, I group the all-career fire departments in my sample into five quantiles based on their absolute change in firefighter employment between 1987 and 2017, as calculated from the ASPEP data. The blue bars in the top panel of Figure 1.10 show the average absolute change in firefighter employment for the departments in each quantile. The red bars report the median percentage change in annual fire incidence between 1987 and 2017 for the departments in each quantile, based on my calculations from the NFIRS data. If an endogeneity story was driving the patterns in Figure 1.1, we would expect increasing declines in fire experience at higher employment growth quantiles. Instead, the figure shows an opposite pattern, whereby the decline in fire incidence is largest for the lowest employment growth quantile and smallest for the highest employment growth quantile. These findings are more consistent with a story of fire department staffing exhibiting at least some level of responsiveness to an exogenous fire trend. Because there are 17 states with minimal or no reporting in the NFIRS data until around 2003, I repeat the exercise in the bottom half of the figure for the 2003-2017 period.²⁶ Again, the same general pattern holds.

Second, I make use of international evidence from the United Kingdom, which releases official statistics on both firefighter membership and fire experience. Like U.S. fire departments, U.K. fire departments engage in preventative activities, such as home risk checks and fire safety audits, that may plausibly reduce fire incidence. Figure 1.11 plots the relationship between full-time firefighter membership and annual fire incidence in the UK for the years 2002-2017. Unlike the inverse trends shown in Figure 1.1, Figure 1.11 reveals a simultaneous and dramatic decline in both firefighter employment and fire incidence. Furthermore, the number of annual home fire risk checks conducted

²⁶The 1987-2017 sample consists of the 902 all-career local fire departments with both employment and fire incidence data in 1987 and 2017. The 2003-2017 sample size increases to 1,267 departments.

Figure 1.10: *Change in fire incidence, by firefighter employment growth quantile: 1987-2017 and 2003-2017*

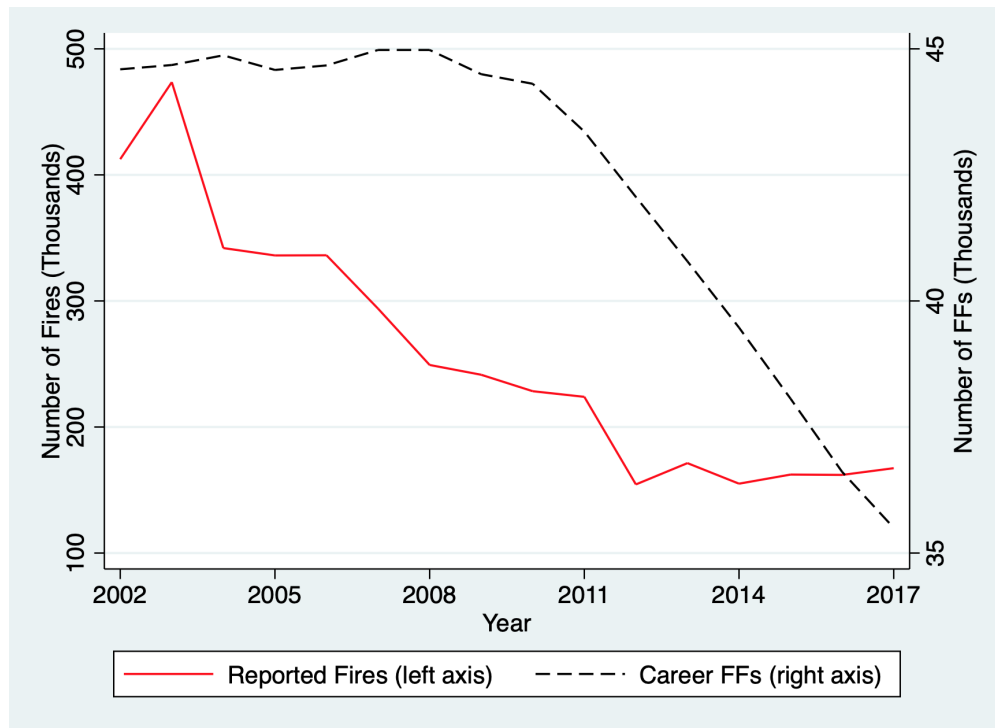


This figure is created by first sorting all-career fire departments into five quantiles based on absolute firefighter employment growth between 1987 and 2017 (top panel) and 2003 and 2017 (bottom panel). The blue bars show the mean absolute change in employment for each of these quantiles. The red bars show the median percentage change in fire incidence over the respective periods across departments in that quantile. There are 902 fire departments represented in the top panel of the figure and 1,267 in the bottom panel. *Source:* Author's calculations based on the U.S. Census Bureau Annual Survey of Public Employment and Payroll and the National Fire Incident Reporting System.

by U.K. fire departments declined by 26 percent between 2010 and 2017, the only years for which this data is available from the United Kingdom Office for National Statistics. These findings again weaken the endogeneity argument for the US. Interestingly, medical calls account for less than one percent of total fire department call volume in the United Kingdom, whereas they have grown to nearly two-thirds of call volume in the US (Knight, 2013).

Finally, as discussed previously, Figure 1.6 shows that the largest percentage decline in U.S. fire incidence has been attributable to vehicle fires, which fell by 63 percent between 1987 and 2017. Whereas firefighter efforts may help to prevent accidental fires, such as cooking and trash fires, it is less plausible that they can materially affect automobile fires. According to Ahrens (2010), 49 percent of highway vehicle fires between 2003 and 2007 were caused by mechanical failure, 23 percent by

Figure 1.11: *Number of annual fire incidents and full-time firefighters in the United Kingdom (2002-2017)*



This figure shows the total number of annual fire incidents in the United Kingdom between 2002 and 2017 (left axis), plotted against the total number of full-time firefighters (right axis). Both are reported in thousands. *Source:* United Kingdom Office for National Statistics.

electrical failure, 3 percent by collision, 5 percent by exposure to other fire, and 8 percent by intention. It is unlikely that the preventative efforts of fire departments could impact any of these margins, except perhaps the latter two. Rather, the dramatic reduction in vehicle fires is more likely attributable to improvements in manufacturing standards.

1.4.2 Substitution for Volunteer Firefighters

A second set of alternative explanations for Figure 1.1 relates to the composition of fire departments and the overall firefighting force. As discussed in Section 1.3, career firefighters may be employed in either all-career or mixed departments, both of which have grown in prevalence over the last several decades, while all-volunteer departments have been in decline (Figure 1.3). Although the number of volunteer firefighters has remained relatively stable over this period, it may be that the growth in career firefighter rolls shown in Figure 1.1 largely represents substitution for volunteers, whose per capita

representation has been declining with population growth. Moreover, it may be that the fire experience for existing all-career departments has been different from the aggregate trend displayed in Figure 1.1. These departments tend to be located in the most highly populated areas, where fires may not have declined as sharply.

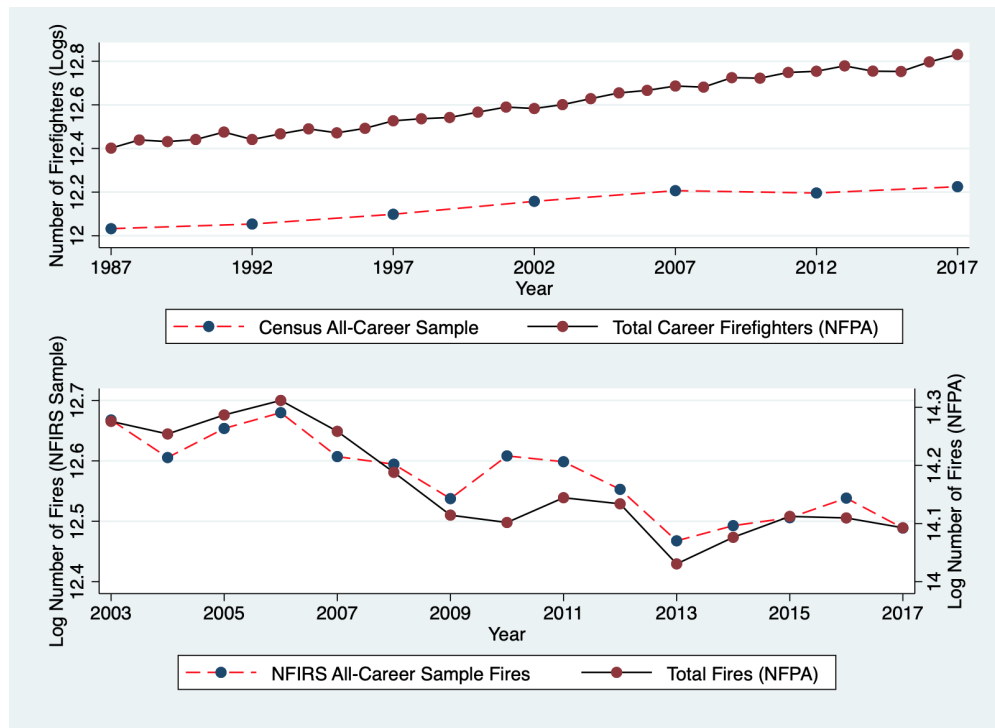
To address these explanations, I first construct the largest possible balanced sample of all-career fire department employment data from 1987 to 2017 using the 5-year census intervals of the ASPEP data. This sample covers 1,483 of the 2,785 existing all-career fire departments. The top panel of Figure 1.12 plots log membership growth for this balanced panel of all-career fire departments relative to the aggregate career firefighter trend (as reported by the NFPA), which also includes firefighters from all-career departments that are not captured in the ASPEP sample and career firefighters from mixed departments. The figure shows that intensive employment growth at the sampled all-career departments lagged behind aggregate growth between 1987 and 2017, but still increased by 21% over the period (relative to 54% growth for the aggregate trend). Prior to the start of the Great Recession at the end of 2007, growth in the all-career sample tracked fairly closely with the aggregate trend, but then stagnated for most of the post-2007 period.

In the bottom panel of Figure 1.12, I then plot total annual fire incidence in the US (as reported by the NFPA) relative to the fire experience of the 887 all-career departments in my sample with both balanced ASPEP employment data (1987-2017) and balanced NFIRS fire incidence data (2003-2017).²⁷ Both series are reported in logs and plotted on separate y-axes. The figure shows that the decline in fire incidence at all-career departments has been no less significant than suggested by the national trend in Figure 1.1. Recent fire experience for all-career departments has moved very closely in sync with the national trend and both series registered a 16 to 17 percent decline between 2003 and 2017.

I find that these trends are also robust at the fire department level. The top panel of Figure 1.13 relates percentage changes in annual fire incidence to percentage changes in firefighter employment for 465 municipal all-career fire departments with available NFIRS and ASPEP data during the period

²⁷I start the NFIRS sample at 2003, in order to yield a large, balanced sample. In subsequent figures that do not require sample balance, I show that the fire trends are also robust going back to 1987.

Figure 1.12: All-career sample relative to NFPA aggregates: employment (1987-2017) and fires (2003-2017)

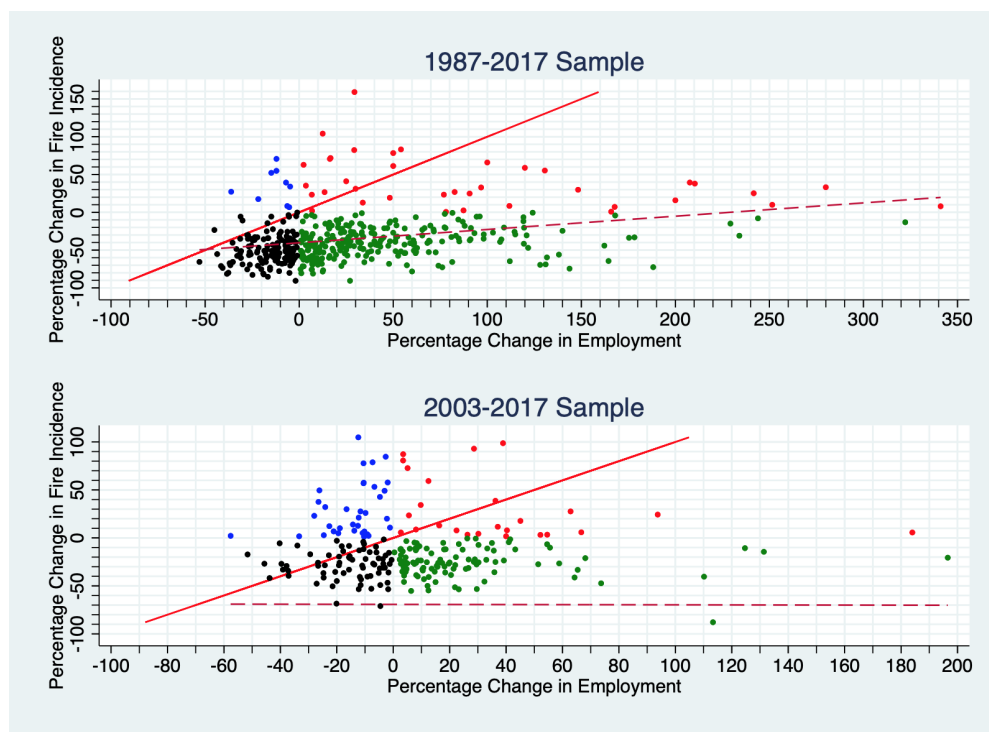


The top panel of this figure plots the total number of (log) career firefighters in the United States from 1987 to 2017 (as reported by the NFPA) against the longest-running balanced Census sample of firefighters working in all-career departments ($N = 1,483$). Note that the aggregate trend includes both (1) firefighters from all-career departments that are not included in the Census sample, and (2) career firefighters from mixed departments. The bottom panel plots the total number of annual reported fires in the United States from 2003 to 2017 (as reported by the NFPA) relative to the 887 all-career departments with both balanced Census employment data (1987-2017) and balanced NFIRS incident data (2003-2017). *Source:* National Fire Protection Association and author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll and National Fire Incident Reporting System.

1987-2017. Rather than require sample balance over the entire period for this exercise, I only require that a department has at least one year of comprehensive NFIRS data between the five-year windows of 1987-1991 and 2013-2017, as well as employment data in 1987 and 2017 (both census years). I then calculate the percentage change in average fire incidence between each five-year window. In addition to yielding a larger sample, this approach also reduces the impact of single-year outliers. I also restrict the sample to all-career fire departments with at least 20 firefighters, 20 reported fires, and a resident population of at least 20,000 in 1987. The data points are color-coded by quadrant and a solid 45-degree line is plotted as a visual aid. The dashed line shows a linear fit of the data. Nearly 60 percent of observations fall in the southeast quadrant (green dots), suggesting simultaneous employment growth and declining fire incidence. An additional third of departments also experienced

a decline in average fire experience, but reduced employment over the period (black dots). For many of these departments, employment changes were mild relative to the change in fire incidence, as indicated by the large mass of data points falling well below the 45-degree line. The bottom panel of this figure repeats the exercise for a separate group of 246 all-career departments with limited NFIRS data until the early 2000s. This sample covers the period from 2003 to 2017. The qualitative patterns are very similar, with about 50 percent of observations falling in the southeast quadrant and about 30 percent in the southwest.²⁸

Figure 1.13: All-career fire department employment growth vs. fire growth: 1987-2017 and 2003-2017



Change in fire incidence is based on the percentage change between the 5-year averages of annual fire incidence in 1987-1991 and 2013-2017. The sample is restricted to municipal all-career fire departments that served a population of at least 20,000, employed at least 20 firefighters, and responded to at least 20 fire calls in the start year. The top panel is restricted to departments with sufficient NFIRS data to account for the period 1987-2017 ($N = 465$); the bottom panel is restricted to a separate group of 246 departments with more limited NFIRS data (2003-2017). Observations are color-coded by quadrant. The solid line represents the 45-degree line; the dashed line shows a linear fit of the data. *Source:* Author's calculations from the National Fire Incident Reporting System and the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

Figures 1.14 and 1.15 separately decompose the top and bottom panels of Figure 1.13 by geographic

²⁸Appendix Figure A.1 replicates Figure 1.13, but based on changes in firefighter density, rather than changes in absolute firefighter employment. The qualitative patterns are again very similar. Two of five departments are in the southeast quadrant and more than half are in the southwest.

region. For the 1987-2017 sample (Figure 1.14), the share of departments with declining fire incidence (bottom quadrants) ranged from 86 percent in the south to 92 percent in the northeast. The share of departments that exhibited rising employment and declining fire incidence (southeast quadrant) ranged from one-fourth in the northeast to nearly three-fourths in the south. Percentage gains in *total* employment (not pictured) were highest in the south and west, which also experienced a much higher rate of population growth than the rest of the country over this period. Interestingly, despite a decline in employment at a majority of northeastern fire departments over this period and an increase at the majority of southern, western, and mid-western departments, firefighter density in the northeast remained well above that of the other regions in 2017. Between 1987 and 2017, the number of firefighters per 1,000 citizens in the northeast departments in the sample fell from 2.6 to 2.2, which is still at least 33 percent higher than any other region in 2017. Figure 1.15 shows similar patterns for the 2003-2017 sample, but with a smaller share of departments falling in the bottom-right quadrant, particularly in the northeast and midwest regions. These patterns are consistent with the aggregate trend in the top panel of Figure 1.12, which shows a slowdown in the employment trend after the Great Recession, which lies in the middle of this sample period.

Finally, career firefighter employment growth at the largest balanced sample of mostly-career fire departments in the ASPEP data was greater than 70 percent between 1987 and 2017.²⁹ A fire department can employ as little as 1 volunteer, or as many as 50 percent of its staff to be classified as “mostly career.” While time-series data on volunteer membership at these departments is not available, it is likely that a significant portion of this employment growth also represents new career positions, rather than volunteer substitution. As seen in Figure 1.2, aggregate volunteer membership has been relatively stable over the last three decades. Moreover, the current volunteer share across the mostly-career departments in this sample is only 20 percent. Figure 1.16 plots indices of aggregate career firefighter employment growth (as reported by the NFPA), all-career fire department employment growth from the ASPEP sample, and mostly-career fire department employment growth from the

²⁹This sample consists of 692 of the 1,238 local fire departments classified as “mostly career” in the USFA Fire Department Registry and accounts for two-thirds of career firefighters at these departments. For the 279 of these departments with balanced NFIRS data between 2003 and 2017, the aggregate decline in annual fire incidence over this period was about 10 percent.

Figure 1.14: All-career fire department employment growth vs. fire growth, by region (1987-2017)



This figure decomposes the top panel of Figure 1.13 by geographic region. Change in fire incidence is based on the percentage change between the 5-year averages of annual fire incidence in 1987-1991 and 2013-2017. The sample is restricted to the 465 municipal all-career fire departments that served a population of at least 20,000, employed at least 20 firefighters, and responded to at least 20 fire calls in the start year. Sample admission also requires having sufficient NFIRS data to account for the period 1987-2017. Observations are color-coded by quadrant. The solid line represents the 45-degree line; the dashed line shows a linear fit of the data. *Source:* Author's calculations from the National Fire Incident Reporting System and the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

ASPEP sample. All indices are set to 1 in 1987. The aggregate trend is nested between the all-career and mostly-career samples from the ASPEP data. The trends in this section suggest that at least 40 percent and potentially a much larger share of the career firefighter growth represents newly-created positions, rather than volunteer substitution.

Thus the patterns in Figure 1.1 cannot be explained by endogeneity between firefighters and fires, substitution from volunteer to career firefighters, or disparate trends in fire incidence at all-career fire departments. Rather, it appears that fires have been declining exogenously in most parts of the country despite significant population growth, while career firefighter growth has continued on both the intensive and extensive margins. At the majority of all-career fire departments, employment has increased or remained relatively stable despite substantial declines in fire experience. In the following

Figure 1.15: All-career fire department employment growth vs. fire growth, by region (2003-2017)



This figure decomposes the bottom panel of Figure 1.13 by geographic region. Change in fire incidence is based on the percentage change between the 5-year averages of annual fire incidence in 2003-2007 and 2013-2017. The sample is restricted to the 246 municipal all-career fire departments that served a population of at least 20,000, employed at least 20 firefighters, and responded to at least 20 fire calls in the start year. Sample admission also requires having sufficient NFIRS data to account for the period 2003-2017. Observations are color-coded by quadrant. The solid line represents the 45-degree line; the dashed line shows a linear fit of the data. *Source:* Author's calculations from the National Fire Incident Reporting System and the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

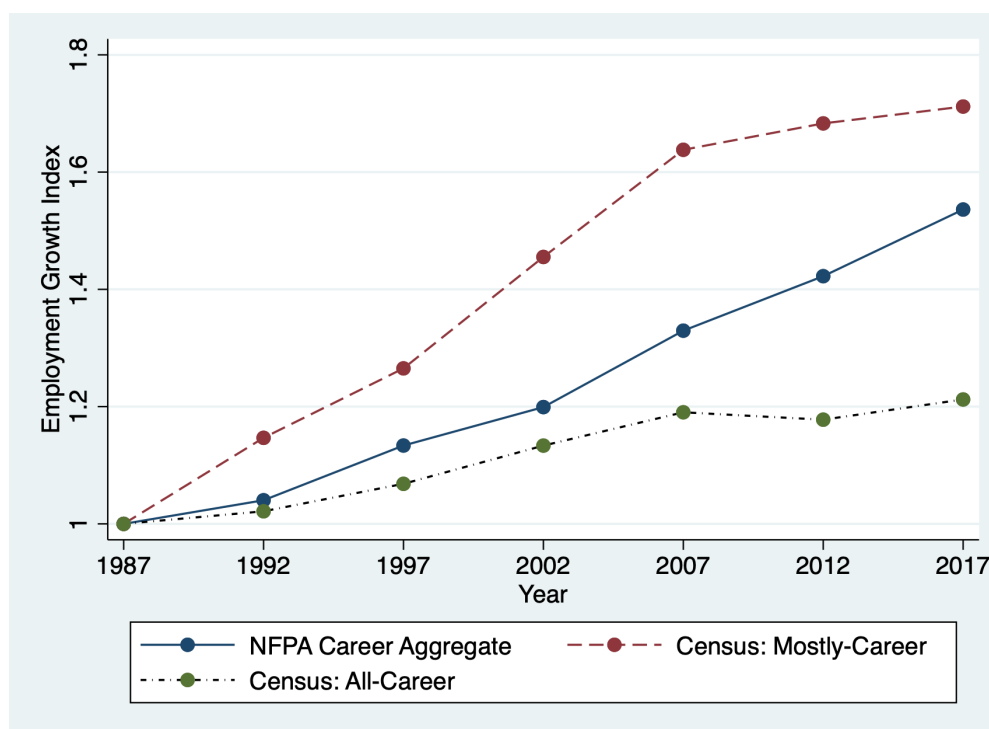
subsections, I explore potential drivers of recent firefighter employment growth, if not the prevalence of fires.

1.4.3 Fire Severity

Fires impose direct economic losses, both by inflicting human casualties and generating property damage. The overall threat due to fire is therefore a product of both fire incidence and fire severity, as measured by the average loss resulting from a fire.³⁰ One potential explanation for the growing supply

³⁰As discussed in Evans (2014) and (Delorme and Waterhouse, 2017, 2020), indirect losses from fire damage, such as business disruptions, lost jobs, and declines in tax revenues, can be commensurate or even greater economically than direct losses. I focus exclusively on direct loss in this section, which presumably is highly correlated with indirect loss as a proxy for fire severity.

Figure 1.16: *Employment growth indices: NFPA aggregate vs. ASPEP samples (1987-2017)*



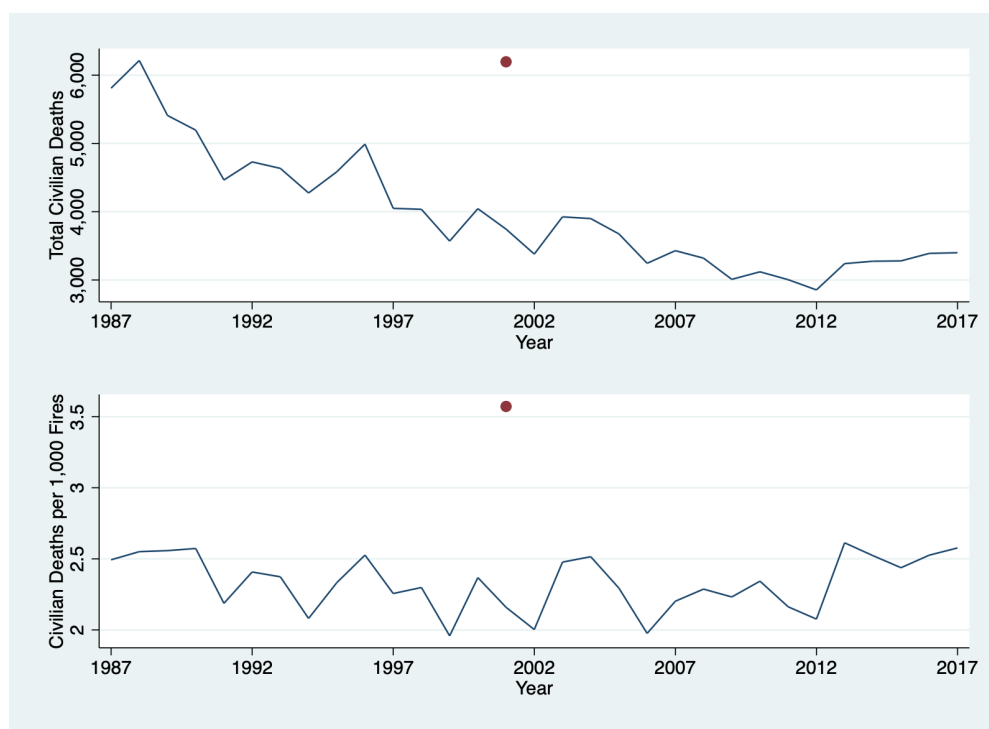
This figure plots indices (all set to 1 in 1987) of aggregate career firefighter growth (as reported by the NFPA), all-career fire department employment growth from the ASPEP sample, and mostly-career fire department employment growth from the ASPEP sample. *Source:* National Fire Protection Association and author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

of firefighters, despite declining fire incidence, is that fires have become more severe over time.

At the national level, there is limited evidence to support this hypothesis. Figure 1.17 shows that annual civilian deaths from fire declined by 41 percent - from 5,810 to 3,400 - between 1987 and 2017 (top panel), implying almost no net change in the risk of death per fire (bottom panel). Figure 1.18 shows that the same qualitative patterns apply for civilian injuries. Similarly, the overall casualty risk for firefighters has declined with incidence and the risk of death per fire attended has experienced almost no net growth (Figures 1.19 and 1.20). Viewed together, I interpret these trends as indicating very little change in the overall risk of civilian or firefighter casualty loss.

The top panel of Figure 1.21 shows that total real property loss from fire, while more volatile than the decline in casualties, has also trended down in recent decades and was more than 15 percent lower in 2017 than in 1987. The bottom panel plots *average* real property loss from fire relative to a fitted

Figure 1.17: *Civilian deaths due to fire (1987-2017)*

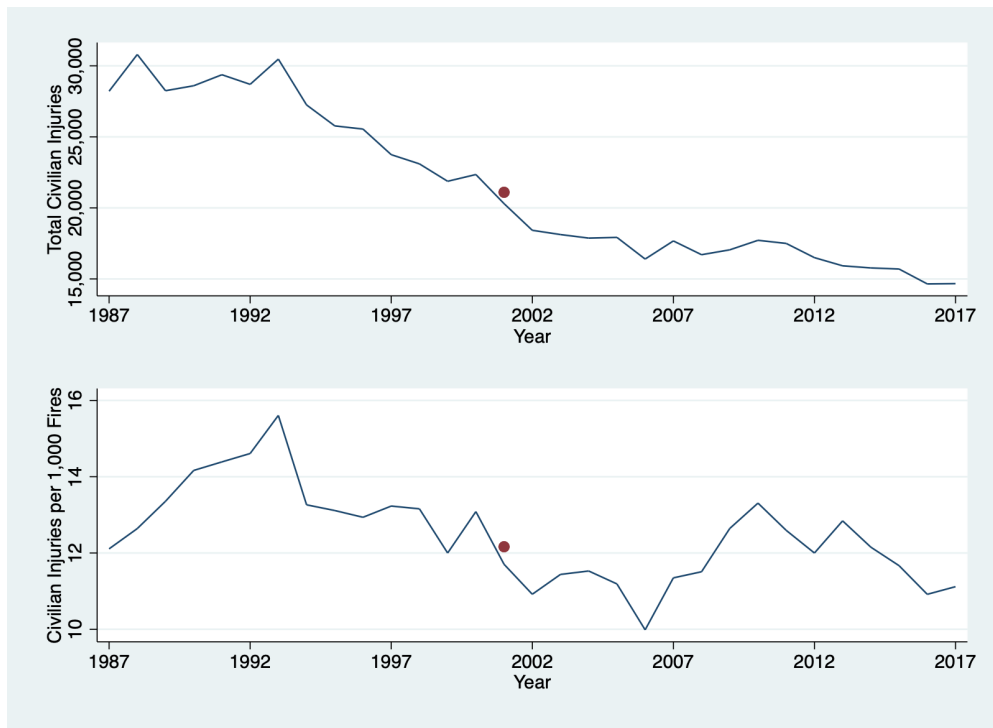


The top panel of this figure plots the total number of civilian deaths due to fire in the United States from 1987 to 2017. The bottom panel plots the civilian mortality rate per 1,000 fires. The markers in 2001 include the events of 9/11. *Source:* National Fire Protection Association.

loss trend that projects forward the experienced loss value in 1987 using the BIS Real Residential Property Price Index for the United States. Actual average property losses track the projection fairly closely, despite some divergence in the period surrounding the housing bubble in the 2000s. By the end of the period, there is little evidence that average real property losses from fire have risen faster than underlying property values.

Given that a non-trivial portion of housing price appreciation can be explained by rising land value, which is less susceptible to economic fire loss than structures, it is reasonable to expect that the average real property loss from fire should rise at a slower rate than overall house prices unless fire severity has increased. However, the loss data used in this figure is based on individual fire department estimates from the NFPA Fire Experience Survey, rather than insurance claims. It is possible that these estimates are more attuned to changes in the total market price of properties than the value of the underlying structure, given the relative salience of the former metric. In this case, we would expect a similar

Figure 1.18: *Civilian injuries due to fire (1987-2017)*

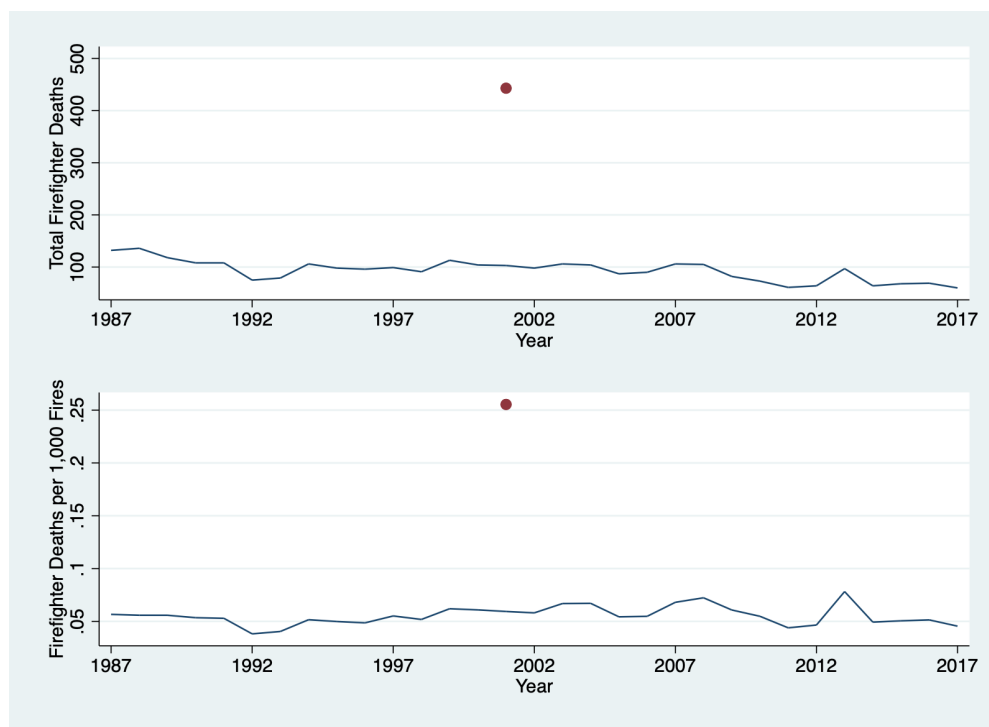


The top panel of this figure plots the total number of civilian injuries due to fire in the United States from 1987 to 2017. The bottom panel plots the civilian injury rate per 1,000 fires. The markers in 2001 include the events of 9/11. *Source:* National Fire Protection Association.

growth trend between average real property loss from fire and average real property values, even with stable fire intensity. However, I cannot rule out an increase in average property loss beyond the rate of structure value appreciation. As discussed in Stoll (2013), there is evidence from safety science organizations that changes in the design and contents of buildings have led to higher fire burn rates and greater risk of full structural collapse, which may be associated with higher average property loss. At the same time, the proliferation of sprinkler systems may limit the number of fires that spread beyond a small initial area, limiting the impact of these trends.

The previous casualty and property loss figures exclude damage from wildfires, since these are typically fought by state, federal and private firefighters, which are not the focus of this paper. However, even when accounting for wildfire, Figure 1.22 shows that there has not been a notable increase in the number of “major fires,” defined as those causing at least \$10 million in property damage. According to data from the National Interagency Fire Center, the number of annual wildfires has also been fairly

Figure 1.19: Firefighter deaths due to fire (1987-2017)



The top panel of this figure plots the total number of firefighter deaths due to fire in the United States from 1987 to 2017. The bottom panel plots the firefighter death rate per 1,000 fires. The markers in 2001 include the events of 9/11. *Source:* National Fire Protection Association.

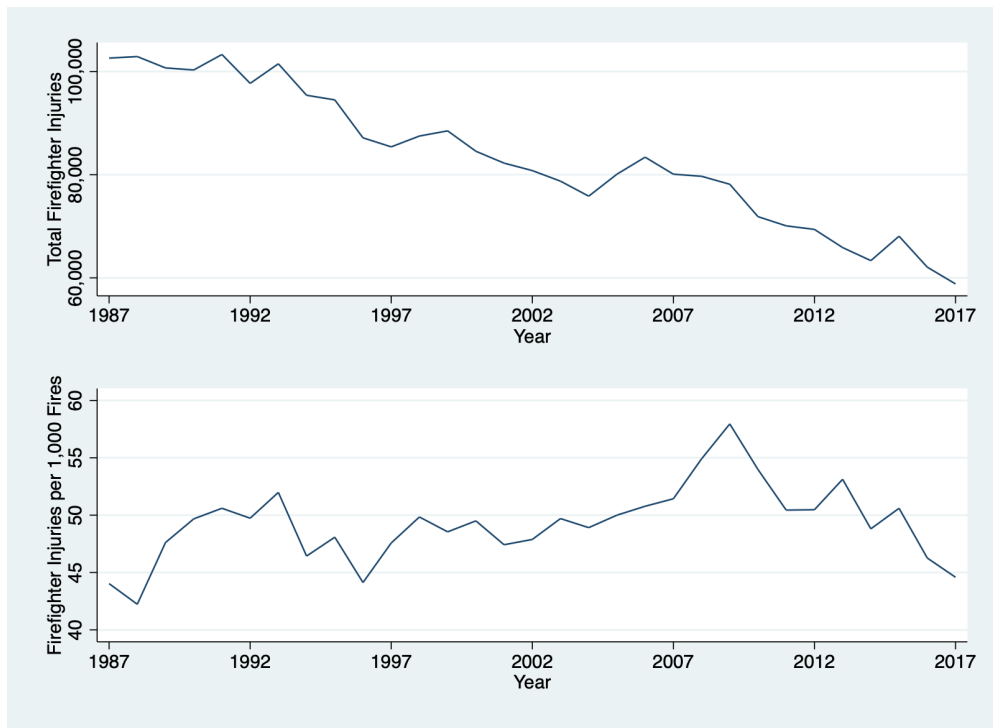
stable over the last three decades, but the average land acreage burned by these fires is rising at a substantial rate.³¹ The growing threat from wildfire in certain parts of the country is a serious policy concern that is distinct from the fire trends studied in this paper.³²

Overall, I find limited evidence that the average severity of fires managed by local fire departments - as proxied by measures of direct loss - has significantly intensified in recent decades. However, the ultimate loss from a fire is also a function of firefighting efficacy, so I cannot rule out the possibility that losses would have been more substantial absent the growth in firefighter membership.

³¹In 1987, the average wildfire burnt about 34 acres of land; by 2017, this figure had gradually risen to about 140 acres.

³²For example, the 2017 wildfire season was the most destructive year on record for the state of California in terms of property damage, resulting in nearly \$20 billion in losses.

Figure 1.20: Firefighter injuries due to fire (1987-2017)



The top panel of this figure plots the total number of firefighter injuries due to fire in the United States from 1987 to 2017. The bottom panel plots the firefighter injury rate per 1,000 fires. *Source:* National Fire Protection Association.

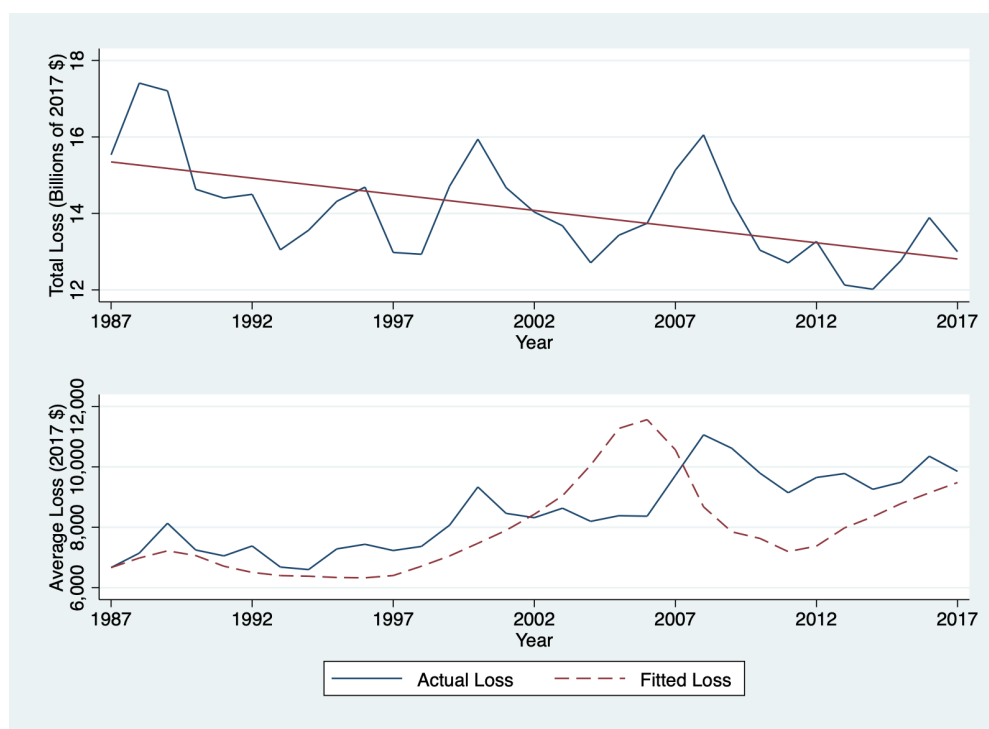
1.4.4 NFPA Staffing Standards

Another potential explanation for the growing supply of firefighters is that evolving standards and regulations on firefighter safety and efficiency have caused fire departments to increase vehicle staffing. Most notably, in 2001 the National Fire Protection Association (NFPA) passed Standard 1710, which was the first to establish minimum staffing criteria for career firefighters. The standard calls for a minimum of four firefighters per engine on fire calls and up to six when dealing with high-hazard occupancies. This standard is generally not mandated but serves as a basis for fire department evaluation, such as by the Insurance Service Office (ISO).³³

NFIRS contains incident-level data on both staffing and apparatus for the years 2003 to 2017. I restrict the sample to the 874 all-career departments with reported personnel data in each year. For

³³The ISO provides comprehensive evaluations of fire departments, which are widely used by insurance companies to price fire insurance.

Figure 1.21: *Direct real property loss due to fire (1987-2017)*

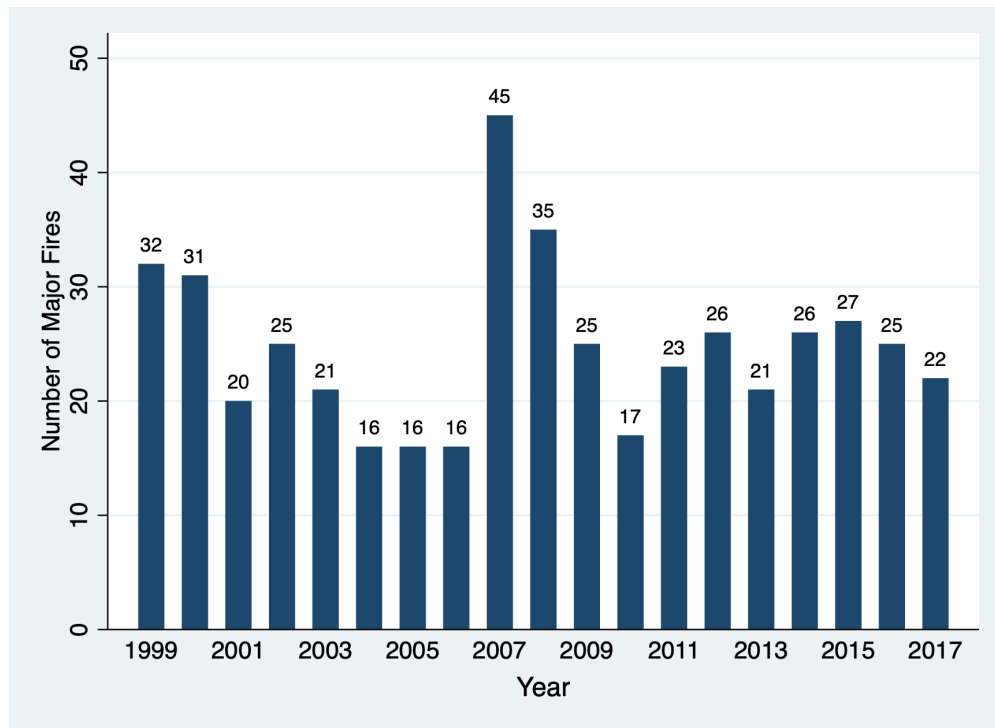


The top panel of this figure plots total direct property loss due to fire in the United States from 1987 to 2017 (in billions of 2017 dollars). The bottom panel plots the average direct property loss per fire (in 2017 dollars). The “fitted loss” trend shows how average property losses would evolve if they grew with the U.S. real residential property price index from the BIS. These figures exclude damage from wildfires and \$33.44 billion of damage that occurred in the events of 9/11. *Source:* National Fire Protection Association and Bank for International Settlements.

each department and year, I first compute the average number of firefighters per attending vehicle at structure fire responses. I then calculate summary statistics across departments and years, weighted by the number of structure fires attended. I find that both the average and median number of firefighters per vehicle actually declined steadily over this period, from 3.58 to 2.77 and 2.77 to 2.59, respectively. Only between 2 and 14 percent of departments average at least four firefighters per vehicle attended on structure fire calls in any year between 2003 and 2017. Moreover, there was also no significant change in the average number of apparatus responding to each structure fire. Between 2003 and 2017, the average number of attending vehicles ranged between 4.2 and 4.9, with most years centered around 4.5. Although this data sample begins two years after Standard 1710 was passed, these findings suggest limited potential scope for a causal increase in staffing per vehicle or overall staffing on fire calls.³⁴

³⁴Moreover, there does not appear to be a kink in the aggregate employment growth trend (Figures 1.1 and 1.2) around

Figure 1.22: *Number of major fires (1999-2017)*



This figure shows the number of “major fires” per year from 1999-2017, defined as fires causing at least \$10 million in property damage. *Source:* Badger (2017).

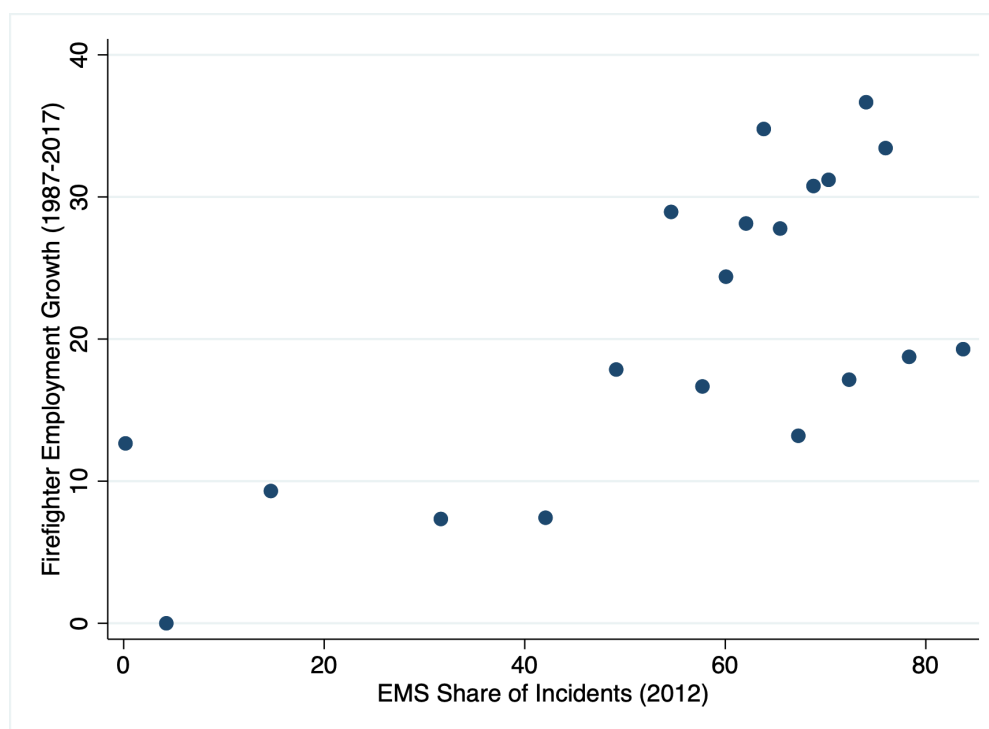
1.4.5 Emergency Medical Services

The trends in fire department call volume shown in Figure 1.8 suggest another potential explanation for the growth in career firefighter membership: the rapidly increasing volume of EMS calls attended by fire departments. Unfortunately, the NFIRS incident data only contain records of medical calls from 2012 to 2017, limiting the potential for time series analysis. However, I am able to provide suggestive evidence that EMS involvement is a likely catalyst for firefighter employment growth. I first restrict the Census employment data to local governments that employ all-career fire departments and have non-missing membership data in 1987 and 2017. For each fire department, I calculate total percentage employment growth over this period. I then require that the fire department has NFIRS incident data for the year 2012 - the first year when EMS outcomes are available. Figure 1.23 shows a bin scatter

the passage of Standard 1710.

(using medians) of employment growth for the 1,452 all-career fire departments represented in this sample relative to the EMS share of their total incident responses in 2012. The chart shows a strong positive relationship between employment growth and the extent to which a department was involved in delivering EMS as of 2012. The scarcity of fire-based EMS data makes it difficult to establish a robust causal relationship, but I interpret these findings as suggestive evidence that medical call growth has likely been an important driver of firefighter employment in recent decades.

Figure 1.23: *Firefighter employment growth rates (1987-2017) by EMS call share (2012)*

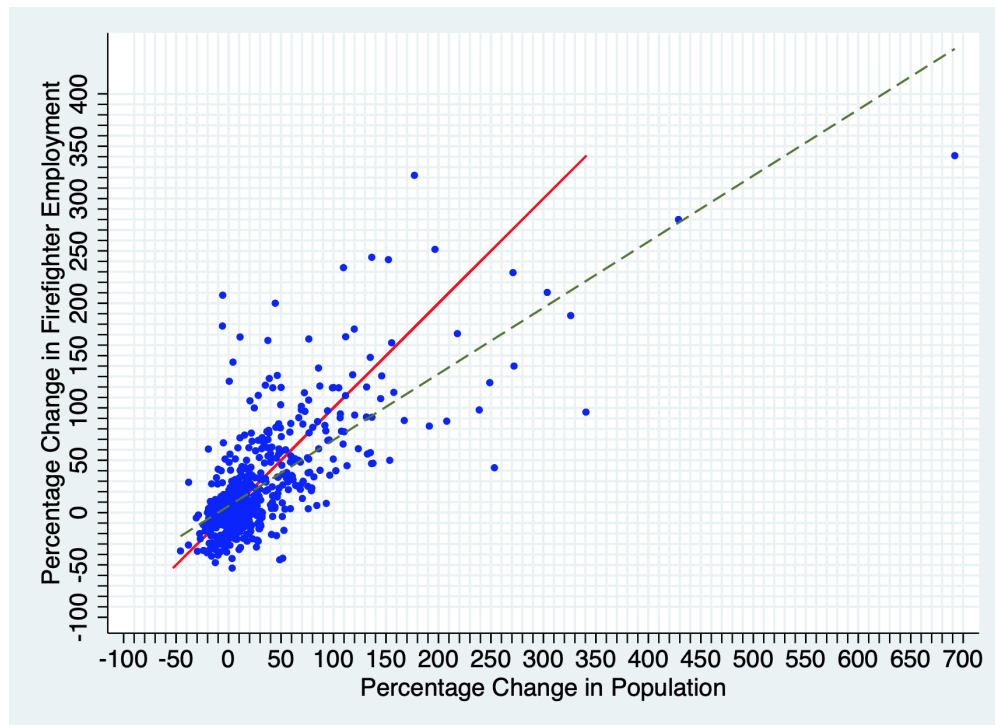


This figure presents a bin scatter (in medians) of firefighter employment growth from 1987 to 2017, relative to the EMS share of a department's total incident responses in 2012. The underlying sample consists of the 1,452 all-career fire departments with non-missing Census employment data in 1987 and 2017, and NFIRS incident data in 2012. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll and the National Fire Incident Reporting System.

Moreover, Figure 1.24 relates percentage growth in firefighter employment at a sample of 530 all-career fire departments with a population of at least 20,000 in 1987 to population growth from 1987 to 2017. The solid line represents the 45-degree line and the dashed line plots a linear fit. Relative to fire incidence (Figure 1.13), population growth is a much better predictor of firefighter employment growth: the estimated slope coefficient is 0.63 for the full sample and 0.73 when excluding the 5 departments

with population growth over 300 percent. Regardless of whether employment is responding causally to the number of EMS calls, which have grown steadily faster than population growth, or is more passively linked to population growth (such as to maintain a certain level of firefighter density), these findings suggest that employment growth is at least highly correlated with growth in EMS call volumes.

Figure 1.24: *Firefighter employment growth rates by population growth rates (1987-2017)*



This figure plots firefighter employment growth from 1987 to 2017 against population growth. The underlying sample consists of the 530 municipal all-career fire departments that served a population of at least 20,000, responded to at least 20 fire calls, and employed at least 20 firefighters in 1987. The solid line represents the 45-degree line; the dashed line shows a linear fit of the data. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

The prevalence, cost, and efficiency of different fire-based EMS models has not been well studied and is an important area for future research (Institute of Medicine, 2007). According to the International Association of Fire Chiefs, there are three primary types of EMS delivery systems involving fire departments. Under the first two models, firefighters provide first response on EMS calls, which in some cases can also include advanced life support, and a separate ambulance unit provides advanced care and transport to the hospital. The affiliation of the ambulance unit is what distinguishes these two models. Under the first model, the ambulance unit will consist of paramedics/EMTs that are employed

by the fire department but not cross-trained as firefighters. Under the second model, this role will be provided by a third-party EMS unit, which can be an independent public organization or a private provider. The third model of fire-based EMS delivery involves employing cross-trained firefighters to supply the full scope of EMS services (first response, advanced care, and patient transport). In this case, firefighters are trained as EMTs or paramedics and rotate time between fire units and ambulance units. Even in the latter case, EMS calls might still be attended by both a fire engine company and an ambulance unit. There is not a detailed national accounting of these systems, but based on a report from the Cleveland Association of Rescue Employees that classifies the EMS-delivery systems for the most populous 66 cities, about 60 percent use one of the first two models and 40 percent use the full-service firefighter approach.

As discussed in the introduction, assessing the marginal value of firefighters on EMS calls is not a straightforward task, even if robust patient and provider data was available. The redundancy built into EMS delivery models, whether from firefighters responding to the same calls as paramedics/EMTs or multiple firefighter units attending the same calls (e.g. one fire engine, one ambulance), makes it difficult to parse out marginal firefighter contributions. Moreover, if value is based on patient outcomes, strong assumptions must be made about the appropriate counterfactual. There is also the issue of how to assign value to the majority of EMS calls that are not life threatening. A tabulation of aggregate 2017-2021 data from the National Emergency Medical Services Information System, which is a standardized reporting system for EMS providers, shows that initial patient acuity was classified as “low” on 73 percent of responses (66 percent if restricting to just fire department responses). This is consistent with breakdowns that are often provided by large cities. For example, in 2017, 61 percent of EMS responses by the FDNY could be classified as non-life threatening events (Citizens Budget Commission, 2018). Recipients of low-acuity medical care surely still value the EMS response, and ex ante may be willing to pay for lower average response times, but these preferences are difficult to observe.

The level of response to a call, whether by an ambulance and/or a fire engine, often depends on the availability of units and the perceived severity of the event. Craig *et al.* (2010) analyze 16 months of EMS response data for the city of Toronto, which uses a dual firefighter and third-party EMS model.

The authors find that urgent firefighter response was warranted in only 1.4% of incidents (ex post), whereas firefighters were dispatched to 42 percent of EMS calls. Based on an optimization model that uses only information available to dispatchers at the time of emergency, the authors estimate the optimal share of firefighter responses to be 7.3% of EMS incidents, more than a 80 percent implied reduction. For half of these responses, it is also estimated that paramedics will arrive on scene before the fire unit. In recent years, some cities have looked at ways to optimize their dispatch systems to prioritize faster response times on the most emergent calls, limit redundancy on non-life threatening calls, and reduce unnecessary crowding of emergency departments.³⁵

I focus exclusively on the economics of fire-based EMS in the third chapter of this thesis and use a quasi-experimental approach to estimate the marginal impact of firefighters on the number of time-sensitive deaths. However, even these estimates take the current structure of fire-based EMS systems as given and therefore do not address the separate issue of whether there are more efficient ways to provide these services. For example, the estimated average cost of a fire engine response to a medical incident in New York City was \$1,970 in 2017, versus \$486 (\$335 after reimbursements) for a paramedic-staffed ambulance run (Citizens Budget Commission, 2018). Firefighters only reported providing a specific form of care on about 2 percent of attended EMS calls and a defibrillator was used in only 72 instances (0.04 percent of calls).³⁶ There is evidence that many types of time-sensitive medical emergencies, while often having low overall survival rates, can benefit from faster response times. For example, Pell *et al.* (2001) estimates that the survival rate for patients with cardiac disease who experience out-of-hospital cardiopulmonary arrest could increase from 6 percent to 8 percent if the 90th percentile response time was reduced from 14 minutes to 8 minutes. Larsen *et al.* (1993) estimate a 5.5 percent reduction in survival for each minute without CPR, defibrillation, or definitive care for a selected group of out-of-hospital cardiac arrest patients. However, there is also research

³⁵For example, 9-1-1 calls in Reno are fielded by nurses who can use some professional discretion regarding the appropriate level of resources and plan of care; paramedics also receive specialized training to make resource assessments on-scene (Gorman, 2015). The city of Houston has implemented a system called ETHAN that connects emergency care patients to local physicians by video, while first responders tend to immediate needs (JEMS, 2015). The physician then makes an assessment about the appropriate mode of transport (e.g. taxi or ambulance) and hospital setting (e.g. emergency department or primary care).

³⁶As discussed more in the third thesis chapter, these statistics may understate some of the practical benefits provided by firefighters.

suggesting that the most important time interval for many medical emergencies is the amount of time it takes to get a patient into definitive care in a hospital setting.³⁷ Thus even in urgent cases where firefighter engine crews are able to provide first response before an ambulance arrives, the patient's outcome will often still depend on the amount of ambulance lag time. In the conclusion to this chapter and in the third chapter, I discuss the need for continued research in this area.

1.5 Fire Department Heterogeneity

In this section, I explore the heterogeneity in firefighter density, call volume per firefighter, and firefighter employment costs across all-career fire departments. I then estimate bounds on the (direct) marginal economic value that a firefighter at each department would need to generate per response in order to cover his or her estimated employment cost per incident.³⁸ I restrict the analysis in this section to the 945 all-career, municipal departments in my sample that serve a population of at least 20,000 and employ at least 20 firefighters in 2017.

1.5.1 Firefighter Density

Figure 1.25 shows how firefighter density (2017) relates to fire density (2015-2017 average) in the cross-section of all-career departments. Firefighter density averages 1.7 firefighters per 1,000 residents and ranges from 0.5 to 6.6. The average fire burden is 3.5 fires per 1,000 residents, but can be as low as 0.3 and as high as 17. The plotted linear fit shows a significant, positive relationship between firefighter density and fire density, suggesting that an increase of 1 fire per 1,000 citizens is associated with an increase of 0.16 firefighters in the cross-section.³⁹

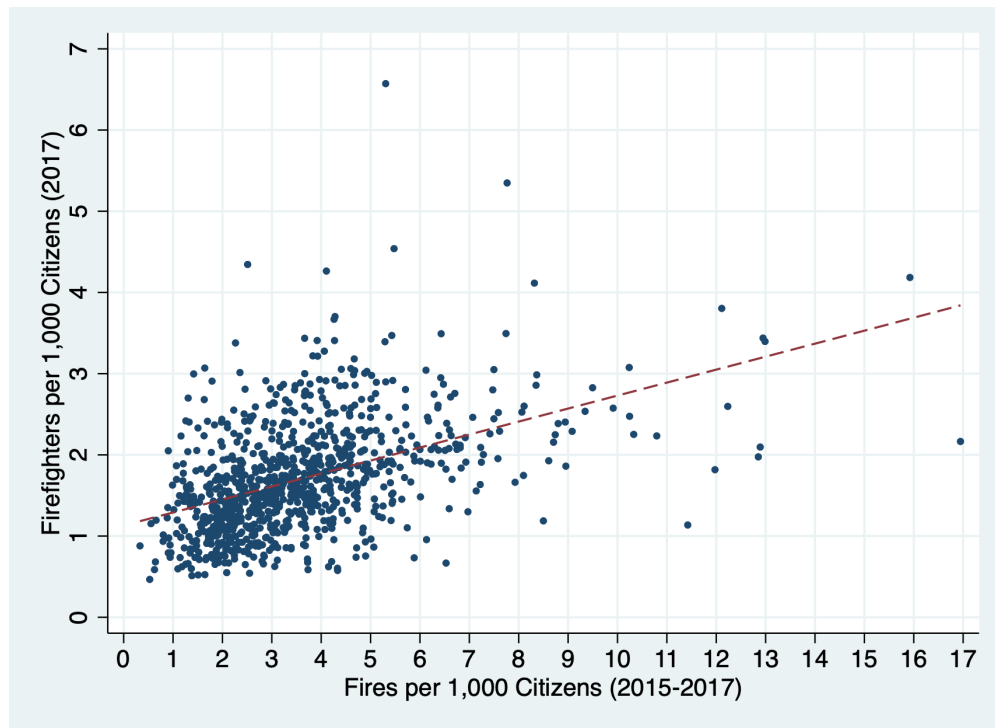
Relative to the time trends presented in the previous section, the cross-sectional relationship is more consistent with supply-demand intuitions. However, there is still substantial variance in fire

³⁷For example, see Robbins (2018), Murray and Kue (2017), Marques-Baptista *et al.* (2012), Kupas *et al.* (1994), O'Brien *et al.* (1999), and Puolakka *et al.* (2016).

³⁸There are some limitations associated with this approach that I discuss in the close of this section.

³⁹Appendix Figure A.2 shows the same figure, but based on EMS call density. The estimated slope coefficient implies that an increase of 100 EMS calls per 1,000 citizens is associated with increase of about 0.4 firefighters.

Figure 1.25: *Firefighter density (2017) vs. fire density (2015-2017) for all-career departments*



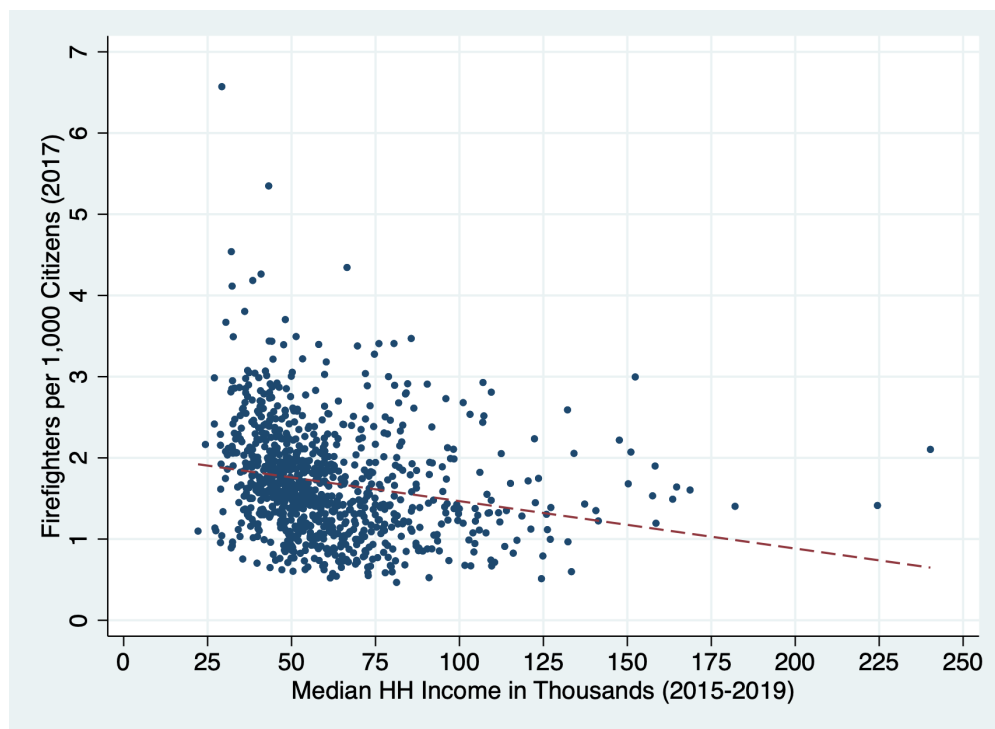
This figure plots firefighter density in 2017 (firefighters per 1,000 citizens) relative to fire density, as averaged over the period 2015-2017. The sample consists of 945 all-career fire departments with a population of at least 20,000 and that employ at least 20 firefighters in 2017. The plotted line represents a linear fit, with an estimated slope coefficient of 0.16. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

density within each plotted row, which represents an increment of one firefighter per 1,000 citizens. For example, Westminster and Pueblo are cities near central Colorado with populations of 113,130 and 109,412 in 2017, respectively. The Westminster Fire Department employed 140 firefighters in 2017 and the Pueblo Fire Department employed 144, such that both cities had very similar firefighter densities (1.24 and 1.32, respectively). However, average fire experience was nearly three times as high in Pueblo as in Westminster between 2015 and 2017; the number of EMS runs by the Pueblo Fire Department was also nearly twice as high. One explanation for the similar levels of fire protection in the two cities is that median household income in Westminster (\$76,142) is nearly twice as high as in Pueblo (\$40,450). As Baicker and Chandra (2020) discuss in the context of high relative U.S. healthcare spending, it is reasonable to expect that citizens would be willing to pay for higher levels of risk protection as income rises. However, there is very little research demonstrating how higher

levels of firefighter employment translate into outcome improvements. In the case of Westminster and Pueblo, response times were nearly identical in 2017 (6.41 and 6.47 minutes, respectively), as were average property losses per fire (\$3,226 and \$3,373, respectively). But without an appropriate counterfactual, it is difficult to determine the elasticity of these outcomes to changes in firefighter employment. In the second and third chapters of this thesis, I use a quasi-experimental approach to assess the marginal impacts of increased firefighter employment.

Moreover, Figure 1.26 shows that the cross-sectional relationship between firefighter density and median household income is weak, and if anything - negative. Even after controlling for fire density in cross-sectional regressions - which is negatively associated with income - as well as EMS density and state fixed effects, income has almost no economic significance and is only marginally significant statistically.

Figure 1.26: *Firefighter density (2017) vs. median household income (2015-2019) for all-career departments*



This figure plots firefighter density in 2017 (firefighters per 1,000 citizens) relative to median household income from the 2015-2019 Census Bureau estimates. The sample consists of 945 all-career fire departments with a population of at least 20,000 and that employ at least 20 firefighters in 2017. The plotted line represents a linear fit, with an estimated slope coefficient of -7.87. *Source:* Author's calculations from the U.S. Census Bureau, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

1.5.2 Call Volume per Firefighter

In this section, I estimate average call volumes per firefighter at the all-career departments in my sample. For each response category, I first multiply the average number of annual responses from 2015 to 2017 by the average number of firefighters that respond to that incident type. I then divide this total by the number of full-time firefighters in 2017 to obtain an estimate of average call volume per firefighter.

I use two different estimates for the number of firefighters attending each call type. The first is calculated individually for each department as the average number of attending fire suppression personnel on incidents where this data is reported.⁴⁰ However, there are many departments that only report this data for a small fraction of responses. Moreover, the NFIRS data separately classifies fire suppression personnel and EMS personnel, the latter of which may also consist of cross-trained firefighters in some EMS delivery systems. Thus I construct an alternative estimate based on the average number of *total* attending personnel (fire plus EMS) across all departments with non-missing data. I intend for this latter estimate to provide an upper bound, so for the small minority of departments for which the former estimate is higher, I replace the latter estimate with this value.

After estimating average call volumes per firefighter at each department using these two methods, I plot empirical cumulative distribution functions (CDFs) for the cross-section of departments. Figure 1.27 shows the CDF for all fire responses in the top panel and exclusively for structure fire responses in the bottom panel.⁴¹ The solid red line is based on the first assumption for firefighter attendance per call; the dashed blue line is based on the latter. I estimate that for 50 percent of departments in my sample, the average firefighter responds to less than 15 fire calls per year based on the first estimate and 20 based on the second.⁴² At the 90th percentile, these values rise to about 30 and 35. For a

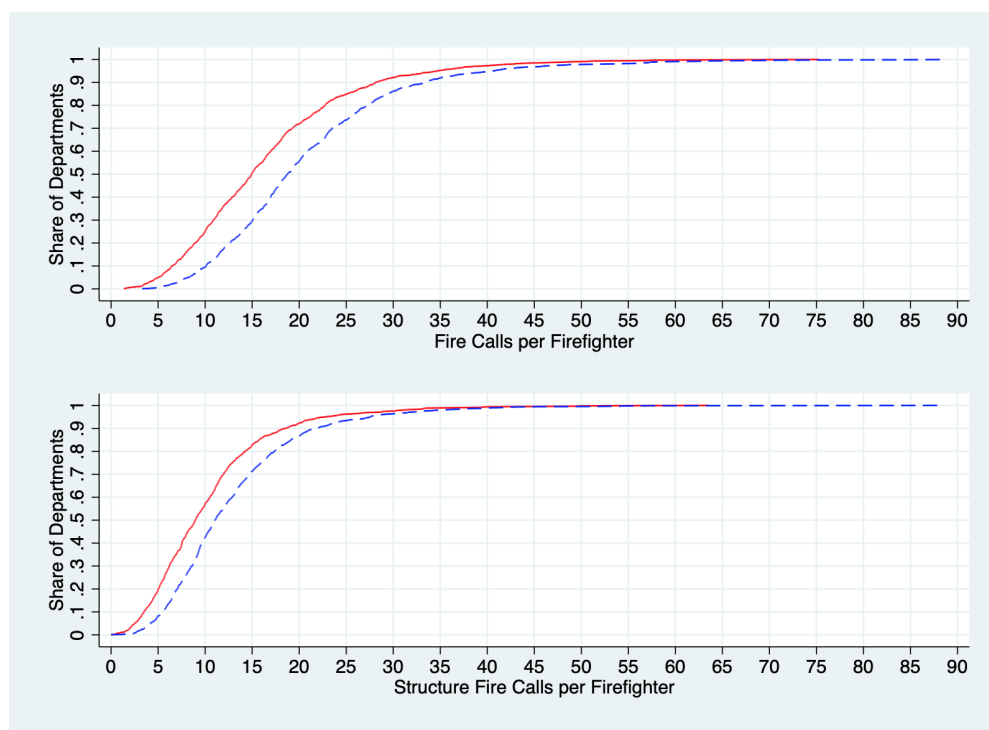
⁴⁰I exclude from this calculation fire calls with zero reported fire suppression personnel and EMS calls with zero reported fire *and* EMS personnel.

⁴¹In addition to structure fires, the top panel includes fires in mobile properties used as a fixed structure, mobile property (vehicle) fires, natural vegetation fires, outside rubbish fires, special outside fires, and cultivated vegetation fires. False alarms are excluded, but fires that are extinguished prior to firefighter arrival are included.

⁴²Note that these estimates exclude mutual aid responses, whereby firefighters provide assistance to a nearby fire department. In total, mutual aid responses across all incident types accounted for just below four percent of fire department call volume in 2017.

firefighter that works 100 total shifts per year, which is slightly below the implied standard for common shift arrangements, this translates at maximum to about one fire response every 5 shifts at the 50th percentile and every 3 shifts at the 90th percentile. For annual structure fire calls attended, the 50th and 90th percentile ranges are 9-11 and 18-22 respectively, which implies about one structure fire response every 10 shifts at the median and every 5 shifts at the 90th percentile.

Figure 1.27: *Empirical CDF of fire call volume per firefighter at all-career departments*



This figure plots empirical cumulative distribution functions of the estimated number of fire calls per firefighter (top panel) and structure fires per firefighter (bottom panel) for a sample of 945 all-career fire departments. This sample is restricted to departments that serve a population of at least 20,000 and employ at least 20 firefighters in 2017. The employment data is from 2017 and the fire data is averaged over the years 2015-2017 to reduce the impact of outliers. The x-axis reports the estimated number of annual fires; the y-axis represents the share of departments with estimated values less than or equal to the x-axis value. The dotted line represents a minimum estimate and the solid line represents a maximum estimate, as described in the text. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

Moreover, only about 30 percent of total fire responses for this sample and 35 percent of structure fire responses are associated with either casualty or property loss of any kind in the NFIRS data.⁴³ These loss shares rise to 35 percent and 45 percent (respectively) if estimated first at the department

⁴³I consider a fire as having resulted in loss if either a civilian or firefighter casualty is reported or the estimated property loss from the fire is greater than 0. The loss shares should be viewed as a minimum, given the potential for under-reporting in the NFIRS data.

level and then averaged across departments. Thus a substantial portion of fire call responses involve fires that are not severe enough to cause loss or are extinguished prior to firefighter arrival.

Figure 1.28 repeats the CDF exercise for total calls attended (top panel) and EMS calls attended (bottom panel). The gap between the two sets of estimates is much larger relative to Figure 1.27 because EMS calls, which comprise the majority of total calls, are often accompanied by both fire suppression personnel and EMS personnel. The solid line only counts fire suppression personnel as attending firefighters on a call; the dashed line includes all attending EMS personnel from fire departments, even though a large share of these responders will be single-purpose paramedics and EMTs in reality. Given these assumptions, I estimate that the average total call load per firefighter at the median department is between 150 and 315 responses per year, about 45 to 60 percent of which are EMS responses. The EMS share per firefighter is smaller than the department-level share because of the larger average staffing level on fire calls. The average call volume rises to between 400 and 570 at the 90th percentile, which translates to about 4 to 6 total calls per shift using the same 100-shift assumption as before.

1.5.3 Firefighter Employment Costs and Marginal Benefit Targets

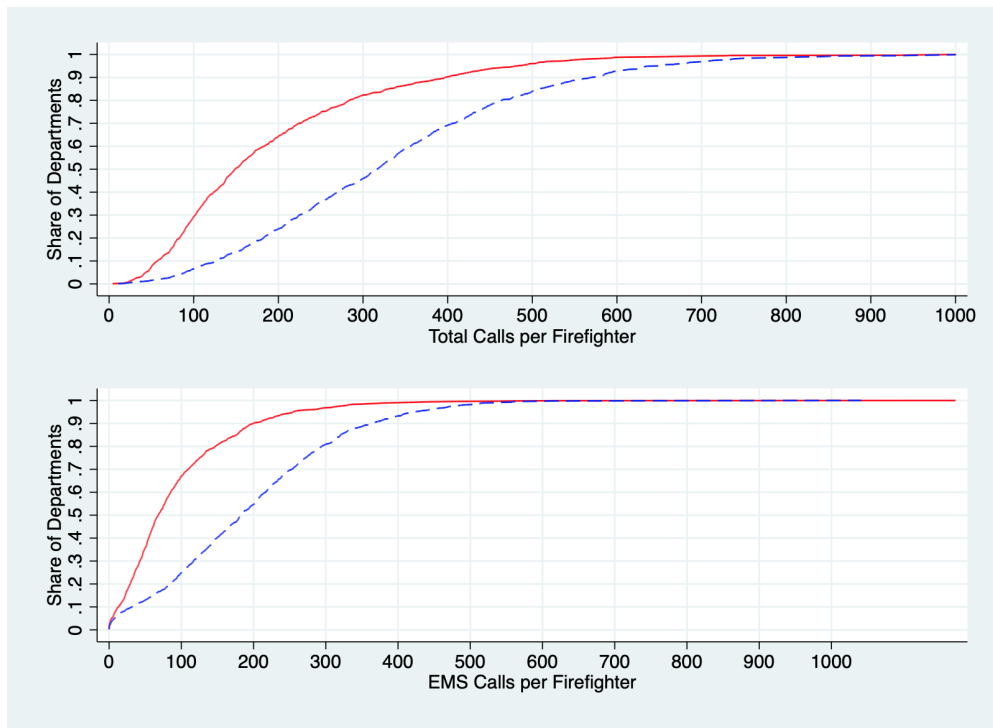
In this section, I first estimate average firefighter compensation for the sample of all-career departments. I then combine these results with the call volume calculations from the previous section to estimate the per-incident economic value implied by these compensation levels in 2017. In the second and third chapters, I use these estimates as a benchmark for the marginal benefit calculations. There are several limitations to this approach that I discuss in the conclusion to this section.

Firefighter Compensation

I obtain the average base salary per firefighter at each department by dividing total full-time firefighter payroll from the 2017 ASPEP data by the number of full-time equivalent employees. I then add a universal premium to account for retirement and health benefits, as explained below. I am not able to account for overtime pay, which as discussed in the introduction, can be significant.

The two primary types of retirement benefits provided by most local governments are defined

Figure 1.28: Empirical CDF of total and EMS call volume per firefighter at all-career departments



This figure plots empirical cumulative distribution functions of the estimated number of total responses per firefighter (top panel) and EMS responses per firefighter (bottom panel) for a sample of 945 all-career fire departments. This sample is restricted to departments that serve a population of at least 20,000 and employ at least 20 firefighters in 2017. The employment data is from 2017 and the incident data is averaged over the years 2015-2017 to reduce the impact of outliers. The x-axis reports the estimated number of responses; the y-axis represents the share of departments with estimated values less than or equal to the x-axis value. The dotted line represents a minimum estimate and the solid line represents a maximum estimate, as described in the text. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

benefit (DB) pensions and retiree health benefits. According to the March 2017 BLS summary of the National Compensation Survey, 90 percent of local government employees have access to a retirement plan and 84 percent have access to a DB pension. Similarly, Brown *et al.* (2017) estimate that about 80 percent of local government employees have retiree health coverage. These breakdowns are not available separately for firefighters, but I use these aggregate coverage rates to adjust for the potential lack of coverage for a small percentage of firefighters.

Relative to general employees and teachers, the cost of funding police and firefighter retirement benefits is nearly twice as high. In 2016, the average expected present contribution needed to finance future DB pension benefits for active employees (the “normal cost”) was 21.8 percent of payroll for

police and firefighters and 11.8 percent for other employee groups (Aubry and Wandrei, 2020). For retiree health benefits, the respective normal costs were 5.9 percent of payroll for police and firefighters and 3.7 percent for non-public-safety workers.⁴⁴ These cost differences are driven largely by the longer average benefit receipt period for public safety workers, due to earlier permissible retirement ages. In the pension domain, it is common for employees to share a portion of the funding costs. Based on the sample of 171 state- and locally-administered pension plans in the Center for Retirement Research Public Plans Database, the average employer share of total normal costs was about 50 percent across all plans and 58 percent for police and fire plans. After making adjustments for coverage rates and employee cost-sharing, I estimate a 15.3 percent average wage premium to cover the employer's share of retirement benefits.

The International Association of Firefighters estimates that only about 25 percent of firefighters are covered by Social Security, so I add 1.5 percent to the wage premium for the Social Security payroll tax (roughly one-quarter of the employer's share) and the full 1.45 percent for Medicare. This brings the total estimated wage premium to about 18.3 percent, which I apply to all base salaries. Finally, the average net premium paid by local government employers for employee health insurance was \$5,385 for single coverage and \$7,850 for family coverage in 2017 according to the March 2017 BLS National Compensation Survey. As a conservative estimate of the share of firefighters with single coverage versus family coverage, I add a flat premium of \$5,500 to all base salaries.

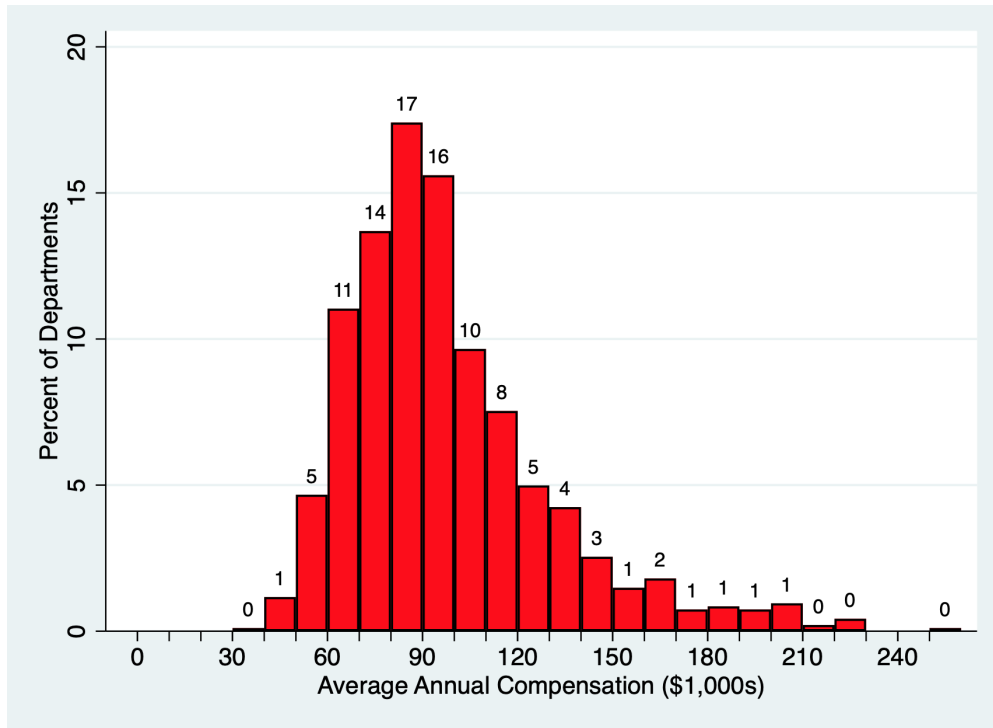
Average estimated compensation is about \$98,000 and ranges from about \$35,000 to more than \$200,000. Figure 1.29 provides a histogram of these estimates for the cross-section of departments, binned in \$10,000 increments.

Per-Incident Benefit Targets

In this subsection, I use the compensation and call volume results to estimate per-incident employment costs for the average firefighter at each department in my sample. These estimates can alternatively be conceptualized as the average marginal benefit required per response by a firefighter to exactly offset compensation costs.

⁴⁴Unlike DB pensions, these plans are typically funded on a pay-as-you-go basis (Brown *et al.*, 2017).

Figure 1.29: Average estimated firefighter compensation at all-career departments (2017)



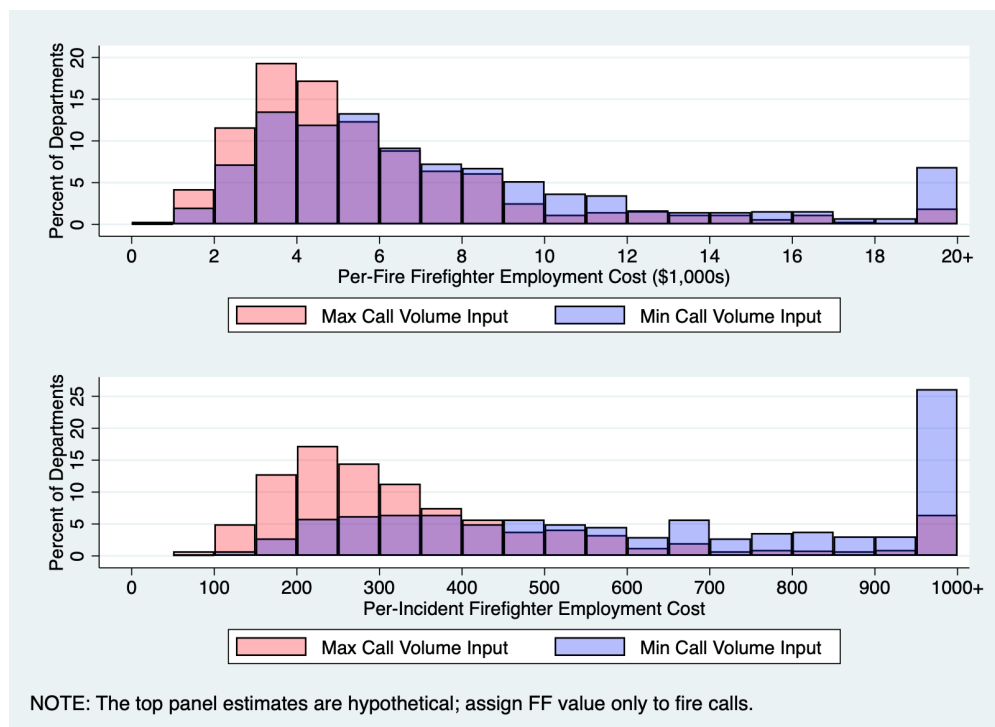
This histogram shows average estimated compensation for the cross-section of all-career fire departments in my sample. See Section 1.5.3 for a discussion of how these values are estimated. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll and the USFA Fire Department Registry.

I start by considering a hypothetical scenario under which a marginal firefighter is only assumed to add value on fire calls. Clearly this is an inaccurate assumption, but the exercise provides a baseline extreme for thinking about current levels of fire protection. To estimate a per-incident employment cost in this case, I divide the average compensation estimate from the previous subsection by the estimated number of fire call responses per firefighter. Corresponding to the results in Figure 1.27, I make use of the two alternative estimates of average fire call volume per firefighter, both based on different assumptions about average staffing levels per incident.

The top panel of Figure 1.30 overlays histograms of the estimated average employment cost per fire call response under the two call volume assumptions. To preserve visual clarity, the cost estimates are top-coded at \$20,000 and lumped into the last bracket. Under this hypothetical scenario, the average firefighter employment cost per fire response is \$5,962 under the maximum call volume assumption and \$8,371 under the minimum call volume assumption; the respective medians are \$4,838 and \$6,251.

About 10% of departments have average costs exceeding \$10,000 per firefighter response under the former assumption and 23% under the latter.

Figure 1.30: *Estimated firefighter employment costs per incident response*



This chart shows the estimated employment cost - on a per-incident basis - for the average firefighter at each all-career department in the sample. The histograms in the top panel apply to a hypothetical scenario where firefighters only respond to fire calls, or equivalently, no value is assigned to non-fire calls. The histograms in the bottom panel are calculated based on the actual total call volume estimated for the average firefighter at each department. These estimates apply to any firefighter response, including fire, EMS, and other. The red histograms are based on the maximum average call volume input assumption; the blue histograms are based on the minimum average call volume input assumption. To preserve visibility, values are top-coded at \$20,000 in the top panel and \$1,000 in the bottom panel. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

The bottom panel of Figure 1.30 repeats the exercise, but in this case accounts for all firefighter responses and assigns equal value to all incident types (e.g. fire, EMS, false alarm). To derive these estimates, I divide estimated firefighter compensation by the estimates for total call volume per firefighter. In this case, the minimum and maximum estimates for the average per-incident employment cost are \$422 and \$822, respectively. Per-incident costs exceed \$1,000 for 5% of departments under the maximum call volume input and 23% under the minimum call volume input.

The assumptions underlying the bottom panel of Figure 1.30 are also strong. First, these estimates

do not differentiate between - for example - a five-alarm structure fire response and a false alarm. Second, they make no adjustment for the fact that the direct economic loss on a large share of fire and EMS responses is zero (or very small), independent of fire department performance.⁴⁵ For example, as mentioned previously, only about one-third of recorded fire responses in the 2017 NFIRS data are associated with any property or casualty loss; similarly, the majority of EMS calls are for non-life-threatening issues and are often also attended by single-purpose EMTs/paramedics. There is still economic value attached to the firefighters' responses in many of these cases, particularly for the recipient, but this value is mostly unobservable.

Moreover, when considering costs and benefits of firefighter employment in a marginal sense, it is only the additional perceived value attributable to higher staffing levels that is relevant. So for example, suppose that a primary benefit of higher staffing levels is reduced response times. Then the relevant value to consider, for say a homeowner who receives a fire department response after self-extinguishing a small stove fire, is the marginal value attached to the faster response - not the response itself. If the economic value of marginal performance improvements on non-urgent calls is low, the estimated thresholds in Figure 1.30 could be two to three times as high.

Potential Limitations of Estimates

The estimates of breakeven average marginal benefits per firefighter response are useful as a benchmark, but have several limitations. First, they rely entirely on the data recorded in NFIRS, which can be subject to underreporting and/or reporting errors, as discussed in Section 1.2. In aggregate, NFIRS captures the majority of incidents and the data quality is generally much better in more recent years. But there is no way to rule out errors in individual reporting.

Second, while defining value on a per-incident basis is useful for conducting cost-benefit analysis over a given period, it is not necessarily how fire departments staff or should staff. To the extent that residents are willing to pay for a fast response time, or that the safety and efficacy of firefighting efforts depend on it, this may imply a floor on the optimal staffing level that is somewhat independent of incidence. Similarly, a certain level of staffing may be necessary to protect against worst-case risks,

⁴⁵Note that this issue also applies for the fire-only estimates in the top panel of Figure 1.30.

regardless of whether such events happen to appear in the observation window (like an insurance policy). This level of fire protection will be unique for each jurisdiction, as it depends on local risk factors, the risk tolerance of the citizenry, the robustness of mutual aid agreements, and other considerations. However, theoretically there is still some level of staffing beyond which there are observable improvements in response times, loss, or tail risk reduction that justify the costs. In the subsequent chapters, I focus on estimating these elasticities for a selected group of departments.⁴⁶

Third, there are general equilibrium effects that these estimates do not capture. For example, home insurance rates are affected by the fire department ratings provided by the ISO. According to the Fire Suppression Rating Schedule, half of the rating classification is based on local fire department quality, which depends in part on staffing levels and performance. Moreover, a higher staffing level may be associated with safer conditions for firefighters. For example, as discussed previously, NFPA Standard 1710 calls for a minimum of four firefighters per engine on structure fire calls to maximize firefighter safety and performance. Although I do not find evidence of compliance to this standard (on average) or that employment growth has been associated with higher per-engine staffing levels, this is still a consideration that is not captured by the estimates in this section.

Lastly, there are unobserved cost differences resulting from the way in which emergency services are delivered. For example, an unknown share of EMS responses in the data are made by cross-trained firefighters in ambulance units. It is typical in many municipalities to charge a user fee for ambulance services, which might reduce the net cost of per-incident firefighter compensation.

Despite these limitations, the estimates provide a useful starting point for analyzing the current economics of fire department staffing. In the subsequent chapters, I refer to these estimates as a benchmark for estimates of per-incident marginal firefighter benefits.

⁴⁶These estimates still assign economic value only to firefighter incident responses. However, firefighters may also provide value through prevention efforts, training programs, equipment maintenance, and other functions that the estimates exclude.

1.6 Discussion

The analysis in this paper confirms that firefighter employment has increased at the majority of all-career fire departments over the last three decades, despite a persistent decline in fire incidence. I find little evidence that this growth can be explained by a significant rise in fire severity, given the corresponding drop in casualties with fire incidence and the overall decline in total real property loss. Average real property loss per fire has risen commensurately with real housing prices, which I explain could be associated with stable fire intensity or a moderate increase. The latter possibility would be consistent with guidance from fire safety organizations that changes in building construction and contents have led to higher fire temperatures and faster growth rates (Stoll, 2013). However, if average fire intensity has risen, I find little evidence in the NFIRS data that fire departments have utilized higher employment levels in order to increase the total amount of staffing per fire incident. Between 2003 and 2017, the average number of vehicles attending each fire remained stable in the NFIRS data and there was a slight decline in staffing per vehicle. Therefore, it is also unlikely that employment increases have been driven by adherence to national staffing standards. Regardless of the primary cause of increased firefighter rolls, it is possible that despite declining fire incidence, higher employment levels have led to performance improvements on fire responses that generate economic benefits which are at least proportional to marginal employment costs.⁴⁷ In the subsequent chapter, I use the variation in staffing levels attributable to a federal hiring grant called SAFER to study direct marginal firefighter value on fire responses, which I compare to the breakeven benefit targets calculated in this chapter.⁴⁸

While data limitations make it difficult to study the causal relationship between firefighter employment and the growth of EMS responses by fire departments, the descriptive evidence in this paper suggests that the surge in EMS calls is a likely catalyst for recent employment growth. In the third chapter of this thesis, I use the SAFER framework to study the impact of increased firefighter employment on major EMS outcomes. These estimates are necessarily specific to the current structure

⁴⁷Moreover, risk-averse citizens may be willing to pay more than one dollar for a one-dollar expected reduction in direct economic loss.

⁴⁸As discussed in the next chapter, this framework is a useful starting point for thinking about firefighter staffing levels but has limitations as a prescriptive tool and is not intended for this purpose.

of fire departments. However, given the redundancy built into many EMS delivery systems and the high relative cost of sending fire engine units to these responses, there is a critical need for additional research regarding the efficiency and effectiveness of different fire-based EMS models. There is a substantial amount of heterogeneity in how these services are provided, how fire department resources are allocated between fire suppression and EMS activities, and how dispatch systems determine the appropriate level of response to an incident. As discussed in Section 1.4.5, there are examples of major fire departments that seemingly have a mismatch between resource allocation and the changing composition of emergency calls. On the other hand, a growing number of cities have also taken initiatives to streamline their emergency response services and implement mechanisms to safely eliminate unnecessary redundancy.

In addition to the need for continued emergency management research in this area, I believe there is an important role for economists in providing a better understanding of the economic tradeoffs associated with different fire department delivery systems and staffing levels. Ultimately the appropriate level of staffing should reflect citizens' willingness to pay for marginal risk reduction. But in order to make an informed assessment of this risk, there needs to be a better understanding of the tradeoffs. Moreover, if there are more efficient ways to provide the same level of risk protection, this is an important policy question that economists can help answer.

Chapter 2

Marginal Firefighter Impacts on Fire Responses: Evidence from the SAFER Grant

2.1 Introduction

In the previous chapter, I found that firefighter employment growth outpaced most major areas of local government employment over the last three decades, despite a sharp decline in fire incidence. These patterns are robust at the fire department level and cannot be explained by endogeneity, volunteer substitution, increasing fire severity, or adherence to national staffing standards. Rather, the most likely explanation for recent employment growth is the surge in emergency medical service (EMS) responses by firefighters.

The decline in fire incidence alone is not a sufficient criterion for assessing the efficiency of marginal staffing, even if ignoring or discounting the role of firefighters in providing EMS and other non-fire services. Employment gains could result in reduced economic loss on fire responses that exceeds marginal employment costs, even despite a shrinking fire base. Moreover, the value of EMS and other services that firefighters provide should be considered in an assessment of their overall economic impact. The goal of the next two chapters is to estimate the net economic value of marginal

firefighter employment using the staffing variation attributable to a federal hiring grant called Staffing for Adequate Fire and Emergency Response (SAFER). In the current chapter, I focus exclusively on fire outcomes to separate the core competency of fire departments from other types of emergencies - particularly EMS - for which there are substitute providers (e.g., single-role paramedics and EMTs). In the subsequent chapter, I extend the analysis to EMS outcomes.

As a starting point for thinking about the optimal level of fire protection in an area, consider staffing perturbations in a simple cost-benefit framework. At one extreme, suppose that a large city employed a single fire engine unit to provide fire protection for all of its residents. In this case, response times would be slow due to poor geographical coverage and overlapping calls for response. The average fire size would be relatively large as a result, implying greater levels of property damage, increased risk of fire spread, and more dangerous conditions for firefighters and civilians. The amount of time between on-scene arrival and fire containment might also be high relative to a counterfactual where multiple fire units respond to every incident. Now suppose the city began to employ and strategically locate additional firefighters. With each marginal firefighter, response times would initially decrease, loss from fire would decline, and casualty risk would fall. But eventually the city would reach a staffing level beyond which the economic costs of additional employment exceeded the direct economic gains.

The estimation framework in this paper seeks to assess the relative position of SAFER grant recipients on this staffing continuum. The SAFER hiring grant is a competitive, non-renewable federal grant made available to career and volunteer fire departments for hiring full-time firefighters. Applicant fire departments request a specific number of firefighter positions to add and the recipients receive federal funding to cover a share of the associated employment costs over the period of the grant. These positions must be filled within six months of grant receipt and recipient departments must maintain their pre-existing staffing level plus the awarded number of firefighters during the entire subsequent period of performance. Grant funds may also not be used to supplant existing expenditures. Any violations of these conditions can result in grant termination and repayment. I use a difference-in-difference (DiD) design to compare changes in outcomes for recipient departments before and after grant receipt to applicant departments that were denied the grant.

There are two potential sources of direct economic loss from a fire: property loss and casualty loss.

I provide estimates of both sources of loss by exploiting the causal link to firefighter response times, which can be calculated for every recorded incident in the National Fire Incident Reporting System (NFIRS) data and is the primary outcome variable in the DiD analysis.¹ In the baseline specification, I find that grant receipt results in an average monthly response time decrease of 6.1 to 9.8 seconds on fire calls over the subsequent two-year period, depending on how treatment periods with insignificant estimates are handled.² I use the higher estimate (9.8 seconds), along with the lower end of the 95 percent confidence interval (17.7 seconds), to produce bounds on economic loss reduction per fire incident for the SAFER grant recipients, which experienced a mean relative employment increase of 6 firefighters.³ I then convert the department-level loss reduction estimates into estimates of marginal firefighter value per incident, which I benchmark against the breakeven benefit targets calculated in the previous chapter.

Fire engineers model the heat index of early fire growth as an exponential function of time and often assume a similar relationship for the total area affected by a fire (Ramachandran, 1986).⁴ However, Challands (2010) matches a large sample of New Zealand structure fire damage estimates to response times and finds a linear fit. I also observe a positive, linear relationship between reported property loss in the NFIRS data and response times, both within the SAFER sample and for the universe of departments in the NFIRS data. I find that a one-minute reduction in response times among the analysis sample is associated with property loss reductions of up to \$2,496 on structure fire responses and \$675 on non-structure fire responses (in 2017 dollars).⁵ I use these linear inputs to translate the

¹I also estimate changes in property loss and casualty loss directly in the DiD model using the reported values in the NFIRS data. However, given the volatility and low overall frequency of these outcomes at the department level, I choose the response time approach to form the baseline estimates.

²Recipient fire departments have 180 days to recruit the allotted firefighter positions (The Department of Homeland Security, 2017). Therefore, the two-year period of performance that I analyze begins six months after the date of grant receipt.

³Based on the FEMA grant data, the mean and median number of hires funded by first grant receipt are 9 and 6, respectively. In the first-stage estimates presented in Section 2.3.1, which are based on Census employment data, I estimate a relative mean employment increase of 6.3 firefighters for treated departments. I use the latter estimate to describe the mean relative hiring increase.

⁴Early fire growth refers to the period before the fire reaches “flashover” - the point of maximum heat release.

⁵These upper-bound estimates are derived from a restricted sample of incidents with non-zero reported property loss. If all reported zeros are instead treated as true zeros, these estimates drop to \$1,248 and \$107, respectively.

estimated response time effects into baseline estimates of reduced property loss. I find that grant receipt is associated with property loss reductions of \$204 to \$737 on structure fire calls and \$18 to \$200 on non-structure fire calls. In the Appendix, I consider how the results change if instead using an exponential model with standard assumptions for fire growth.

The casualty risk from a direct burn or smoke inhalation for a civilian victim or responding firefighter also increases with time as a fire intensifies (Marsar, 2010). However, there is mixed evidence about the overall impact of firefighter response times in reducing the casualty risk from fire. For example, Chris Wormald, a senior official representing the Communities and Local Government Committee in the United Kingdom reported that “around 80 per cent of fire deaths have already happened at the point at which the fire brigade is called,” suggesting a limited baseline opportunity for saving lives. However, the U.K. Fire Brigade Union disputes the credibility of this estimate and suggests that the risk of death rises non-linearly with response times (Fire Brigade Union, 2012). Using the NFIRS incident-level data for the SAFER sample, I do not find a significant relationship between structure fire fatalities and response times and find no evidence of increasing returns as response time rises. However, when restricting to the response time region with the most mass (4 to 9 minutes), I find a positive, linear relationship that I use (conservatively) to generate loss estimates.⁶ Scaling the estimated slope by the response time inputs and assuming a value of a statistical life (VSL) of \$10 million, I find that grant receipt is associated with \$201 to \$363 of reduced fatality loss per structure fire call. Applying the same methodology to non-structure fire fatalities, for which I do observe a significant relationship with response times, I estimate a range for grant-induced loss reduction of \$41 to \$73 per response.⁷

Combining both the property loss and casualty loss estimates, I find that SAFER grant receipt reduces direct economic loss by \$405 to \$1,100 on structure fire calls and \$59 to \$273 on non-structure fire calls, on average.⁸ Based on average fire call volumes at SAFER departments between 2004 and

⁶For this restricted sample, I estimate a slope coefficient of 0.00012, implying an additional 0.12 saves per 1,000 structure fires for a one-minute decrease in response time.

⁷In this case, the estimated coefficient of 0.00002 (i.e., 0.02 additional saves per 1,000 non-structure fire calls) is highly significant.

⁸I do not find evidence that faster response times are associated with a reduction in non-fatal injuries from fire.

2017, I estimate that grant receipt results in \$53,290 to \$162,215 of direct annual fire loss reduction per average recipient department, which accounts for 8 to 25 percent of estimated annual employment costs. If the per-incident estimates of loss reduction are allocated equally across the mean relative increase in grant-allocated hires (6), I estimate that a marginal firefighter at the average treated department reduces direct economic loss by up to \$184 per structure fire call and up to \$46 per non-structure fire call. As a benchmark for these estimates, I found in the previous chapter that a marginal firefighter at an average all-career department would need to provide between \$422 and \$822 of economic value per incident to break even on employment costs, if these employment costs are allocated equally across all incident types (e.g. fires, EMS, false alarms).

The framework employed in this paper is useful for estimating observable costs and benefits, but may have limitations as a prescriptive tool for fire department staffing levels. First, a non-trivial share of the value provided by firefighters may be unobserved or indirect. For example, even for non-emergency incidents that result in no direct loss (ex post), recipients of a firefighter response likely still value this service. Given that the analysis in this chapter is marginal, it may be reasonable to assume that no *additional* unobserved value is transferred absent improvements in observable outcomes (such as response times). However, any quantification of directly observed improvements in fire department performance may underestimate citizens' willingness to pay for these gains. Welfare-based frameworks, such as the the marginal value of public funds and others cited in Hendren and Sprung-Keyser (2020), are better suited for normative analysis. Moreover, there may be general equilibrium effects of increased firefighter employment that these estimates do not capture. For example, home insurance premiums depend in part on the ISO rating assigned to the local fire department, which is a function of firefighter staffing levels. Similarly, other research has shown that the indirect benefits of successful fire suppression in terms of limiting job loss, business closures, and declines in tax receipts can outweigh the direct benefits.⁹ The relatively small perturbations considered in this paper may not be highly consequential for these types of losses, but these indirect impacts should be considered if

Surprisingly, I find a stable negative relationship between injuries and response times.

⁹For example, Evans (2014) estimates that as a result of 42 successful fire interventions by the Phoenix Fire Department, nearly 7,500 jobs could have been saved, gross state product could be almost \$650 million higher (2012 dollars), and tax revenues could be more than \$35 million higher (2012 dollars).

using this type of analysis to guide staffing decisions.

Second, the estimates in this paper are averaged over a sample of fire departments and do not speak to the heterogeneity among individual departments. It is possible that the benefit-to-cost ratio attributable to the grant is much higher for individual departments in the sample and/or is highly dependent on how marginal staffing is utilized. For example, departments that are able to deploy additional engine units as a result of the grant may experience greater response time improvements than those that maintain the same number of active vehicles. While the estimates in this paper abstract from the underlying mechanism(s) relating higher employment levels to faster response times, these considerations are important for the policy environment.

Third, the analysis is restricted to fire responses in this chapter and EMS responses in the subsequent chapter, which combined account for the vast majority of fire department call volume. However, fire departments also provide other types of services, such as hazardous conditions responses, rescues, and service calls, which the analysis does not capture. For example, the estimates in Castalia (2012) suggest that between 2.8 and 8.5 percent of the quantifiable value attributable to New Zealand firefighters comes from response types not considered in this chapter or the next.

Fourth, as discussed in Section 2.2, the NFIRS data used to analyze fire and EMS outcomes is entered by fire department staff and may be subject to reporting errors and underreporting (FEMA, 2011). The precision of the response time estimates - expressed in seconds - may also be affected by the one-minute reporting intervals in the NFIRS data.

Fifth, fire departments may need to maintain a minimum level of staffing to address tail risks that are not easily captured by this type of marginal analysis. The sample period in this paper is limited to 14 years of fire data and the damage estimates are based off of average sample relationships. In practice, the needed level of fire protection will vary across jurisdictions based on local risk factors, risk preferences, and importantly - the extent of mutual aid agreements. Many fire departments have preexisting arrangements with surrounding departments to provide resources and support in the event of severe emergencies. If these agreements are being used strategically to protect against worst-case risks, then this issue does not likely pose a meaningful constraint for the analysis in this chapter. However, some emergency response researchers caution altogether against applying standard

cost-benefit approaches to assess the complex issue of optimal fire department staffing.¹⁰ I am modest in drawing broad policy proposals from the findings given these considerations, but pose the estimates as a useful starting point for thinking about current staffing levels.

Lastly, these estimates take the current structure of fire departments as given, whereas there may be more efficient ways of providing the same level of services. For example, as discussed in the opening chapter, the majority of fire department responses are for EMS calls, which may also be provided by single-role paramedics/EMTs. If, for example, it was determined that the optimal firefighter staffing level should be evaluated from a counterfactual where fire engine units respond to EMS calls on a much more limited basis, the marginal benefit estimates for fire calls would likely be overstated.

Relative to the expansive literature on the relationship between policing and crime, there are few academic studies on the economic impacts of firefighting.¹¹ This paper is most similar methodologically to Mello (2019), which studies the crime impacts associated with higher policing levels enabled by a federal hiring grant. A number of studies, such as Delorme and Waterhouse (2017), Delorme and Waterhouse (2020), and Evans (2014) estimate the overall economic impact provided by individual fire departments over a given period.¹² These studies tend to find very high total returns on fire departments, where the implicit counterfactual is the absence of a fire department. Given that a single structure fire can result in millions of dollars worth of direct and indirect loss, a successful firefighting intervention can have enormous economic value. The intended contribution of this paper is to provide a starting point for thinking about the *marginal* economic value of firefighter staffing, rather than the absolute value of fire departments.

The rest of the paper proceeds as follows. In Section 2.2, I provide an overview of the SAFER hiring grant, describe the data sources used in the analysis, and define the analysis sample. I then explain the methodology used to estimate marginal response time improvements attributable to the

¹⁰For example, Natalie Simpson emphasizes the potentially catastrophic consequences of being understaffed due to shortsighted budget cuts when a substantial fire arises, regardless of frequency (for example, see Stromberg (2015) and Catron (2020)).

¹¹See Cameron (1998), Nagin (1998), Eck and Maguire (2000), Skogan and Frydl (2004), Levitt and Miles (2006), and Chalfin and McCrary (2017) for extensive summaries of the policing literature.

¹²The National Fire Protection Association also publishes economic studies pertaining to the national cost of fire, such as Zhuang *et al.* (2017)).

grant. In Section 2.3, I first present the first-stage results showing that SAFER grant receipt results in a relative employment gain for treated departments relative to denied grant recipients during the period of performance. I then provide the baseline response time estimates. In Section 2.4, I translate the estimated response time improvements into dollar estimates of reduced economic loss, which I convert to the marginal firefighter level. I then discuss how these estimates relate to the breakeven per-incident benefit targets calculated in the previous chapter. In Section 2.5, I provide a concluding discussion.

2.2 Estimating Marginal Firefighter Impacts on Fire Calls

In this section, I first describe the Staffing for Adequate Fire and Emergency Response (SAFER) grant, which is the source of the employment variation studied in this paper. I then present the data sources, analysis sample, and methodology for estimating marginal firefighter impacts on fire calls.

2.2.1 SAFER Grants

To study plausibly exogenous changes in firefighter employment, I make use of a competitive, federal hiring grant known as the SAFER grant. This grant has been administered annually by FEMA since fiscal year 2005 and has separate funding tranches for hiring full-time firefighters (available to both career and volunteer departments) and recruitment and retention of volunteers (available only to volunteer departments).¹³ I work exclusively with the hiring portion of the grant and restrict the sample to all-career and mostly-career fire departments.¹⁴ The stated goal of the hiring grant is to help fire departments increase their staffing of front-line workers to improve compliance with NFPA standards for staffing and performance (NFPA 1710).¹⁵ Applicant fire departments must request a specific number of positions to fill and their exact financial need, as well as some descriptive information

¹³In certain years, the hiring grant may also be used to avoid otherwise inevitable staffing layoffs or convert part-time firefighters into full-time employees.

¹⁴To be classified as “mostly-career”, a department can employ as few as one volunteer firefighter and as many as half of its staff.

¹⁵For example, NFPA 1710 specifies that the first responding engine unit should be staffed with a minimum of four firefighters for fire responses. The standard also implies a 90th percentile total response time of 6 minutes and 39 seconds, which is the duration between initial alarm onset and when the first unit arrives on scene.

pertaining to their request. A comprehensive review is performed by FEMA and each application is assigned a standardized technical score based on the funding priorities for that cycle. Grants are then awarded to the highest-scoring applicants until the available funding for that cycle has been exhausted. While the award process targets fire departments that stand to benefit most from the grant in terms of increasing compliance with NFPA standards, I show in a later subsection that grant recipients look very similar to denied departments on most observable dimensions. There are also no significant differences in performance in the periods leading up to grant assignment.

Importantly, recipient departments must fill the awarded positions within six months of grant receipt and then maintain their existing staffing level plus the awarded number of positions through the entire period of grant performance (3-4 years, depending on the year). This means that if retirements occur during the grant period, these positions must be replenished in order to stay in compliance with the grant conditions. This requirement of the grant ensures that recipient departments actually maintain a net gain in firefighter employment, which is important for the econometric framework. Grant funds may also not be used to supplant existing expenditures or serve any other purpose other than increasing hiring. Failure to comply with any of the grant regulations can result in termination and repayment of the grant.

Between fiscal years 2005 and 2015, the sample period that I study, a total of \$2.4 billion in hiring grants was allocated over 1,974 awards, implying an average grant size of about \$1.2 million.¹⁶ This funding was used to employ nearly 16,000 firefighters. The average number of annual fire department recipients is 179 and the average number of grant-funded hires is 8. About 1,000 applicant fire departments are denied the grant in an average year. The funding commitments and grant durations differ by funding cycle, but in all grant periods FEMA pays for at least 75 percent of each new firefighter's first two years of employment. For this reason, I focus on the two-year performance period after grant receipt in the analysis.¹⁷

¹⁶About 350 fire departments received more than one grant over this period.

¹⁷There is also a decreasing likelihood that the relative employment increase attributable to the grant will be sustained as the observation period widens. In the first-stage analysis, I show that this employment increase is sustained for at least two years after grant receipt.

2.2.2 Data

Through a FOIA request to FEMA, I obtained SAFER grant data for the fiscal years 2005 to 2015, including the identity of all denied and awarded departments, the date of application or award, the served population size, the number of hires granted to each recipient department, and the total requested and awarded dollar amounts. I use the provided name, location, and population information to match each department to the USFA National Fire Department Registry, which contains descriptive information and a unique fire department identifier (FDID) for each department.

I then match this data to the National Fire Incident Reporting System (NFIRS) data by state and FDID. NFIRS is a standardized incident reporting system used by fire departments across the country to document incident responses. For each response, it contains information on the date, response type (e.g. fire, EMS, false alarm), and alarm and arrival times. For a large subset of responses, the data also contains information on the number of responding firefighters and apparatus, number of civilian and firefighter casualties, and estimates of property damage. I calculate response time as the difference between the arrival time on scene of the first responding unit and the time the fire department received the emergency alarm. Unfortunately, this data is only provided in one-minute intervals, rather than in second increments. I discuss the potential impact of this limitation in the subsequent analysis.

NFIRS reporting is voluntary at the national level, but many states impose their own reporting requirements (FEMA, 2015). As of 2017, every state reports to NFIRS; however, individual fire departments may report in some years, but not others. There are also obvious cases of under-reporting by some fire departments that do report in a given year, both in terms of the number of incidents documented and the scope of the data that is provided. Despite these shortcomings, the NFIRS data is estimated by the USFA to account for about 75 percent of annually reported fires and it serves as a primary input for national estimates of fire trends. The data integrity also tends to be more robust for larger departments that employ career firefighters, which is the focus of this paper.

Lastly, I merge this data with employment data from the Annual Survey of State and Local Governments (ASPEP) based on government name and government type to test the first stage of increased relative employment among the treated departments.

2.2.3 Sample

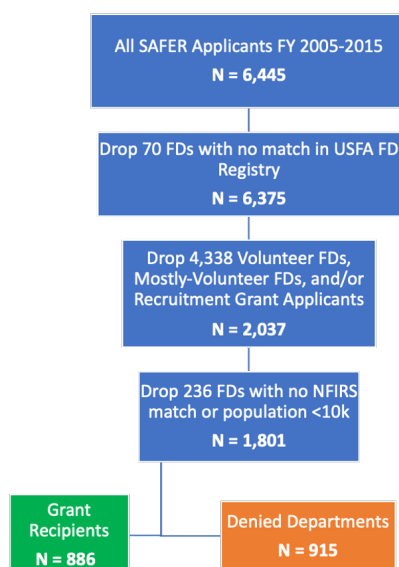
Figure 2.1 shows how the analysis sample is defined. I start with the pool of 6,445 fire departments that applied at least once for a SAFER grant between fiscal years 2005 and 2015, whether for the hiring program or the recruitment program. I then drop the 70 fire departments for which there is no observed match in the USFA Fire Department Registry, since these departments cannot be linked to the incident-level NFIRS data. I then exclude the 4,338 departments that are either all-volunteer or mostly-volunteer, and/or that applied for a recruitment grant (rather than a hiring grant). The remaining sample consists of 2,037 all-career and mostly-career fire departments that applied for a SAFER hiring grant, which is the primary focus of this paper. The only additional restriction I impose is to drop the 236 departments with no match in the NFIRS data during the analysis period or that serve populations of less than 10,000 citizens.¹⁸ The final sample consists of 1,801 all-career and mostly-career departments, of which 886 received a SAFER hiring grant during the analysis period and 915 were denied in one or more attempts.

For this sample, I then restrict the NFIRS data to reported fire calls over the period 2004 to 2017. These incidents encompass every type of fire-related response, including five-alarm structure fires, small stove fires that are extinguished prior to firefighter arrival, and confined outdoor rubbish fires. False alarm responses, however, are excluded from this category. I also exclude incidents that correspond to a department providing mutual aid to another department, since these out-of-jurisdiction responses will naturally be associated with higher response times. Finally, I winsorize the 0.48 percent of response times greater than 30 minutes and collapse the data to the monthly level. It is likely that many of these extreme response times are either based on reporting errors or involve minor incidents where the department decided an urgent response was not necessary. For example, there are some reported incidents with an implied response time of more than one day. These incidents can change average response times by orders of magnitude. I discuss in Section 2.3 how the results are affected by the winsorization choice.

Table 2.1 provides a comparison of the grant recipients and denied departments in the analysis

¹⁸For the latter subgroup, local fire departments are very small, absolute fire incidence is low and volatile, and NFIRS reporting tends to be sparse.

Figure 2.1: *Sample definition flow chart for fire outcome analysis*



This chart shows how the analysis sample for Chapter 2 is defined. The final sample consists of 1,801 departments (886 grant recipients; 915 denied departments).

sample during their first application year.¹⁹ Variable means are reported separately for each group and marked with an asterisk if found to reject a null hypothesis of equality (at 5%) in a two-sided t-test. Grant recipients are about 7 percentage points more likely to be all-career departments (rather than mostly-career) and on average submit funding requests that are about 54 percent higher than denied departments. Grant recipients also average about 0.6 additional fire personnel on each fire response, which is somewhat unexpected given the stated grant priorities. However, these are the only significant differences between grant recipients and denied departments that I observe. Across most departmental features and performance metrics, including firefighter density (firefighters per 1,000 citizens), response time, fire density, average alarm level, and fire type, recipient and denied departments look very similar.²⁰ Grant recipients tend to serve larger populations on average, consistent

¹⁹For grant recipients, I also show the median and mean number of allocated hires during the first grant receipt period, based on the FEMA data.

²⁰The “alarms” variable refers to the average alarm level of each fire call (1-5 scale), 1 being the lowest emergency and 5 being the highest. The “fire type code” refers to the average mix of structure fires (coded 1), vehicle fires (coded 2), and

with their higher likelihood of being all-career, and are less likely to be southern, but these differences are not significant.

Table 2.1: *Regression sample balance for fire outcome analysis*

	Grant Recipients (Treated)	Denied Departments
Number of Departments	886	915
Department Type*		
Career	71%	64%
Mostly Career	29%	36%
Region		
MW	27%	26%
NE	17%	15%
S	35%	40%
W	22%	19%
Population	101,451	78,496
Firefighter Density	1.60	1.54
Response Time (Mins.)	5.46	5.46
Fire Density	3.70	3.56
Alarms	0.77	0.78
Fire Type Code	2.07	2.10
Staffing per Fire Call		
Fire Engines	2.8	2.7
Suppression Personnel*	7.0	6.4
SAFER		
Amount Requested*	\$2,129,276	\$1,413,407
Mean Hires	9	N/A
Median Hires	6	N/A

This table presents average sample characteristics for the fire departments used in the DiD analysis. The “alarms” variable refers to the average alarm level of each fire call (1-5 scale), 1 being the lowest emergency and 5 being the highest. The “fire type code” refers to the average mix of structure fires (coded 1), vehicle fires (coded 2), and outdoor/other fires (coded 3). For all variables, I fail to reject a two-sided t-test for equality of means between recipient and denied departments, except for those marked with an asterisk. *Source:* Author’s calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

outdoor/other fires (coded 3).

2.2.4 Methodology

In order to estimate the direct impacts of employing additional firefighters, I use a dynamic DiD design to compare how outcomes evolve for recipient fire departments before and after grant receipt relative to denied applicants. Specifically, I estimate the following regression:

$$Y_{dt} = \gamma_d + \delta_t + \sum_{j=-18}^{30} \beta_j D_{dt+j} + \rho X_{dt} + \varepsilon_{dt} \quad (2.1)$$

Here t indexes the analysis month, Y_{dt} is the outcome variable for department d (response time in the baseline estimates), δ_t is a period fixed effect, D_{dt+j} is a binary treatment indicator for department d equaling 1 when first grant receipt is j periods away, X_{dt} controls for incident characteristics, and ε_{dt} is an error term.²¹

Treatment is absorbing in the model, so treatment indicators are equal to 1 in every period after first grant receipt. I focus the analysis on the first 30 months after treatment, but particularly the 24-month period following the 6-month window granted to perform the designated hiring. Each monthly observation is weighted by the total number of fire calls and standard errors are clustered at the fire department level. The (unbalanced) estimation sample consists of 249,392 monthly observations for 1,801 fire departments over the years 2004 to 2017. The estimated effects can be viewed as intent-to-treat measures.

Given that grant receipt is determined by a cutoff rule based on assigned application scores, a regression discontinuity design might be the preferred starting point methodologically. Unfortunately, these scores were not granted for public release by FEMA. However, Mello (2019) performs a similar analysis using police hiring grants and ultimately uses a DiD specification despite having access to application scores, in order to overcome power issues. Based on the balance test in the previous subsection, SAFER recipients and denied departments have very similar characteristics and performance metrics prior to grant assignment, which lends some assurance to the DiD approach. I also perform standard tests for pre-trends in the subsequent estimates.

²¹The incident characteristics I control for in the baseline estimates are the time distribution of fire responses (e.g., noon-6pm, 6pm-midnight) and the fire type distribution (e.g., structure fire, vehicle fire).

2.3 Results

In this section, I provide a first-stage analysis to verify the relative employment impact for grant recipients. I then present the baseline results from estimating the DiD model described in equation (2.1).

2.3.1 First Stage

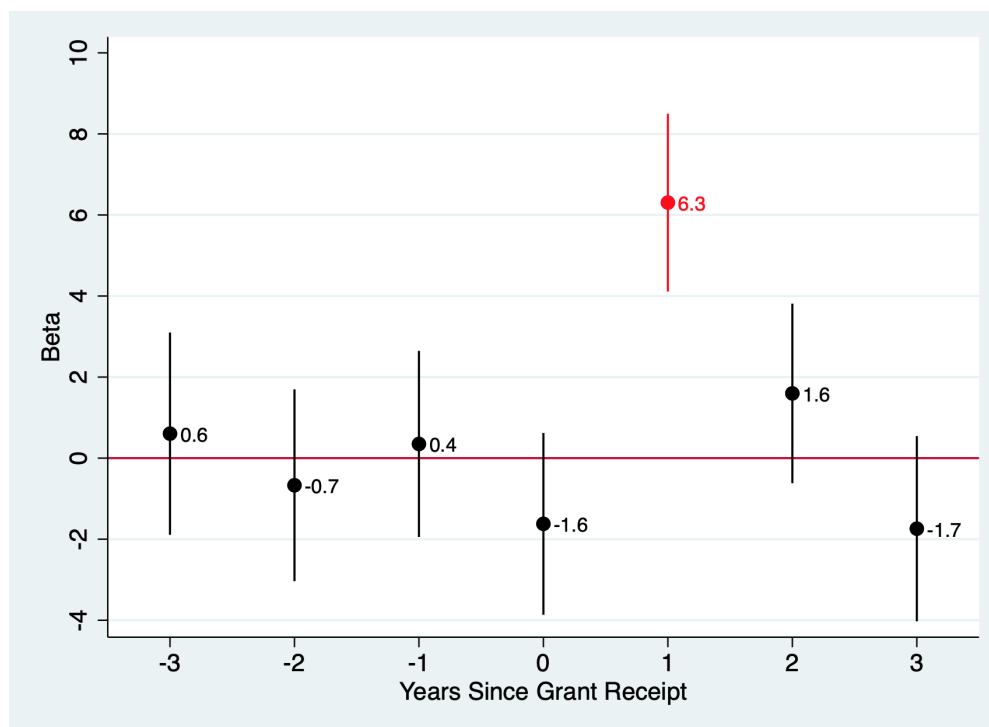
To confirm that the grant results in an employment increase for the recipient departments relative to the denied departments, I first match the administrative FEMA data to the ASPEP employment data for the years 2002 to 2017. For each $j \in [-3, 3]$, I then run the following first-stage regression:

$$\Delta FF_{dt} = \alpha + \beta_j D_{dt+j} + \delta_t + \varepsilon_{dt} \quad (2.2)$$

Here ΔFF_{dt} is the change in the number of firefighters at department d in year t , D_{dt+j} again indicates treatment occurrence in j periods, and δ_t is a period fixed effect. For this regression, j is measured in years to comply with the minimum reporting interval in the ASPEP data. The regression sample for the first-stage analysis is necessarily limited to the 1,430 departments (707 grant recipients and 723 denied applicants) with annually-reported ASPEP employment data. For the other 373 departments in the analysis sample, employment data is only available in the comprehensive census years, which occur every fifth year.

Figure 2.2 plots the β_j estimate for each $j \in [-3, 3]$, as well as the 95 percent confidence intervals. In the first year of treatment - labeled "1" on the chart - there is a statistically significant increase in employment of 6.3 firefighters for the recipient departments, with the upper bound of the confidence interval extending to 8.6. These estimates are aligned with the median and mean number of grant-allocated hires reported for the analysis sample in Table 2.1 (6 and 9, respectively). In all other periods, the beta coefficients are insignificant (even at 10%), including the three years preceding treatment and the two years following treatment. These estimates confirm that the SAFER grants effectively generate a relative increase in employment for the recipient departments in the first year of treatment that is sustained throughout the analysis period.

Figure 2.2: *First-stage regression results*



This figure plots the individual beta estimates from equation (2.2) for the years preceding and following treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. The regression sample consists of the 1,430 fire departments among the 1,801 in the analysis sample with annually-reported ASPEP employment data between 2002 and 2017. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the Annual Survey of Public Employment and Payroll.

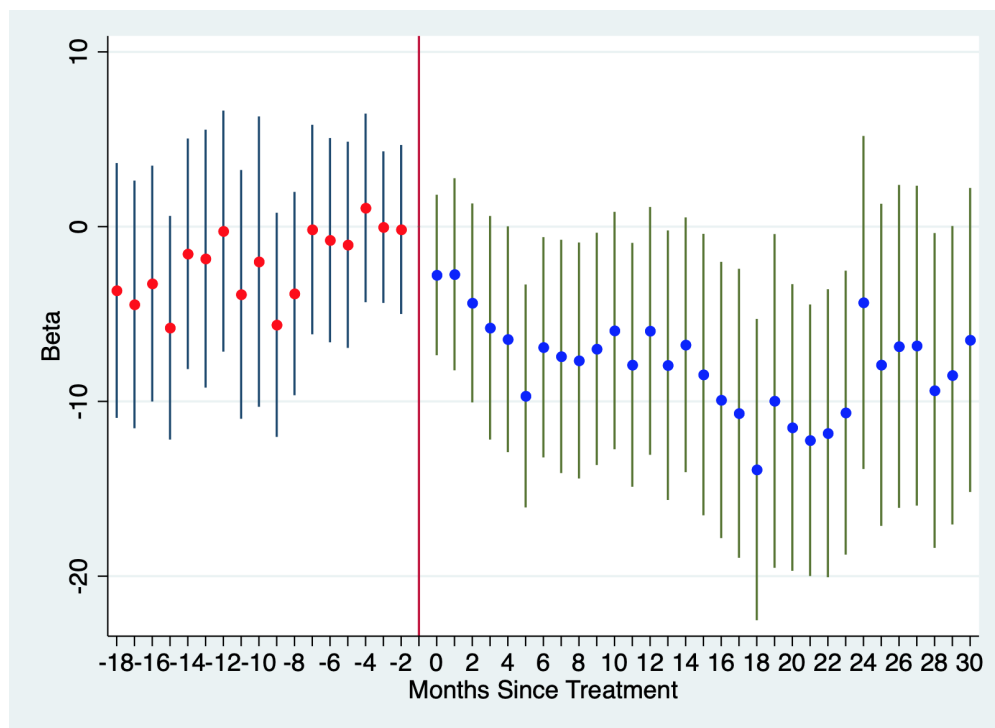
2.3.2 Response Time Results

There are three primary channels by which employing more firefighters could result in faster response times. First, having more firefighters could allow for the staffing and distribution of more engines. Second, a larger firefighting force could result in general productivity improvements from lower average caseloads. Finally, if higher employment leads to increased staffing per engine, this could result in faster resolution of incidents and less delay between calls attended.²² I do not attempt to separately identify the relative impact of each mechanism in this paper, but rather average across all of these potential effects.

²²Experimental studies have shown that having more firefighters per engine can also result in a faster “water on fire” time, holding the travel distance fixed. For example, Averill *et al.* (2010) found that a five-person crew put water on fire 22% faster than a two-person crew. This is a potential added benefit of marginal firefighter employment that is not captured in this analysis.

Figure 2.3 plots the baseline estimates of equation (2.1) for the response time outcome variable during the 18 months preceding first grant receipt and the 30 months following first grant receipt, along with 95 percent confidence intervals.²³ All estimates are interpreted relative to the month prior to treatment. Although actual response times are recorded in minute intervals, the beta estimates are converted to seconds to simplify interpretation.

Figure 2.3: *Baseline response time estimates*



This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for the baseline response time outcome variable. The baseline mean for this variable, which is first winsorized at 30 minutes, is 341 seconds in the year prior to first treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

In the early half of the pre-treatment window, response times at treated departments appear to be slightly lower (faster) than at denied departments, but none of these estimates are statistically significant at 5%.²⁴ In the seven months leading up to grant assignment, the beta estimates hover

²³The coefficient estimates and standard errors are reported in Appendix Table B.1.

²⁴The estimates for the pre-treatment periods 9 and 15 months prior to grant receipt (-5.6 and -5.8, respectively) are

closely around zero and are highly insignificant. Immediately following grant receipt, there is a gradual decline in relative response times for the recipient departments that becomes significant by the fifth month after treatment, which is consistent with the 6-month grace period provided to fulfill the designated hiring obligations. For much of the subsequent 2-year period, the recipient departments maintain a relative improvement in response times that ranges from 4.3 to 13.9 seconds (on a baseline mean of 341 seconds). The estimates are significant in 15 of 24 months, but lose significance in some periods, particularly towards the end of the analysis window. The average monthly response time improvement is 6.1 to 9.8 seconds, depending on whether the insignificant estimates are ignored or treated as zeros, and the lower end of the 95 percent confidence interval is 17.7 seconds.^{25,26}

To offer further support for the robustness of the baseline response time results, I also analyze equation (2.1) using alternative specifications for the response time outcome variable. In Figure 2.4, I show how treatment affects the share of a department's fire call response times (in percentage points) that are below 4 minutes (top panel) and below 6 minutes (bottom panel). The 6-minute threshold is particularly significant, as it represents the NFPA's performance expectation for at least 90 percent of structure fire responses.²⁷

The baseline means for the 4-minute and 6-minute call share outcomes are 44 percent and 73 percent, respectively. The top panel of Figure 2.4 shows that by the end of the 6-month hiring period, there is a significant jump in the share of fire calls with a response time below 4 minutes. The results remain significant in most subsequent periods and hover between about 1 and 3 percentage points. The bottom panel shows a similar trajectory for the 6-minute threshold estimates, but the results lose

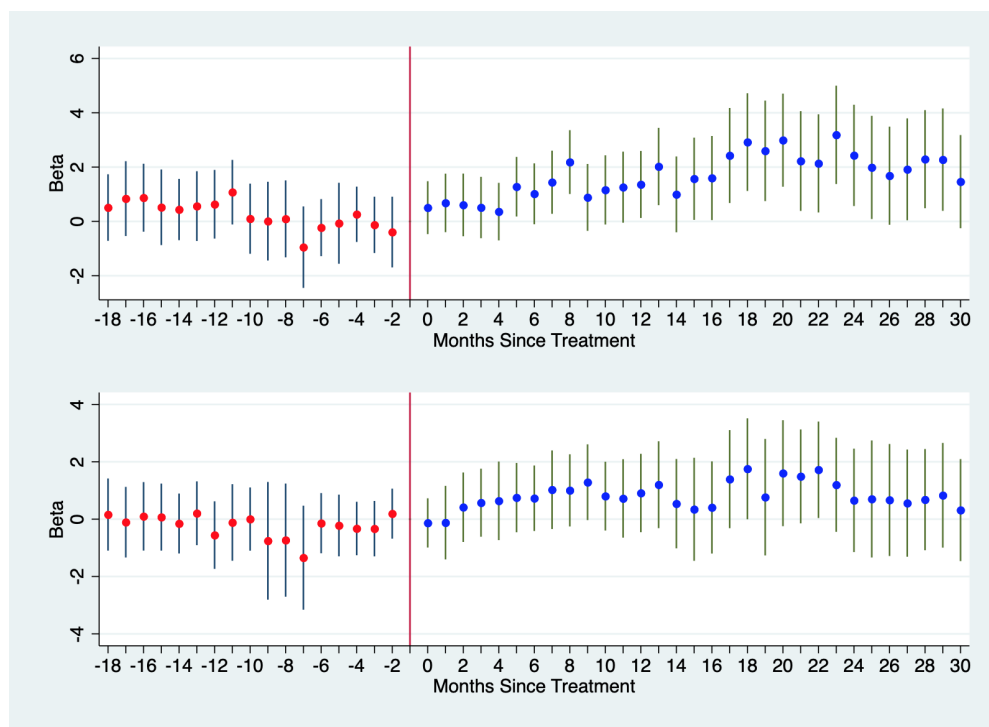
significant at 10%.

²⁵I also find very similar results when estimating the DiD model exclusively for structure fire calls. I therefore apply the aggregate response time estimates when separately modelling structure fire loss reduction in the next section.

²⁶The response time result is sensitive to the winsorization choice. If the winsorization cutoff is increased from 30 minutes (0.48% of the sample) to 60 minutes (0.24% of the sample), the mean response time result falls from -9.8 seconds to -12.3 seconds. If the cutoff is increased to 120 minutes (0.17% of the sample), the mean response time result falls to -16.2 seconds. Both of these estimates are bounded by the lower end of the 95 percent confidence interval for the baseline estimate, which I use to generate the upper bound of the loss reduction estimates. At higher winsorization choices, which almost certainly represent reporting errors or deliberately delayed responses, the response time estimates become insignificant.

²⁷The exact standard is 6 minutes and 39 seconds, based on an alarm answering time of 15 seconds, an alarm processing time of 64 seconds, a turnout time of 80 seconds, and a travel time of 240 seconds (Moore-Merrell, 2019). Given that the NFIRS data is only available in one-minute intervals, I use the 6-minute threshold as a proxy.

Figure 2.4: *Alternative response time outcomes: share of calls below four and six minutes*

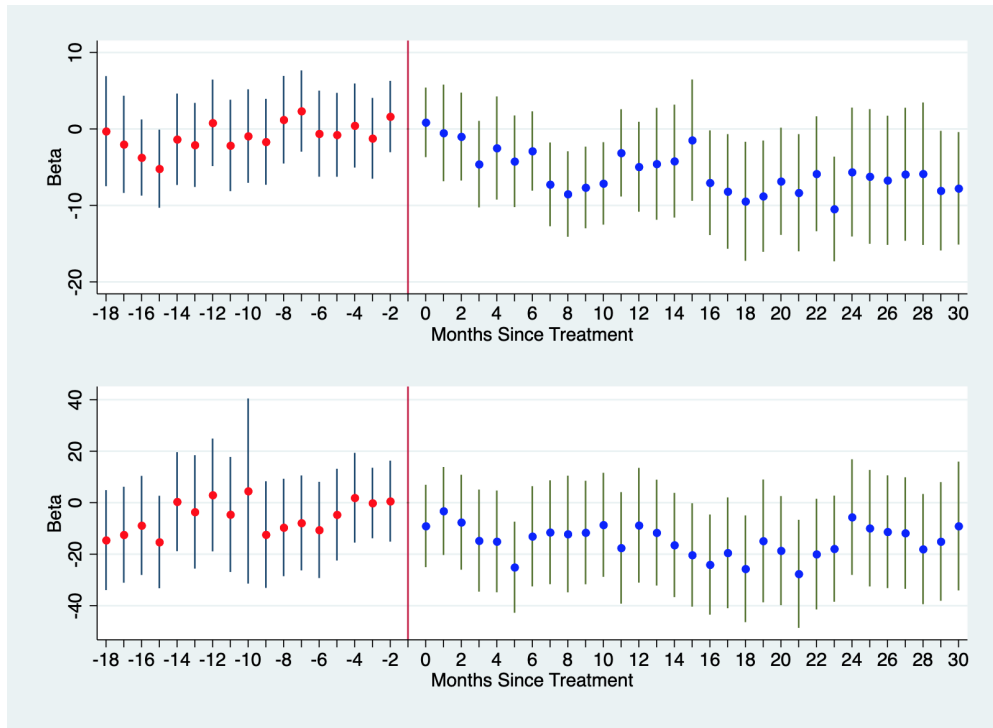


This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for the share of fire call response times below 4 minutes (top panel) and below 6 minutes (bottom panel). The respective baseline means are 44 percent and 73 percent. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

significance in many periods. Nonetheless, these patterns provide support for an overall distributional shift, which is also apparent in the top and bottom panels of Figure 2.5, showing the 50th and 90th percentile response time outcomes (respectively). During the 24 months following the hiring period, the median response time fell by 4.1 to 8.2 seconds on average (from a baseline of 308 seconds) and the 90th percentile response time fell by 4.1 to 24.4 seconds (from a baseline of 521 seconds), again depending on how insignificant estimates are treated.

Finally, Appendix Figure B.1 uses the mean of a categorical response time variable grouped into four buckets as the outcome variable. The general result pattern again looks very similar to the baseline result in Figure 2.3.

Figure 2.5: *Alternative response time outcomes: median and 90th percentile response times*



This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for median response times (top panel) and 90th percentile response times (bottom panel). The respective baseline means are 308 seconds and 521 seconds. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

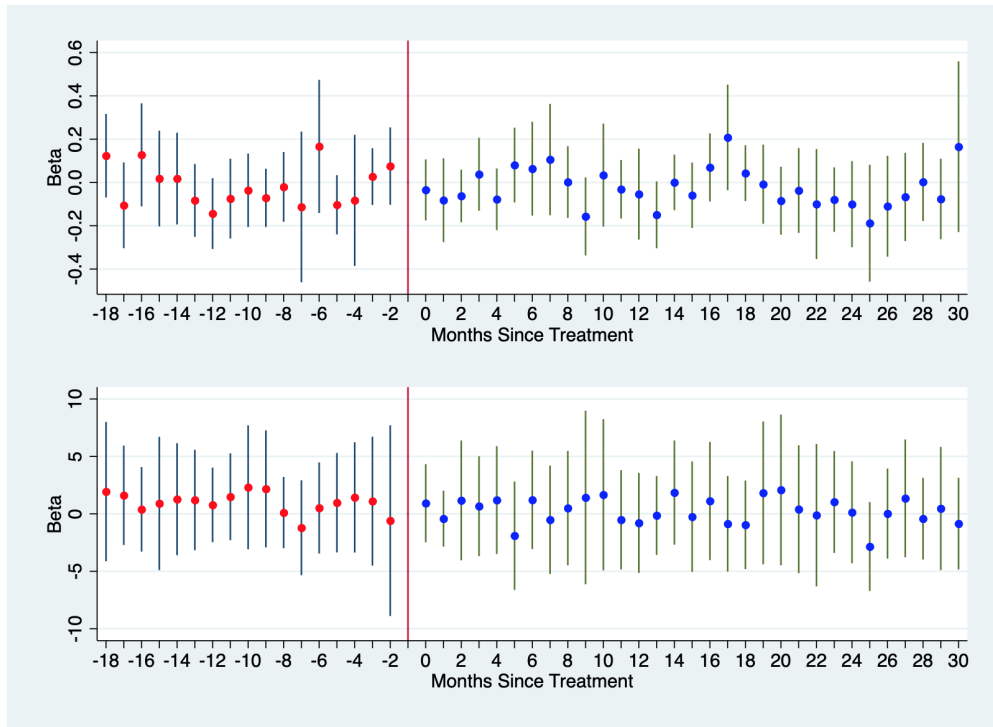
2.3.3 Additional Outcomes

In the subsequent section, I use response time as the primary input to indirectly estimate property and casualty loss reductions attributable to the grant. However, I show in this subsection how the direct loss outcomes (as reported) are affected by the marginal employment increases. I also highlight the impact on average staffing levels.

The top and bottom panels of Figure 2.6 show the results from an estimation of equation (2.1) on the total number of monthly deaths and injuries from fire (civilian plus firefighter), respectively. In both cases, there are no detected effects, but the baseline frequency of these events is very low (0.05 deaths and 0.6 injuries per month). Similarly, Figure 2.7 shows that there is no discernible reduction

in average real property loss per fire.²⁸ However, given the low overall probability of these events, noisiness of the DiD estimates, and higher potential for misreporting, I rely on the response time approach to form the baseline loss estimates.

Figure 2.6: *Additional outcomes: deaths and injuries from fire*

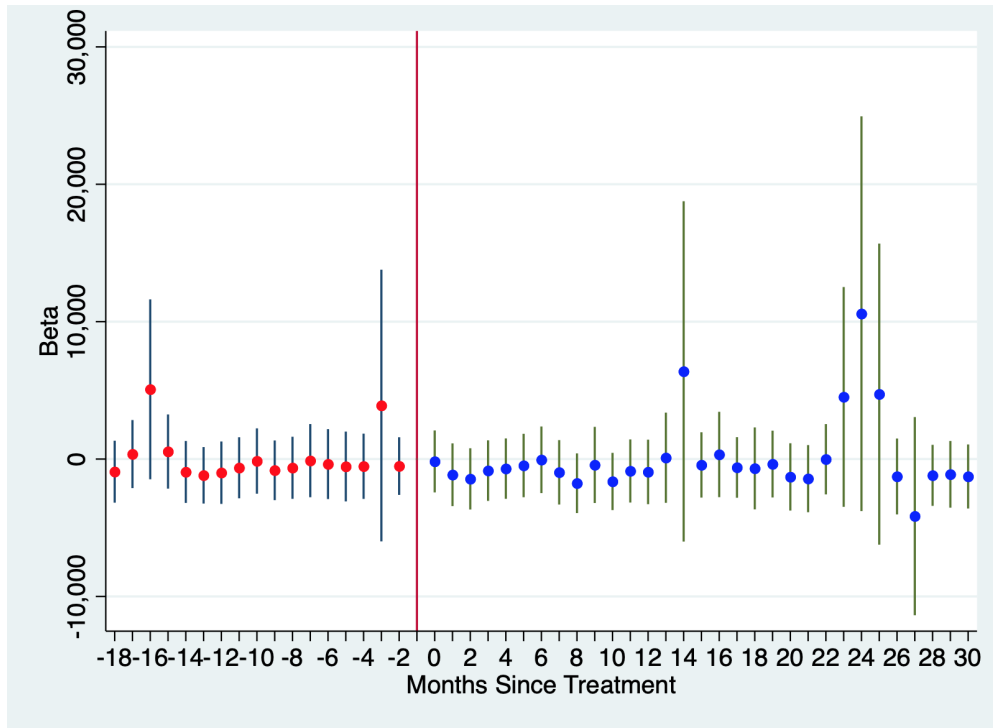


This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for total reported deaths (top panel) and injuries (bottom panel). Both civilian and firefighter deaths and injuries are included in these outcomes. The respective baseline means are 0.05 deaths and 0.6 injuries per month. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

There is, however, evidence that the grant allowed for higher average staffing per fire incident. While the number of responding engines per call remained stable over the grant period, the number of total attending firefighters showed a modest increase. As shown in Figure 2.8, the implication is that grant receipt resulted in an average staffing increase per fire call of about 0.12 firefighters per engine, which has a baseline mean of 2.64 in the year prior to treatment. This result pattern is consistent with a

²⁸The baseline value of average property loss per fire is \$7,248. I also find no impact on total real property loss per month.

Figure 2.7: Additional outcomes: average property loss per fire



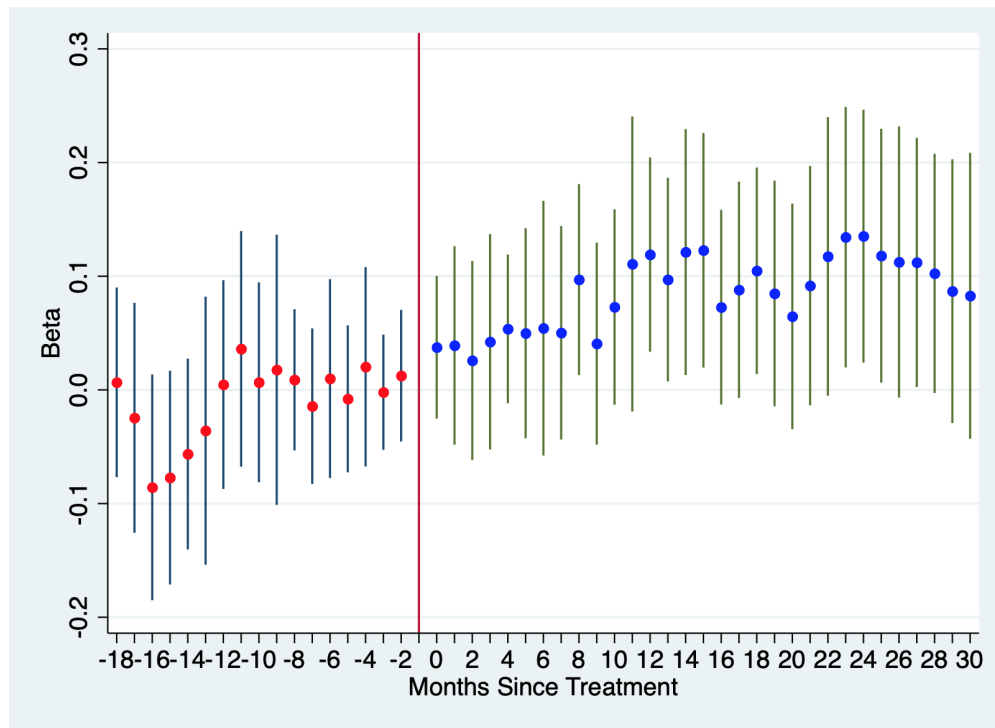
This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for average property loss per fire response. The baseline mean for this variable in the year prior to treatment is \$7,248. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

primary goal of the SAFER grant, which is to increase compliance with NFPA standard 1710, which calls for at least four firefighters per engine on structure fire calls. Some experimental evidence, such as Averill *et al.* (2010), suggests that higher staffing per vehicle can result in on-scene performance improvements, which is a potential benefit of grant receipt that is not considered in the subsequent loss analysis.

2.4 Economic Loss Estimates

In this section, I attempt to quantify the direct economic impact of the estimated response time improvements. I start by estimating overall loss reductions attributable to the SAFER hiring grant, which I then convert to estimates of marginal firefighter value on fire responses.

Figure 2.8: *Additional outcomes: firefighters per engine on fire calls*



This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for the number of firefighters per engine. The baseline mean for this variable in the year prior to treatment is 2.64. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

As discussed in the introduction, there are two types of direct loss from fire - property loss and casualty loss - both of which are increasing in the exposure time to a fire. Whereas faster interventions by firefighters indisputably lead to lower average property losses, there is less consensus about the stability of the relationship between response times and casualty rates. A quick Google search will reveal examples of firefighters saving people (and pets) from structure fires, so these events can and do occur. It is also easy to hypothesize situations in which a fire victim might benefit from a faster response time.

But both the frequency of potential saves and the statistical dependence on firefighter response times is less certain. According to the NFPA, about 3,400 civilians died from fire in 2017 and 60 firefighters died in the course of attending a fire. Smoke inhalation is the most common cause of death

from fire and can occur in a matter of minutes as a fire grows and consumes more of the available oxygen. A large share of the households exposed to a fire will either be able to evacuate the area quickly or will be killed before the fire engines have even left the station. The growth rate of a fire depends on many situational factors, such as the source of ignition and the level of oxygen depletion, and affects both the likelihood that civilians can escape on their own and the probability that firefighters will attempt a life-threatening save.

In the analysis that follows, I consider the sensitivity of the results to different assumptions about the relationship between response times and direct loss outcomes. I first provide estimates of property loss reductions attributable to SAFER hiring, followed by estimates of reduced casualty loss. I then convert the department-level estimates to the marginal firefighter level and benchmark these estimates against the benefit targets calculated in the previous chapter.

2.4.1 Property Loss Estimates

Fire engineers typically model the heat output of a fire as growing exponentially until the fire reaches maximum heat capacity ("flashover"), which is consistent with experimental evidence.²⁹ Based on this relationship, studies such as Ramachandran (1986) have modelled the total area damaged by fire as an exponential function of time. For example, the total floor area damaged T minutes since ignition would be assumed to evolve according to equation (2.3) below, where $A(o)$ is the area initially ignited and β is the growth parameter of the fire.

$$A(T) = A(o) \times \exp(\beta T) \quad (2.3)$$

If the dollar loss from fire also grows exponentially, then marginal response time improvements can have especially high economic benefits, particularly if directed towards areas with abnormally high response times and/or property values. However, there is not strong empirical support for this relationship. Challands (2010) fits loss estimates for the universe of structure fires in New Zealand between 2003 and 2008 to response times and finds a strong linear pattern. He estimates that a one-minute reduction in response time is associated on average with a NZ\$4,024 decrease in property

²⁹For example, see Averill *et al.* (2010).

damage, or about US\$2,414 at the time of writing.

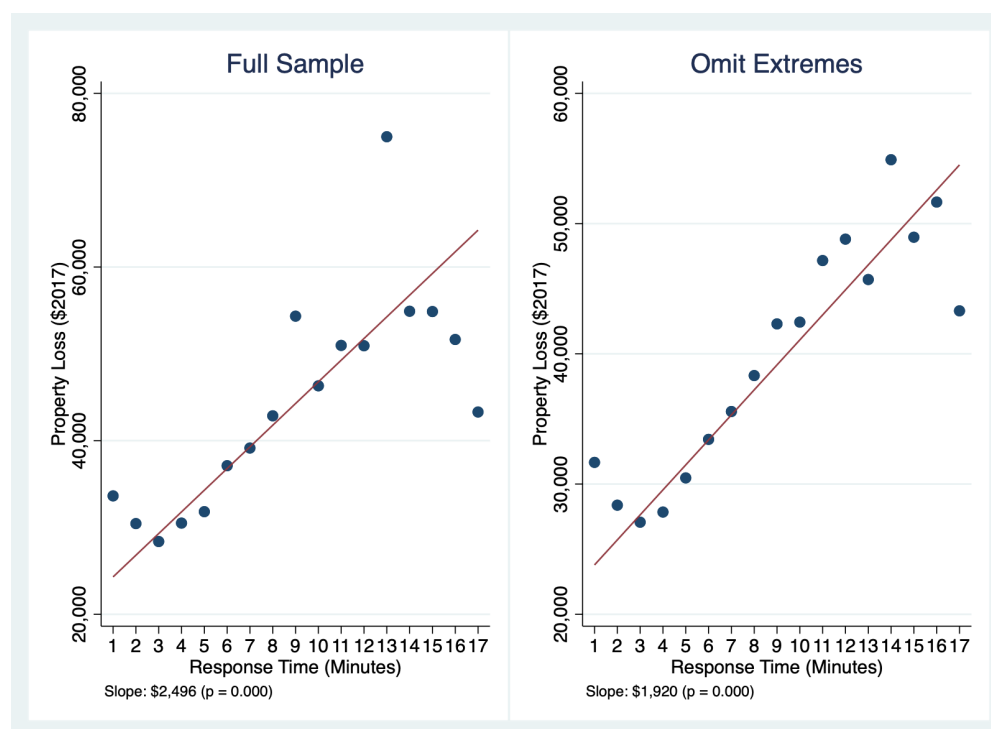
I find a very similar relationship between estimated property loss in the NFIRS data and response times, both for the SAFER analysis sample and across the full universe of fire outcomes. Figures 2.9 and 2.10 show bin scatters of NFIRS property loss data (in 2017 dollars) versus response times for the 1,801 departments in the SAFER analysis sample. The underlying data consists of 5,766,746 total fire incident responses over the period 2004 to 2017; non-zero property losses are reported for 1,679,041 of these incidents. Among the fire responses, 2,406,107 are for structure fires and nearly 40 percent of these incidents have non-zero reported losses. Given that I do not know the ratio of true zeros to reporting omissions, I present estimates both for the full samples and restricting only to incidents with non-zero reported loss.

Figure 2.9 shows the relationship between structure fire losses and response times, in both cases restricting only to incidents with reported loss. The left panel includes all reported incidents and the right panel omits the 82 incidents (0.01% of the sample) with reported loss greater than \$10 million to show how sensitive average losses are to extreme fires. Response times are reported in 1-minute intervals up to 17 minutes, which is the 99th percentile outcome for the sample; more than 95 percent of response times fall under the 9-minute threshold. The data in both panels are fit nicely by a linear regression line, particularly in the 3-to-9 minute range where the vast majority of observations fall. When excluding extreme outliers in the right panel, the fit is even tighter. The estimated coefficients suggest property loss reductions of \$2,496 and \$1,920 (respectively) per minute of reduced response time.³⁰ Excluding just the most extreme 0.01% of fires over the 14-year period reduces the per-minute loss reduction by more than 20%. Moreover, if all reported zeros are instead treated as true zeros, the estimated coefficients for the full sample fall to \$1,248 and \$1,005, respectively.

Figure 2.10 shows the same relationship, but in this case for non-structure fires. Included in this category are vehicle fires, mobile home fires, vegetation fires, outside trash fires, and other fires. The qualitative patterns are very similar. The estimated reduction in property loss per minute of decreased response time is \$675 for the full sample and \$635 excluding the 24 fires causing damage greater than

³⁰Both estimates are highly significant ($p = 0.000$). If fire-department fixed effects are residualized from the bin scatter, based on the possibility that individual fire departments measure response times differently, these estimates fall to \$1,694 and \$1,260, respectively. The data is still fit nicely by a linear trend.

Figure 2.9: Relationship between structure fire property loss and response times



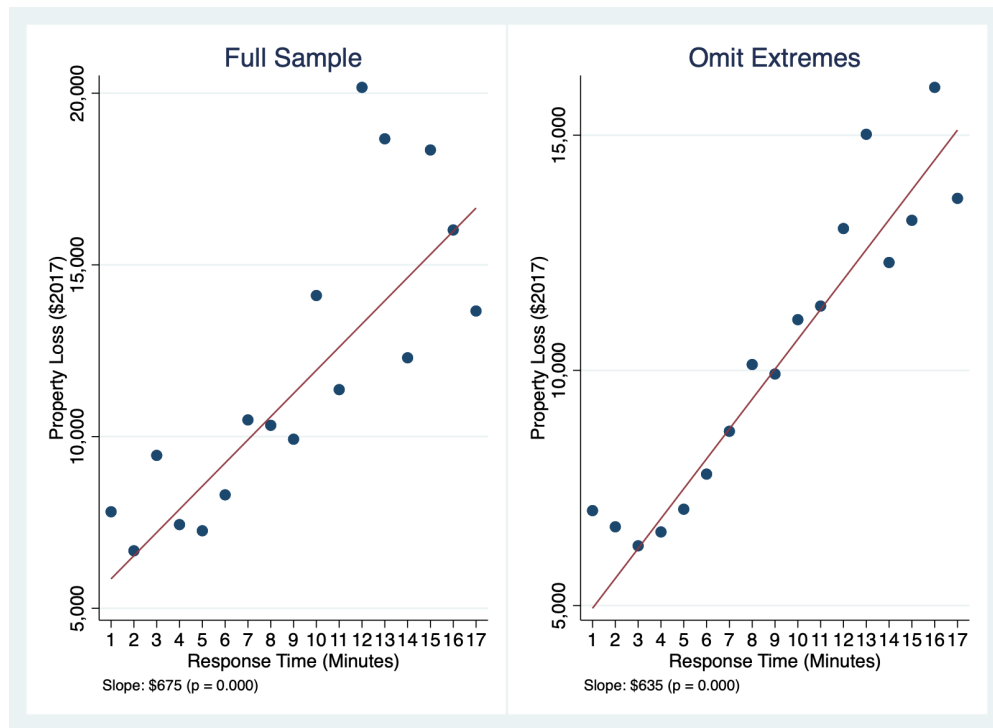
This figure presents bin scatters of reported property losses for structure fire calls relative to response times, based on 2004-2017 NFIRS data for the SAFER analysis sample. Of the 2,406,107 observed structure fire incidents, I restrict both panels of this figure to the 859,681 with non-zero reported property loss. The left panel includes all incidents; the right panel excludes the 82 structure fires with reported loss in excess of \$10 million (0.01% of the sample). The estimated slope coefficients of \$2,496 and \$1,920 are highly significant ($p = 0.000$). *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

\$10 million. When including incidents with zero reported loss in the sample, these estimates fall to \$107 and \$103, respectively. In Appendix Figures B.2 and B.3, I show that very similar results hold when estimating the same regressions across the full universe of fire incidents in the 2004-2017 NFIRS data.

Given the empirical support for a linear relationship between property loss and response time, both within the analysis sample and in external data, I use a linear framework for the baseline estimates. In the Appendix, I show how the results would change if applying an exponential framework.

In the previous section, I found that grant receipt is associated with an average response time improvement of 6.1 to 9.8 seconds, depending on how the insignificant monthly estimates are treated. I use the higher estimate (9.8 seconds) and the lower end of the 95 percent confidence interval (17.7

Figure 2.10: Relationship between non-structure fire property loss and response times



This figure presents bin scatters of reported property losses for non-structure fire calls relative to response times, based on 2004-2017 NFIRS data for the SAFER analysis sample. Of the 3,360,639 observed incidents, I restrict both panels of this figure to the 819,360 with non-zero reported property loss. The left panel includes all incidents; the right panel excludes the 24 fires with reported loss in excess of \$10 million (0.003% of the sample). The estimated slope coefficients of \$675 and \$635 are highly significant ($p = 0.000$). *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

seconds) to generate the subsequent loss estimates. In Table 2.2, I use this response time range, along with the linear slope coefficients estimated above, to provide bounded estimates of average property loss reductions per fire incident attributable to grant receipt. Results are again shown separately for structure fire and non-structure fire responses, as well as for the two extreme approaches for handling reported property losses of \$0. The first column shows estimates for the full sample; the second column omits the extreme fires causing property loss greater than \$10 million.

For structure fires, the estimated range of per-incident property loss reductions attributable to the grant is [\$204, \$737] for the full sample and [\$165, \$567] when omitting the extremes. For non-structure fires, the respective ranges are [\$18, \$200] and [\$17, \$188]. Later in this section, I use these intervals to estimate marginal firefighter impacts on fire responses.

Table 2.2: *Estimated property loss reductions (per incident) attributable to grant receipt*

	Full Sample	Omit Extremes
Structure Fires		
Include 0s	[204, 369]	[165, 297]
Exclude 0s	[408, 737]	[314, 567]
Non-Structure Fires		
Include 0s	[18, 32]	[17, 31]
Exclude 0s	[111, 200]	[104, 188]

This table presents the baseline estimates of property loss reductions attributable to grant receipt. Results are shown separately for structure fires and non-structure fire responses. For each category, results are presented both excluding all reported property losses of \$0 and treating these observations as true zeros. The first column comprises the full sample; the second column omits fires with reported loss greater than \$10 million. The interval for each category is based on the average response time reduction estimate of 9.8 seconds and the lower end of the confidence interval (17.7 seconds). The property loss data is expressed in 2017 dollars. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

2.4.2 Casualty Loss Estimates

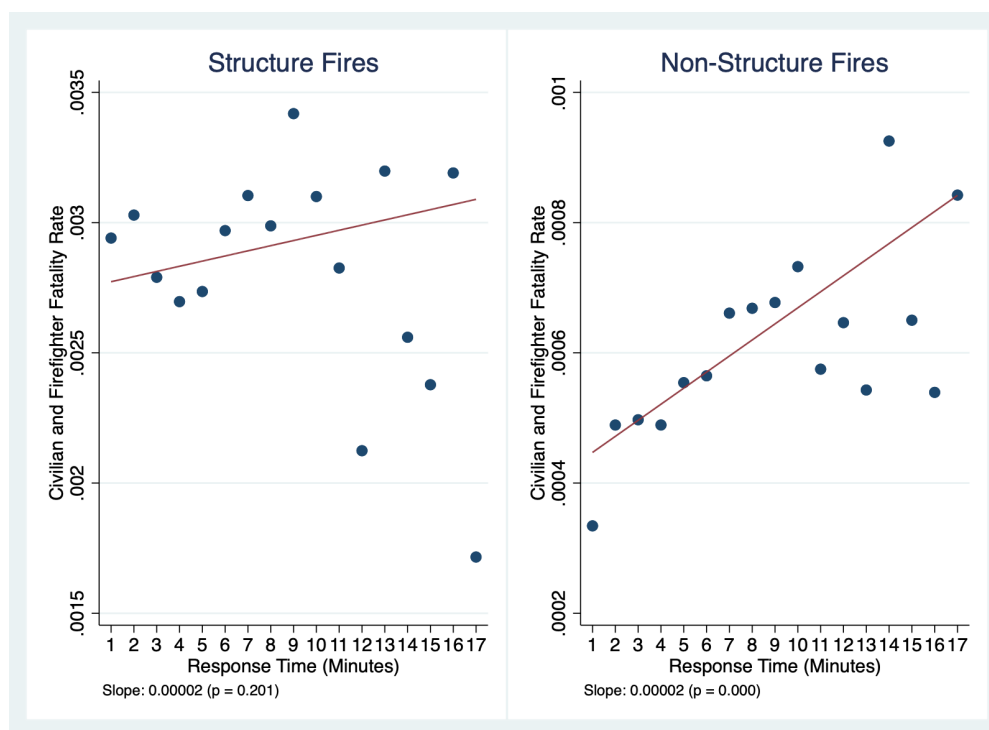
For the 1,801 departments in the analysis sample, there was at least one reported fatality (civilian or firefighter) in 7,068 structure fire incidents and 1,960 non-structure fire incidents between 2004 and 2017. This implies a fatality rate of 0.0028 for structure fires, which is about five times the fatality rate for the other fire types.³¹ Figure 2.11 shows the relationship between the fatality rate and response times on structure fire calls (left panel) and non-structure fire calls (right panel), again using the 2004-2017 NFIRS data for the analysis sample. As discussed in the introduction, the U.K. estimates cited in Fire Brigade Union (2012) suggest an exponential relationship between structure fire deaths and response time, which I do not observe in the NFIRS data. For structure fires, the estimated slope of 0.00002 is insignificant ($p = 0.201$) and the overall relationship between the fatality rate and response time appears weak.³² If the sample is restricted to response times between 4 minutes and 9 minutes, which accounts for 67 percent of observations, the slope coefficient rises to 0.00012 and is highly significant. This implies that a one-minute reduction in response time is associated with

³¹The fatality rate here is calculated as the number of incidents with at least one death divided by the total number of incidents. Thus the baseline fatality rate for structure fires corresponds to 2.8 incidents with at least one reported death for every 1,000 incidents.

³²If fire-department fixed effects are included in the bin scatter, a highly-significant *negative* relationship emerges (coefficient: -0.00007; $p = 0.000$). One possible explanation for this result is that faster response times are prioritized for the most severe fires.

a decrease of 0.12 fatal structure fires per 1,000 occurrences. I use this estimate as an upper-bound input when calculating the economic value of grant-induced saves. For non-structure fire calls, the estimated coefficient is also 0.00002, but in this case is highly significant. The data is fit well by a linear trend, particularly for the majority of response times below 10 minutes, and provides little evidence for increasing returns at higher response time levels.

Figure 2.11: Relationship between fire fatality rate and response times



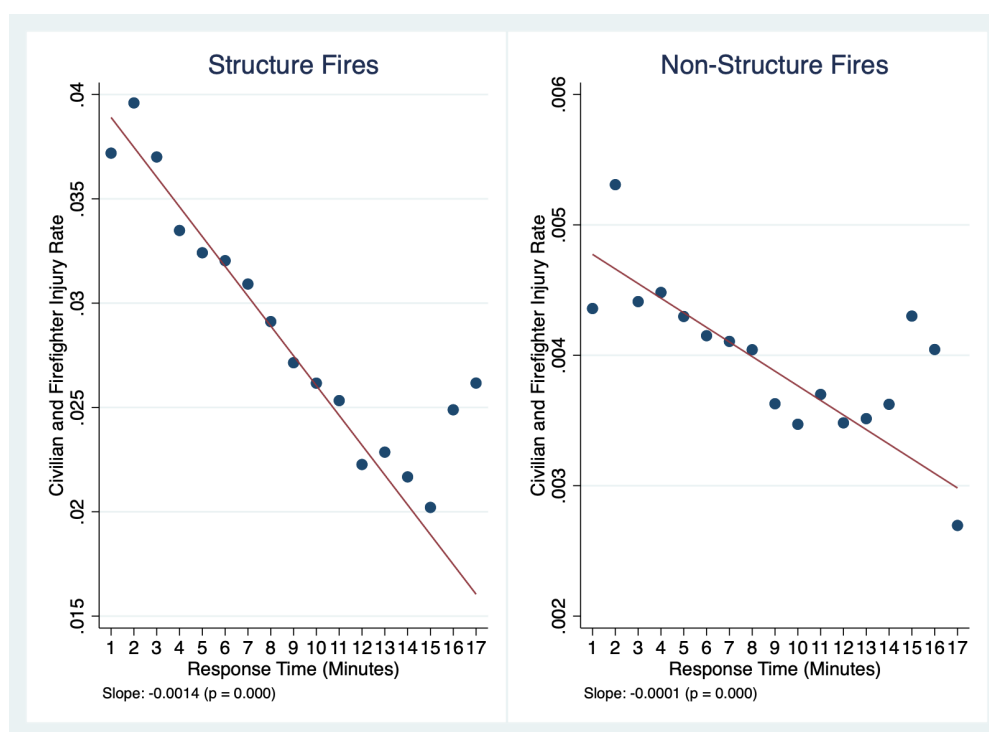
This figure presents bin scatters of the fatality rate on structure fire calls (left panel) and non-structure fire calls (right panel) relative to response times, based on 2004-2017 NFIRS data for the SAFER analysis sample. The respective sample sizes are 2,406,107 and 3,360,639. The fatality rate is defined as the number of incidents with at least one death (civilian or firefighter) divided by the total number of incidents. The baseline mean fatality rate is 0.0028 for structure fires and 0.0006 for non-structure fires. The estimated slope coefficient is 0.00002 in both panels, but is only significant for non-structure fires. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

To attach a dollar value to the lives potentially saved from fire as a result of grant receipt, I assume a value of a statistical life (VSL) of \$10 million, which is consistent with the estimates in Kniesner and Viscusi (2019) and guidance from the U.S. Department of Transportation. If a one-minute reduction in structure fire response times results in 0.00012 saved lives (based on the upper-bound estimate), and the grant results in a response time improvement of 9.8 to 17.7 seconds, then between \$201 and

\$363 worth of life could be saved per structure fire as a result of the grant. For non-structure fires, the respective range is \$41 to \$73 per fire.

Finally, there are 80,617 structure fire incidents and 14,276 non-structure fire incidents in the analysis sample with at least one reported non-fatal injury between 2004 and 2017. The respective injury rates are 0.034 and 0.004. Figure 2.12 shows a significant, *negative* relationship between the injury rate and response times for both fire categories. One possible explanation for this result is that faster responses are prioritized for more severe incidents. I ignore injuries from fire in the final loss estimates.

Figure 2.12: Relationship between fire injury rate and response times



This figure presents bin scatters of the injury rate on structure fire calls (left panel) and non-structure fire calls (right panel) relative to response times, based on 2004-2017 NFIRS data for the SAFER analysis sample. The respective sample sizes are 2,406,107 and 3,360,639. The injury rate is defined as the number of incidents with at least one injury (civilian or firefighter) divided by the total number of incidents. The baseline mean injury rate is 0.034 for structure fires and 0.004 for non-structure fires. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

2.4.3 Total Loss Estimates

Summing the per-incident property loss and casualty loss estimates suggests that grant receipt could reduce direct economic loss on average by \$405 to \$1,100 per structure fire response and by \$59 to \$273 per non-structure fire response. Based on the mean relative employment increase estimated in the first-stage regressions (6), this suggests maximum loss reductions of \$184 and \$46 per marginal firefighter (respectively), if the gains are distributed equally across each new hire.

As a point of reference for these estimates, I found in the previous chapter that a marginal firefighter at an all-career department (on average) would need to provide between \$5,962 and \$8,371 of value per fire response to cover employment costs under an extreme hypothetical where firefighters have no marginal value on non-fire responses. At the other extreme, if firefighter employment costs are distributed equally across all types of incident responses (including fires, EMS, and false alarms), then the average breakeven benefit target is between \$422 and \$822 per incident. Thus the estimated upper bound for direct loss reduction per marginal firefighter on structure fire responses (\$184) is well below the most conservative average breakeven value for all incident types (\$422). Even if the response-time impacts are attenuated due to the one-minute reporting intervals in the NFIRS data, the mean response time estimate (9.8 seconds) would have to be understated by more than 30 seconds for the upper bound on marginal loss reduction per structure fire to exceed the minimum per-incident breakeven target.

Another way of benchmarking these estimates is to compare them to the annualized employment costs implied by grant funding levels. Based on the cost-sharing schedules for each funding cycle, I estimate annual employment costs of \$579.8 million (in 2017 dollars) for the 886 grant recipients in my sample during the first year of grant receipt, or about \$655,000 per department. Between 2004 and 2017, the average grant recipient responded to 264 total fire calls per year, 109 of which were for structure fire responses. Based on the range of per-incident estimates for each fire category, this implies a total annual loss reduction of \$53,290 to \$162,215 per average recipient department, or between 8% and 25% of marginal employment costs.

2.5 Discussion

Based on the cost-benefit framework applied in this paper, it appears that the average department in the SAFER sample is beyond the staffing threshold where marginal employment costs exceed the direct benefits of marginal employment on fire responses. Although the fire incidents considered in this paper account for less than five percent of total call volume nationally, fire events are associated with relatively high levels of economic loss compared to other incident types. Given that the marginal employment benefits estimated for these responses fall well short of the minimum breakeven targets calculated in the previous chapter, this implies increasing targets for the other response types not considered in this paper. The majority of remaining firefighter responses are for EMS events, which I study in the following chapter. But the leftover slack from the fire category must also be absorbed by response types that involve little or no potential for loss, such as false alarms and service calls.

While the estimates in this chapter are useful as a starting point for assessing current staffing levels, there are several ways in which they are limited as a normative staffing tool and I caution strongly against using them for this purpose. First, they are based on average relationships for a large sample of fire departments and cannot speak to the substantial heterogeneity across departments and jurisdictions. Second, they only account for the major forms of direct loss associated with one service provided by firefighters and do not capture general equilibrium effects or individuals' willingness to pay for a marginal decrease in risk (or a decrease in response times, independent of risk).³³ Third, a marginal framework may not be suitable for addressing tail risks. While the existence of mutual aid agreements reduces the need for every department to staff for the worst-case event, a minimum level of staffing beyond what is optimal in a simple cost-benefit framework may still be desirable. Fourth, although I make every effort to minimize bias resulting from omissions and reporting errors in the NFIRS data, the precision of the estimates could still be affected by these issues. Moreover, the response time results could be biased due to the one-minute reporting intervals in the NFIRS data.

Lastly, the estimates in this chapter take the current structure of fire departments as given. However, as discussed in the previous chapter, there is an important policy need to better understand the

³³As previously mentioned, the estimates in this chapter also do not account for non-fire services provided by firefighters.

economics of fire-based EMS, given that EMS responses comprise about 2/3 of total fire department activity and are often handled by multiple providers. For example, if it is found that firefighter turnout could be reduced significantly on EMS calls with a negligible effect on the wellbeing of patients, then baseline response times on fire calls could be faster absent an increase in employment. In the subsequent chapter, I use the framework developed in this chapter to study EMS outcomes.

Chapter 3

Marginal Firefighter Impacts on EMS Responses: Evidence from the SAFER Grant

3.1 Introduction

In the opening chapter, I found that the rapid growth of emergency medical service (EMS) provision by fire departments has likely been a primary driver of firefighter employment growth in recent decades, despite the persistent decline in fire incidence. Between 1987 and 2017, the number of EMS responses by fire departments increased by about 250 percent, from 6.4 million to 22.3 million (National Fire Protection Association, 2019). For the average all-career fire department in the National Fire Incident Reporting System (NFIRS) data, EMS responses accounted for about 60 percent of total call volume in 2017, whereas fire responses made up less than 5 percent. Unlike fire protection, which is provided exclusively by the fire service, there are multiple providers of EMS (e.g., public EMS agencies employing single-role paramedics/EMTs, private ambulance units) and a variety of different delivery systems involving firefighters. This institutional complexity, as well as the methodological challenges associated with identifying the marginal impact of providers on medical outcomes, likely contribute to the scarcity of academic research on fire-based EMS. In this chapter, I abstract from institutional

nuance and focus on the broad relationship between firefighter employment and critical EMS outcomes. Specifically, I use the difference-in-difference (DiD) estimation framework established in the previous chapter to study whether firefighter employment increases brought about by SAFER hiring grants are associated with a reduction in the incidence of “time-sensitive” deaths.

A primary goal of firefighters in any fire-based EMS system is to help “stop the clock” on medical emergencies, such as heart attacks, strokes, sepsis, and acute trauma, which are associated with lower rates of survival as the time without emergency medical treatment rises. For example, Larsen *et al.* (1993) estimate a 5.5 percent reduction in the probability of survival for each minute without CPR, defibrillation, or definitive care for a selected group of out-of-hospital cardiac arrest patients. Saver (2006) finds that the typical victim of an ischemic stroke loses 1.9 million brain cells in every minute the condition is left untreated, hence the expression “time is brain.” Kumar *et al.* (2006) find that the probability of survival for a patient experiencing septic shock declines by about 8 percent per hour without antibiotics. Finally, Byrne *et al.* (2019) finds that faster ambulance response times are associated with lower mortality rates for victims of motor vehicle crashes and McCoy *et al.* (2013) finds similar results for victims of general trauma. As first responders, firefighters seek to stabilize patients suffering from these types of emergencies until they can be brought into definitive hospital care, whether or not they are the party responsible for patient transport. It is therefore critical to account for the impact made by firefighters on these types of responses as part of a continued evaluation of direct marginal firefighter value, particularly to the extent that EMS needs are driving firefighter employment growth.

For each available jurisdiction represented in the SAFER analysis sample, which is defined in Figure 2.1 of the previous chapter, I obtain counts of monthly deaths caused by time-sensitive conditions from the National Center for Health Statistics (NCHS) restricted mortality data. The primary outcome variable I construct pools mortalities resulting from cardiovascular disease, stroke, sepsis, and external causes, including trauma.¹ I am able to further restrict this data based on the place of death, for example to run specifications that exclude hospice deaths, which may be less likely to receive a fire

¹The external deaths category includes those caused by motor vehicle and other transportation accidents, firearms, poison, explosions, and assaults.

department response. Unfortunately, the restricted mortality data is only available at the appropriate government level for 310 of the 1,801 departments in the SAFER analysis sample that have populations greater than 100,000. Despite the resulting sample attrition, I show that grant recipient departments and denied departments in this subgroup are still well balanced on most observable dimensions. I also rerun the first-stage analysis for this reduced sample and confirm that SAFER grant receipt results in a relative employment increase of expected magnitude and timing.

I do not find any evidence that grant receipt, which is associated with a relative mean employment increase of 10.5 firefighters, has any impact on the incidence of time-sensitive deaths in the two years following treatment.² This is the case both for the pooled outcome variable and individual causes of death. Although I do not detect a relationship between marginal staffing increases and time-sensitive deaths, these estimates do not imply that EMS interventions by firefighters do not save lives in general or that employment increases do not provide economic value on EMS responses in other ways. For example, the data does not allow me to study marginal improvements in non-fatal outcomes. Moreover, in the previous chapter I found that grant receipt improved average response times on fire calls by about 10 seconds on average and up to 18 seconds at the lower end of the confidence interval. Unfortunately, EMS incident reporting is restricted to the years 2012-2017 in the NFIRS data, which limits a similar analysis of EMS response times.³ But if there are comparable effects in the EMS domain, these faster response times could also be valued by recipients of firefighter care, independent of medical outcomes. While the results in this chapter are useful for assessing the sensitivity of emergency medical deaths to firefighter employment levels, a welfare analysis that captures citizens' willingness to pay for marginal performance improvements may be a more appropriate tool for thinking about optimal staffing levels.

However, even the most comprehensive analysis of marginal firefighter value on EMS responses would not address the broader policy question of whether there are more efficient ways to provide the same level of services. There are three primary models of fire-based EMS, according to the

²This stated employment increase corresponds to the first-stage result in Section 3.4.1, which is based on data from the Annual Survey of Public Employment and Payroll. The median and mean number of grant-allocated hires is 12 and 20 based on the FEMA grant data.

³In the appendix, I do repeat this analysis for the 277 departments that first applied for a SAFER grant on or after January 1, 2012. For this sample, I do not find any effect on response times.

International Association of Fire Chiefs. Under the first two models, firefighters respond to EMS events in fire engines and provide first response, basic life support (BLS), and/or advanced life support (ALS), often until an ambulance unit arrives to take control of the patient and provide transport to the hospital.⁴ The ambulance will typically be staffed by single-role paramedics and/or EMTs that are not cross-trained as firefighters but are employed under the fire department umbrella (first model) or that work for a third-service public agency or private contracted ambulance company (second model). Under the third model, cross-trained firefighters provide the full scope of EMS services, from first response, to BLS/ALS, to hospital transport. A common practice under this arrangement is to have firefighters rotate between engine units and ambulance units, both of which may still respond to EMS events.⁵ The efficiency considerations discussed in this section have potential implications for all three delivery models, but may be especially relevant for the first two systems that feature provider redundancy.

The marginal labor cost of sending existing firefighters to EMS responses is low, which provides a compelling economic basis for this practice, particularly given the declining frequency of fires. However, once the fire protection needs of a community have been met, there is less of a clear economic rationale for meeting the growing EMS needs of the community with more firefighters and fire engines, rather than more paramedics/EMTs and ambulances. According to the Bureau of Labor Statistics (BLS), there were 265,200 paid EMTs and paramedics in 2019, which is less than 80 percent of the national supply of career firefighters, despite the fact that EMS incidents are more than 20 times as prevalent as fire incidents and the median base salary for a paramedic/EMT is less than 70 percent of the median firefighter salary. Moreover, a typical fire engine costs more than \$500,000 and has an average shelf life of about 80,000 miles, whereas a fully-equipped ambulance costs about \$70,000 (Rowe, 2009).⁶ In New York City, the estimated average cost of a fire engine response to a

⁴BLS involves the basic first steps in stabilizing a patient, whereas ALS involves more advanced resuscitation and management procedures. Only professionals trained in ALS are able to administer emergency drugs and invasive treatments.

⁵While I was unable to locate national statistics on the prevalence of each delivery system, the Cleveland Association of Rescue Employees provided classifications for the 66 most populous cities. Among these cities, 60 percent used one of the first two models and 40 percent used the all-service model.

⁶Both of these cost figures are based on 2009 estimates for the city of San Diego. More recent reports show considerable inflation for state-of-the-art models of both apparatus types, but a sustained cost discrepancy.

medical incident was \$1,970 in 2017, versus \$486 (\$335 after reimbursements) for a paramedic-staffed ambulance run (Citizens Budget Commission, 2018).⁷

A common explanation for the prevalence of fire engine responses to EMS events is that these units are often the closest available resource, based on the strategic positioning of fire stations for rapid response (Institute of Medicine, 2007; Eng, 2017; Pratt *et al.*, 2007). Caserta (2020) also defends the frequent dispatch of fire engines to EMS events as a time-saving decision, given that firefighters already in route would otherwise have to make an additional stop at the fire station to switch to an ambulance. While these explanations may be practical based on the current organizational structure, they beg the question of why there is a relative lack of ambulance units compared to fire engine units, given the drastic, long-term shift in the distribution of emergency calls. Based on the NFPA Needs Assessment Survey, the ratio of fire engines to ambulances at fire departments is nearly 2.5 to 1 (National Fire Protection Association, 2016). This is consistent with the status quo in many large cities, such as Chicago, which operates about 158 fire trucks or engines and 85 ambulances, although EMS responses account for nearly 3/4 of total call volume and fire responses less than 4 percent (Eng, 2017). As a result, ambulances are highly strained, which can result in patients with intensive needs receiving first response from firefighters, but still having to wait for transport to the hospital. In Chicago, these bottlenecks resulted in 97 percent of paramedics collecting overtime pay in 2016, totalling about \$15 million.

Moreover, the high volume of EMS responses can be draining for firefighters, resulting in high occupational stress, low morale, and desensitization to community needs (Cannuscio *et al.*, 2016). Institute of Medicine (2007) describes a cultural divide between firefighters, who are mostly motivated by fighting fires and providing rescues, and single-role EMS personnel, who are focused exclusively on providing medical care, that often makes it difficult for these groups to work well together. This difference in orientations may also contribute to a disparity in resources directed to EMS when budgetary decisions are under the purview of the fire department.

There is also a perception among many firefighters that low-acuity EMS calls crowd out true emergency responses and hinder the continued development of their firefighting skills. Among the

⁷ Ambulance runs in many cities are subject to user fees, whereas fire engine runs are typically not.

more than 80 million recorded EMS responses between 2017 and 2021 in the National Emergency Medical Services Information System (NEMSIS), about 73 percent of patients are classified as “low” initial acuity, 22 percent as “emergent”, and only 4 percent in “critical” condition.⁸ If restricting just to the EMS responses attended by fire departments, the low-acuity share is still about 66 percent. Nonetheless, there is an expectation in communities that even non-emergent needs will be addressed promptly, which adds to the strain on 9-1-1 systems and likely results in firefighters being frequently dispatched, often as the path of least resistance.⁹ As highlighted in the opening chapter, some cities have made efforts to streamline their dispatch and response systems to better match the appropriate level of resources to patient needs and reduce unnecessary burdens on the hospital system.¹⁰ However, the national trends discussed in this chapter and the seemingly disparate allocation of resources at many fire departments suggests there is a broader need to reassess and more effectively coordinate EMS delivery systems. For example, Craig *et al.* (2010) analyze 16 months of EMS response data for the city of Toronto, which like many U.S. cities deploys both firefighter units and single-role ambulance units to EMS incidents. The authors estimate that the number of fire engine responses could be reduced by nearly 85 percent without adding unacceptable risk, just by restricting responses based on a subset of existing inputs in the dispatch system. Similarly, New York City firefighters only reported providing a specific form of care on about 2 percent of attended EMS calls in 2017 and a defibrillator was used in only 72 instances (0.04 percent of calls) (Citizens Budget Commission, 2018). The latter statistics may understate some of the practical benefits provided by firefighters. For example, as discussed on the Consumnes Fire Department’s website, having additional personnel on scene to assist a two-person ambulance crew can increase the speed and safety with which patients are transported to a gurney and improve traffic control. However, the policy need remains in many jurisdictions to understand whether there are more efficient ways to deliver the same level of care.

⁸The remaining 0.7 percent of patients were reported as being dead without resuscitation efforts.

⁹Cannuscio *et al.* (2016) finds that many of the low-acuity EMS responses are for low-income and elderly populations with few alternative sources of support, much like the emergency system at hospitals.

¹⁰For example, the city of Houston has implemented a system called ETHAN that connects emergency care patients to local physicians by video, while first responders tend to immediate needs (JEMS, 2015). The physician then makes an assessment about the appropriate mode of transport (e.g. taxi or ambulance) and hospital setting (e.g. emergency department or primary care).

If current levels of firefighting manpower and apparatus are required to safely provide the desired level of fire protection, then the potential inefficiencies resulting from the reliance on firefighters for EMS provision will be more limited. However, the findings in the first chapter of this thesis suggest that growing EMS needs have been a primary driver of firefighter employment growth, while there is little evidence to support fire-based factors. As a starting point for thinking about the optimal level of fire protection in an area, I pose as a threshold the number of fire vehicle units needed to resolve most fire incidents at a performance level consistent with local risk preferences, and to safely address maximum fire risks after incorporating mutual aid coverage.¹¹ By strategically implementing mutual aid agreements with surrounding departments, which is a widespread feature of modern firefighting, each individual fire department can avoid staffing for the worst conceivable fire risk. From this baseline, firefighters could continue to provide support on EMS responses, but would ideally be triaged to high-acuity patients. The remaining EMS needs in the community would be met by a fleet of paramedic- and EMT-staffed ambulance units, which could be staffed and positioned strategically to achieve desired response time targets.¹² For fire departments that employ an all-service EMS response model, firefighters could continue to provide the full range of EMS services, but the allocation of fire department resources would be optimized to reflect the relative incidence of fire and EMS events.

As an illustrative example of this concept, again consider Chicago. For more perspective on how resource allocation (158 fire apparatus and 85 ambulances) relates to daily needs in this case, I pool the 2012-2017 NFIRS data for the Chicago Fire Department and generate a distribution of daily call volumes over this six-year period. I find that the department responds to an average of about 32 fire calls per day, 8 of which are associated with any reported property loss or casualty loss (including injuries). The respective volumes rise to 73/18 at the 99th percentile and 308/50 on the worst recorded day. On average, four fire apparatus are sent to each fire incident, rising to 18 at the 99th percentile and 96 for the most severe fire. Thus if the fire department prioritized its fire suppression vehicles for fire calls, then on 99 percent of days, it could immediately send at least two different fire apparatus

¹¹Firefighters also uniquely provide other types of emergency services, such as hazardous condition responses and emergency rescues, which should also be factored into this threshold.

¹²This proposal is built on the assumption that firefighters and paramedics/EMTs are perfectly substitutable in terms of their proficiency at providing EMS.

to every fire incident, even if all events occurred simultaneously.¹³ Given that only one-fourth of these responses result in any reported loss, the fire department could alternatively send five different engine units to each event with loss and still send at least one unit to the other events, again even if all calls perfectly overlapped.¹⁴ On the other hand, the fire department responds to 573 EMS calls on an *average* day, sending one fire engine unit and one ambulance unit to each event.¹⁵ This implies about seven daily EMS runs per ambulance and four per fire vehicle. The proposed policy framework for assessing this level of fire protection would consider the dollar-weighted welfare effects (e.g., Hendren and Sprung-Keyser (2020)) of replacing marginal fire engine units with ambulance units in a revenue-neutral way, whether these ambulances are staffed with cross-trained firefighters or single-role paramedics/EMTs.¹⁶

The rest of this paper proceeds as follows. In Section 3.2, I provide a brief history of EMS in the United States and the origins of fire department provision. In Section 3.3, I describe the mortality data used in the analysis and explain how the methodology from the previous chapter is adapted to study EMS outcomes. In Section 3.4, I present the results demonstrating the impact of grant-induced firefighter employment increases on the incidence of time-sensitive deaths. In Section 3.5, I provide a concluding discussion for the three chapters of this dissertation.

3.2 A Brief History of EMS in the United States

The origins of emergency medical care in the US can be traced back to the Civil War, when Jonathan Letterman, a Union military surgeon, created an organized system for treating and transporting injured soldiers (Institute of Medicine, 2007). This model then inspired the first hospital-based ambulance service in Cincinnati in 1865 and the first city-wide EMS program in New York in 1869. Further advances were made in World Wars I and II for dealing with victims of acute trauma, but there was little

¹³This hypothetical does not consider the possible implications for response times.

¹⁴This assumes (unrealistically) that a dispatcher could perfectly anticipate the loss potential of each event.

¹⁵The respective 99th percentile and maximum daily EMS call volumes are 746 and 889.

¹⁶Based on the data cited earlier, a new fire engine could conservatively afford at least five new ambulances, and marginal employment costs would also be weakly lower, depending on the staffing choice. The welfare calculations would account for remaining tail risks after incorporating the coverage offered via mutual aid agreements.

knowledge transfer to the civilian setting until years later. Until the 1960s, most pre-hospital medicine was the modern equivalent of basic first aid (Institute of Medicine, 1993). As of this time, some fire departments, police departments, and municipal hospitals in large cities had begun responding to EMS events, but about half of nationwide ambulance runs were provided by morticians in hearses, particularly in smaller communities (National Academy of Sciences and National Research Council, 1966).

The major catalyst often credited for paving the way for the modern EMS system in the US was the 1966 white paper from the National Academy of Sciences and National Research Council (NAS/NRC) called "Accidental Death and Disability: The Neglected Disease of Modern Society" (JEMS, 2016). This paper highlighted the fact that injuries had become the leading cause of death for individuals age 1-37 and brought attention to the glaring inadequacies of ambulances, personnel training, and public awareness of basic first aid.¹⁷ A total of 29 recommendations were made in the report, nearly half of which pertained to the provision of pre-hospital care, and were influential in laying the groundwork for the development of modern trauma response systems. Later that year, the Highway Safety Act of 1966 was passed, marking the beginning of a federal push to institutionalize EMS that endured through much of the 1970s. The Act established the National Highway Traffic Safety Administration (NHTSA) as a branch of the Department of Transportation (DOT), which quickly developed the first national standards for EMS education, as well as model EMS legislation for states. The NHTSA was given authority to fund advancements in EMS and the DOT began providing grant funding to states that was earmarked towards improving EMS delivery.

NAS/NRC issued another report in 1972 that called for a more integrated approach across federal agencies to keep pace with unmet EMS needs and guide efforts towards establishing EMS authority at the regional level.¹⁸ Shortly after, Congress passed the EMS Systems Act of 1973, which established a system of categorical grant funding that was highly influential for the development of regional EMS systems across the country. By the mid 1970s, about 300 EMS regions had been established across the

¹⁷The paper also famously posed that Americans had a higher likelihood of dying on a U.S. highway than did injured soldiers on the battlefield during the Korean War.

¹⁸This report was entitled "Roles and Resources of Federal Agencies in Support of Comprehensive Emergency Medical Services."

US, each typically covering several counties. The federal efforts attempted to standardize essential features of pre-hospital care and guide best practices, while also giving regional agencies authority to adapt to local needs. Despite the federal attempt at coordination, regional EMS systems quickly evolved into a variety of different arrangements with varying scopes, structures, and practices (Institute of Medicine, 2007).

This shift from a more unified model of EMS provision to a more scattered system was accelerated by the Omnibus Budget Reconciliation Act of 1981, which replaced the categorical EMS funding established in 1973 with block grants to states for preventative health services (Shah, 2006). This transfer of authority to states resulted in an effective decline in total EMS funding, as most chose to redirect grant funds to health needs other than EMS (Institute of Medicine, 2007). While all states maintained a lead EMS agency at the state level, some stayed actively involved with coordinating EMS provision across regions and localities, whereas others shifted most authority over EMS to smaller branches of government. In many states, the regional EMS systems fractured and a variety of different arrangements emerged at the local level.

While the enormous amount of heterogeneity across the US makes it difficult to pinpoint an exact time when the majority of career fire departments began providing a semblance of modern EMS, this movement undoubtedly accelerated in the late 1970s to early 1980s. As mentioned previously, fire department roots in EMS trace back decades before, but the first firefighter-paramedic models were developed in the late 1960s and early 1970s (Institute of Medicine, 2007). A handful of large, urban fire departments, such as the Seattle Fire Department, were instrumental in the initial roll-out of paramedic services following the advancements in CPR and defibrillation in the 1960s. Firefighters were viewed as a natural personnel choice to pilot these programs, given their experience dealing with other emergencies and the strategic orientation of fire stations for rapid response. As of 1972, there were only three paramedic programs operating in the US; by 1977, there was at least one program operating in every state (Forster, 2014).

Thus there is a historical sense in which the fire service was foundational in the modern provision of EMS. Yet, the widespread adoption of fire-based EMS models also coincided with the withdrawal of federal oversight and coordination in the late 1970s and 1980s, which resulted in more fragmented,

locally-driven delivery models. As discussed in Institute of Medicine (2007), even recently “...there is little or no scientific evidence to support many widely employed EMS clinical procedures and system design features.” Moreover, “...evidence on the value of delivery models, such as tiered levels of response, intensity of on-line medical direction, type of EMS system (e.g., fire-based, volunteer), and deployment of paramedics, is either nonexistent or inconclusive.”¹⁹ Regardless of how fire-based EMS became the status quo in most U.S. cities, there remains an enormous research gap when it comes to understanding the economic tradeoffs associated with these delivery systems.

3.3 Estimating Marginal Firefighter Impacts on EMS Calls

The remainder of this chapter continues the evaluation of marginal firefighter value by extending the analysis to EMS outcomes. Importantly, the estimates in this chapter take the current structure of fire-based EMS delivery systems as given and do not speak to the relative efficiency of these arrangements. I again apply the DiD framework established in the previous chapter, which makes use of the employment variation brought about by the SAFER hiring grants, to study changes in the incidence of time-sensitive deaths. A summary of the SAFER grant structure and provisions can be found in Section 2.2.1 of the previous chapter. In this section, I first describe the additional NCHS mortality data procured for this analysis. I then discuss necessary changes to the analysis sample to conform with the granularity of the mortality data. Finally, I quickly review the methodology.

3.3.1 Data

In the previous chapter, I matched the administrative SAFER grant data from FEMA, which spans the fiscal years 2005 to 2015, to NFIRS incident data on fire responses for the period 2004 to 2017. For the baseline specifications, I used response time as the outcome variable and applied these estimates to indirectly estimate measures of direct fire loss reduction. Unfortunately, EMS incident data is only

¹⁹Moreover, there are coordination problems between firefighters and other EMS providers in many jurisdictions, a lack of national requirements to ensure uniform training of personnel, and funding challenges facing many EMS agencies.

available as early as 2012, which restricts the scope of any medical analysis using the NFIRS data.²⁰ However, in this chapter I am able to study one set of critical EMS outcomes directly: the incidence of time-sensitive deaths.

To construct the outcome variables, I make use of the NCHS restricted, all-counties mortality data for the years 2004 to 2018.²¹ Each observation in this data represents a death reported to the NCHS by one of 57 vital statistics jurisdictions across the country. A detailed cause of death is listed for each record, as well as basic demographics, the month and place of death, and some geographic identifiers, which I discuss below. As previewed in the introduction, I define “time-sensitive” deaths as those resulting from cardiovascular disease, stroke, sepsis, or external causes, including acute trauma.²² While there are likely other causes of death that could be mitigated by faster treatment, these are the major conditions commonly referenced in EMS materials (JEMS, 2016). Moreover, some of the deaths classified as “time-sensitive” may not have been subject to an emergency response by firefighters. There is no way to directly control for this, but I run alternate specifications that restrict the sample to places of death that are more likely to have received a fire department response (e.g., emergency room deaths, deaths on arrival to the hospital).

One limitation of the mortality data is that geographic identifiers are only available for counties or for cities with more than 100,000 residents. Given that most fire departments in the sample are affiliated with a city or municipality, this restricts the group for which I can obtain a direct match in the mortality data. Moreover, while the deceased’s state and county of residence and state and county of death are reported for each record, only the city of residence is available for the restricted sample of large cities. Therefore, I further restrict the large-city sample to deaths in which the state and county of residence matches the state and county of death.

²⁰The publicly-obtained NFIRS data including EMS events is limited to 2014 at the earliest. I obtained the 2012-2013 EMS-inclusive NFIRS data through a data-sharing agreement with FireCARES. Credit line: *FireCARES: Community Assessment/Response Evaluation System: The content reproduced from the FireCARES Database remains the property of FireCARES and contributing fire departments. The FireCARES team and partners are not responsible for any claims arising from works based on the original Data, Text, Tables, or Figures.*

²¹National Center for Health Statistics (2020).

²²Included in the “external cause” category are transportation accidents, firearm accidents, assaults, drownings, poisonings, and other less common factors.

3.3.2 Sample

I start with the SAFER analysis sample defined in Figure 2.1 of the previous chapter. This sample consists of 1,801 all-career and mostly-career fire departments that serve a population of at least 10,000 and applied for a SAFER hiring grant between FY 2005 and 2015. Among these departments, 915 received at least one grant (treated group) and 886 applied but were never treated.

From this sample, I construct a sub-sample consisting of the 310 departments with a direct match in the 2004-2018 NCHS mortality data. Among this group are 97 county-level departments and 213 (non-overlapping) city-level departments that represent populations of at least 100,000. Within this sub-sample are 185 grant recipients and 125 denied applicants. I again collapse the data to the monthly level. Sample statistics for these departments in the year prior to first application are reported in Table 3.1.²³ Although the initial sample balance induced by the grant is obstructed due to limitations in the NCHS data, the grant recipients and denied departments for this sub-sample still look very similar on most dimensions. While treated departments are more likely to be all-career and have a slightly different regional composition, there is no statistical difference between grant recipients and denied departments in terms of population, firefighter staffing, population-weighted EMS volume, or time-sensitive deaths. For this group of large departments, the median (12) and mean (20) number of grant-induced hires are both about twice the size of the respective hiring increases for the full analysis sample in Chapter 2. As is the case with the full sample, grant recipients request substantially more funding on average than denied departments.

In Appendix Figure C.2, I also repeat the response time analysis from the previous chapter, but in this case applied to EMS responses in the NFIRS data. As mentioned previously, the EMS data is only available beginning in 2012, so I restrict this sample to the 277 departments that first applied for a SAFER hiring grant on or after January 1, 2012.

²³Due to data limitations, the EMS density variable, which represents the number of annual EMS responses per 1,000 citizens, is based on 2017 data. The mean and median number of hires correspond to the period of first grant receipt.

Table 3.1: *Regression sample balance for EMS outcome analysis*

	Grant Recipients (Treated)	Denied Departments
Number of Departments	185	125
Department Type*		
Career	82%	67%
Mostly Career	18%	33%
Region*		
MW	19%	9%
NE	9%	5%
S	44%	51%
W	28%	35%
Population	331,517	349,453
Number of Firefighters	401	411
Monthly Time-Sensitive Deaths	89.6	89.0
EMS Density	70.8	66.6
SAFER		
Amount Requested*	\$4,245,544	\$2,839,271
Mean Hires	20	N/A
Median Hires	12	N/A

This table presents average sample characteristics for the fire departments used in the primary DiD analysis in the year prior to first application. The “EMS Density” variable corresponds to the number of 2017 EMS responses per 1,000 citizens. For variables marked with an asterisk, a two-sided t-test for equality of means between recipient and denied departments is rejected at 5%. *Source:* Author’s calculations from FEMA grant data, the USFA Fire Department Registry, the National Fire Incident Reporting System, and the NCHS Restricted All-Counties Mortality Data.

3.3.3 Methodology

I again estimate the following dynamic DiD specification, where treatment is an absorbing, binary indicator of grant receipt:

$$Y_{dt} = \gamma_d + \delta_t + \sum_{j=-18}^{30} \beta_j D_{dt+j} + \rho X_{dt} + \varepsilon_{dt} \quad (3.1)$$

Here t indexes the analysis month, Y_{dt} is the outcome variable for department d (time-sensitive deaths in the baseline specification), δ_t is a period fixed effect, D_{dt+j} is a binary treatment indicator for department d equaling 1 when first grant receipt is j periods away, X_{dt} allows for time-varying mortality characteristics, and ε_{dt} is an error term.

I again focus on the 18-month interval preceding treatment through the 30th month following grant receipt. Recipient departments have up to six months to add the designated hires, so I consider the seventh month following grant receipt as the first official treatment period. Standard errors in all specifications are clustered at the fire department level. The (unbalanced) estimation sample consists of 52,065 monthly observations for 310 departments over the period 2004 to 2018.

3.4 Results

In this section, I first reproduce the first-stage results for the restricted sample used in this analysis. I then provide the primary DiD results for time-sensitive deaths, as well as several alternative specifications.

3.4.1 First Stage

Given the restrictions imposed on the analysis sample by the mortality data constraints, I first rerun the first-stage regression from the previous chapter to confirm there is a relative hiring increase for this smaller group of fire departments. I again match each department in the sample to its respective government in the Annual Survey of Public Employment and Payroll (ASPEP) data to obtain employment data for the period 2002-2017. For each $j \in [-3, 3]$, I then run the following regression:

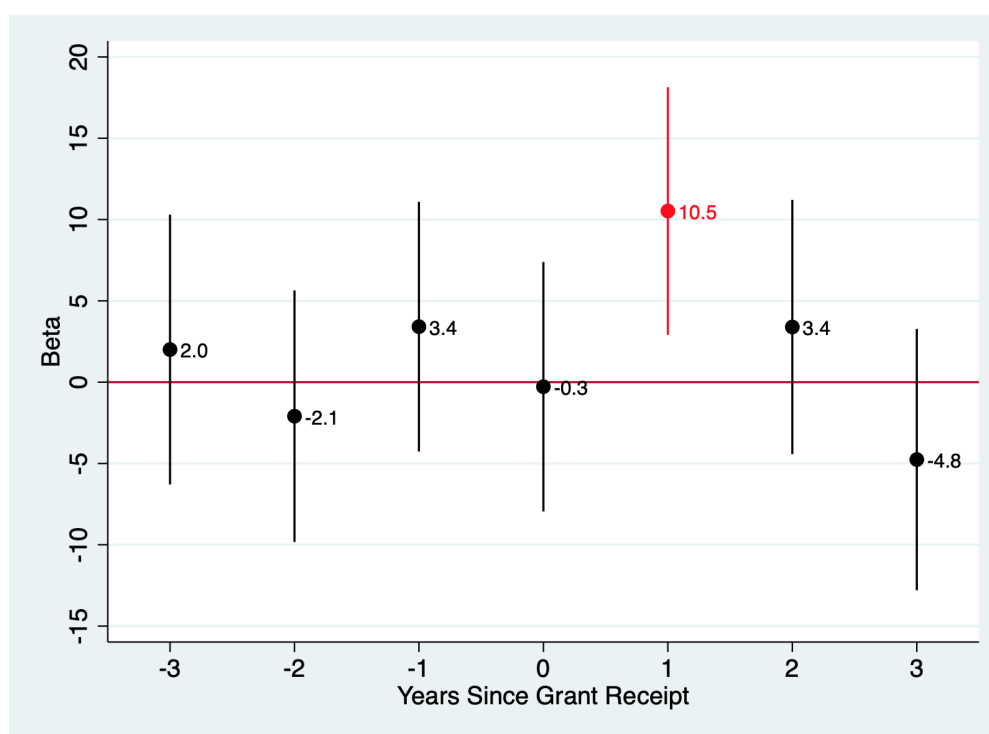
$$\Delta FF_{dt} = \alpha + \beta_j D_{dt+j} + \delta_t + \varepsilon_{dt} \quad (3.2)$$

Here ΔFF_{dt} is the change in the number of firefighters at department d in year t , D_{dt+j} again indicates treatment occurrence in j periods, and δ_t is a period fixed effect. For this regression, j is measured in years to comply with the minimum reporting interval in the ASPEP data. The first-stage sample consists of the 305 (out of 310) departments (182 recipients and 123 denied departments) with reported ASPEP employment data in annual periods between the five-year census intervals.

Figure 3.1 plots the individual beta estimates. The qualitative pattern is very similar to the first-stage result obtained in the previous chapter. In the first year following treatment, there is a significant

jump in mean relative employment at recipient departments of 10.5 firefighters, or 18.1 at the upper end of the confidence interval. Again, this range tracks closely to the median (12) and mean (20) number of hires suggested by the FEMA grant data. In the years preceding and following treatment, there are no significant differences in employment changes between treated and denied departments. Despite the sample attrition, Figure 3.1 shows that even for this restricted group, the relative employment patterns are consistent in timing and magnitude with an effective first stage.²⁴

Figure 3.1: *First-stage regression results*



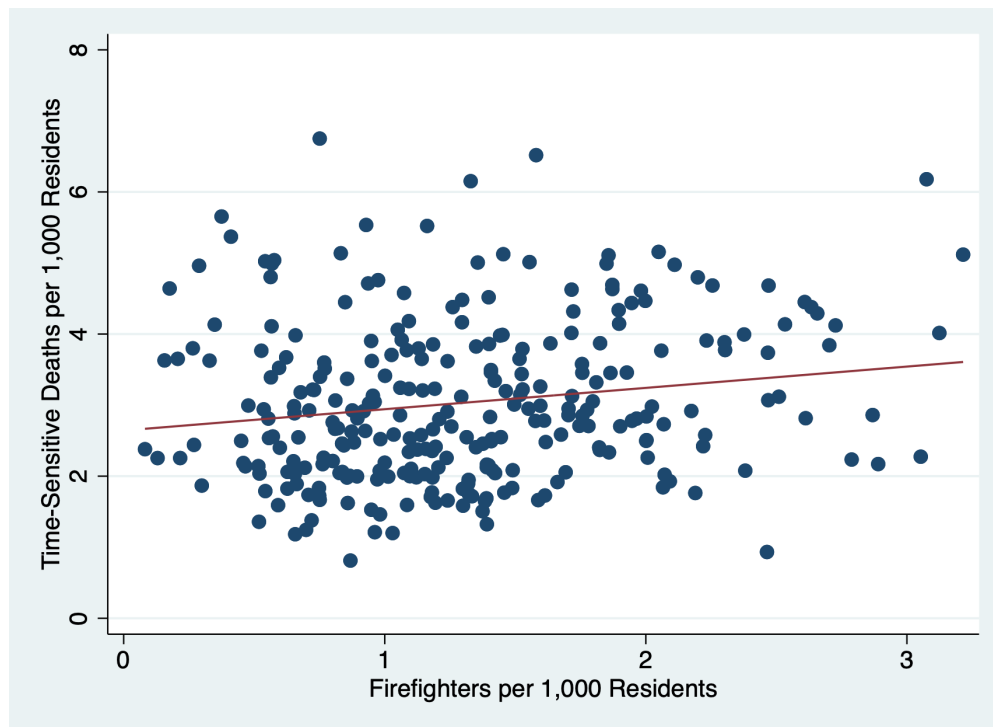
This figure plots the individual beta estimates from equation (3.2) for the years preceding and following treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. The regression sample consists of the 305 fire departments among the 310 in the restricted analysis sample with annually-reported ASPEP employment data between 2002 and 2017. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the Annual Survey of Public Employment and Payroll.

²⁴However, as discussed in the following sub-section, I cannot rule out grant-induced employment changes among substitute EMS providers.

3.4.2 Time-Sensitive Death Results

In Figure 3.2, I show the cross-sectional relationship between firefighters per 1,000 residents and time-sensitive deaths per 1,000 residents for the analysis sample in 2017. Overall, there is a weak, positive relationship between these variables. If there is a causal relationship between employment levels and mortality, the direction of causality could go either way. For example, if a larger firefighter presence reduces time-sensitive emergency deaths, we would expect a negative relationship. However, areas with higher mortality rates are likely staffed with more emergency responders, supporting a positive relationship.

Figure 3.2: *Relationship between firefighter density and time-sensitive deaths (2017)*

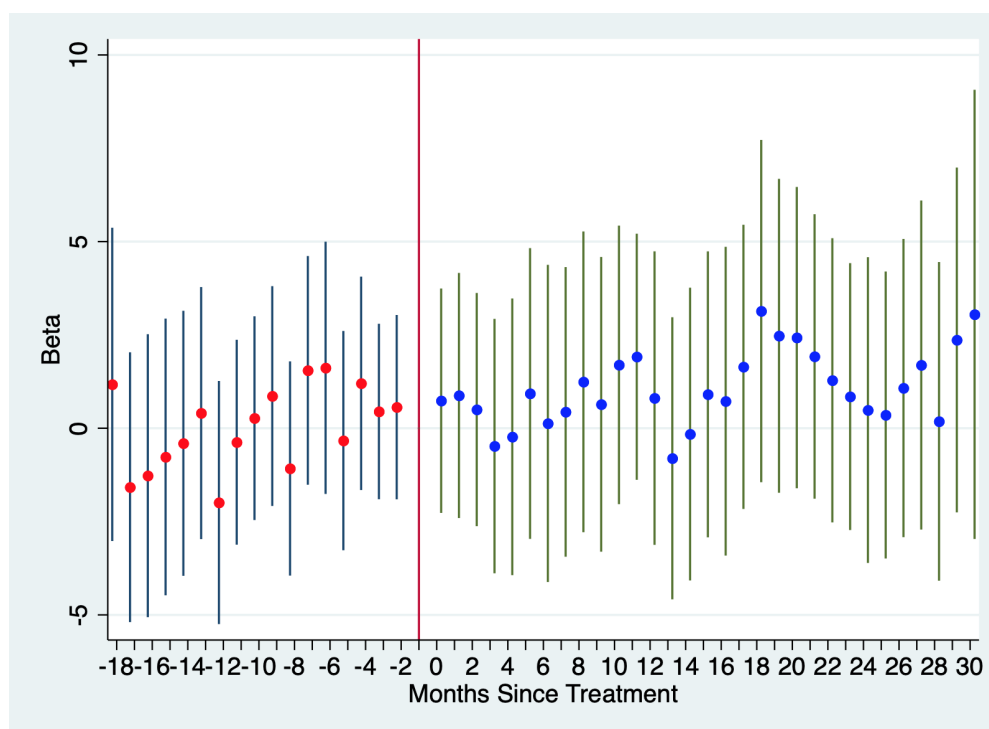


This figure plots the cross-sectional relationship between firefighter density (i.e., firefighters per 1,000 citizens) and the density of time-sensitive deaths for the analysis sample in 2017. Time-sensitive deaths are defined as those caused by cardiovascular disease, strokes, sepsis, or external injuries. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, the Annual Survey of Public Employment and Payroll, and the NCHS Restricted All-Counties Mortality Data.

In Figure 3.3, I present the baseline results from estimating equation (3.1) on the incidence of time-sensitive deaths. The baseline mean for this variable in the year leading up to first treatment is 87.6 deaths per month. The markers plot the point estimates for the given pre- and post-treatment

periods, all expressed relative to the period prior to treatment. The bars represent 95 percent confidence intervals. As shown in Figure 3.3, all of the estimated coefficients, both before and after treatment, are close to zero and highly insignificant.

Figure 3.3: *Baseline time-sensitive death estimates*



This figure plots the estimated betas from equation (3.1) in the 18 months preceding treatment and the 30 months following treatment for the primary outcome variable: time-sensitive deaths. The baseline mean for this variable is 87.6 deaths per month in the year prior to first treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 52,065 monthly observations for the 310 fire departments in the restricted analysis sample. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the NCHS Restricted All-Counties Mortality Data.

In Appendix Figure C.1, I repeat this analysis, but restricting deaths to those that occur at the decedent's home, in an outpatient or emergency room hospital setting, or upon arrival to a hospital. These events may be more likely associated with an emergency fire department response than for example hospice, nursing home, or inpatient hospital deaths. The qualitative results are similar, although there is a significant, *positive* point estimate 20 months into the treatment period, which is likely spurious.

Figure 3.4 presents these estimates separately for deaths caused by cardiovascular disease (top

panel) and strokes (bottom panel). Cardiovascular disease is the most prevalent cause of death among the conditions considered, with a baseline monthly mean of 54.7 in the year leading up to first treatment. Among the other included deaths due to internal factors, strokes are the next most important cause (11.6 per month). As shown in Figure 3.4, there are again no significant differences for either variable prior to treatment or in the 30 months following grant receipt.²⁵ Figure 3.5 repeats the analysis of Figure 3.4, but for deaths caused by sepsis and external factors. Sepsis is the rarest condition considered, with a baseline mean of only 3.2 deaths per month. Externally-caused deaths are more frequent (18.1 per month), but relatively volatile. Unlike the other causes considered, multiple externally-caused deaths may also result from a single incident, such as a car accident. Again, I find no evidence of a decline in either cause of death. For both outcomes, there are actually 2 to 3 post-treatment periods with significant, positive estimates that I again view as likely being spurious.

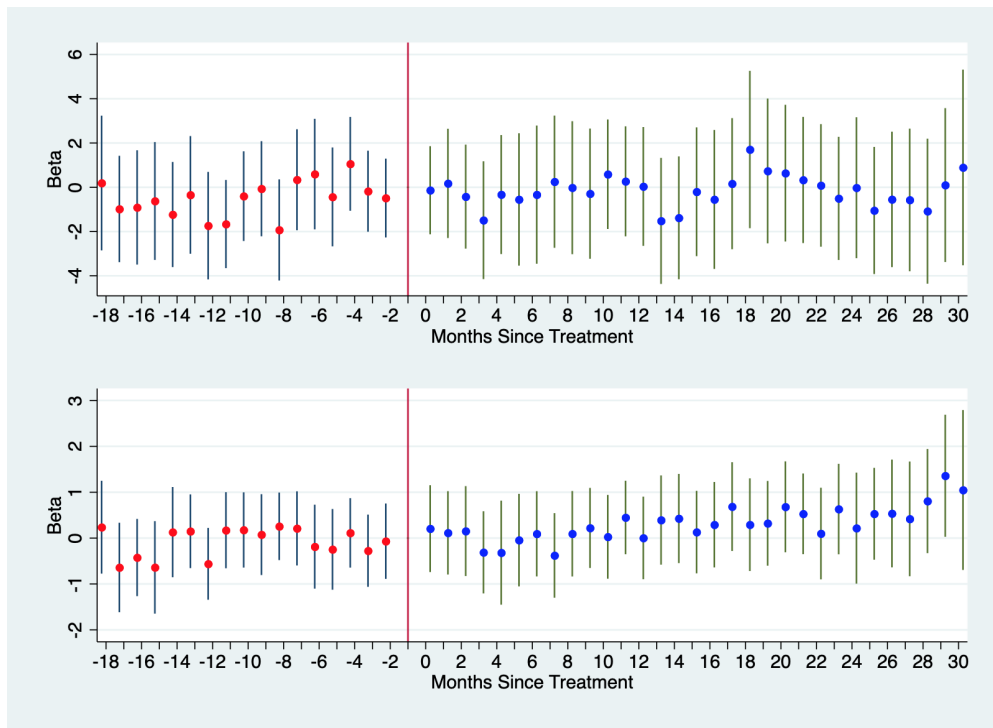
In summary, I find no direct evidence that the grant-induced increase in firefighter employment caused a reduction in the incidence of deaths associated with time-sensitive conditions. However, one limitation of these estimates is that despite finding a strong first stage for firefighter employment, I am unable to observe potential employment substitution among alternate providers of EMS, such as single-role paramedics and EMTs. I cannot rule out that grant receipt also caused differential staffing of these substitute providers in a way that is consequential for the results.

3.5 Discussion

In the opening chapter of this thesis, I found that the long-term, aggregate trends of declining fire incidence and rising firefighter employment have also been visible at the fire department level in many cities. There is little evidence to support any fire-based explanation for this employment growth, given that the direct loss from fire has fallen with incidence, adherence to vehicle staffing standards has not increased, and there is no apparent causal relationship between firefighter employment and fire incidence. The most likely driver of recent firefighter employment growth is the rapid increase in EMS incidents, which now account for about two-thirds of total fire department call volume.

²⁵For strokes, there is a marginally significant, positive effect 29 months after treatment, which again is likely spurious.

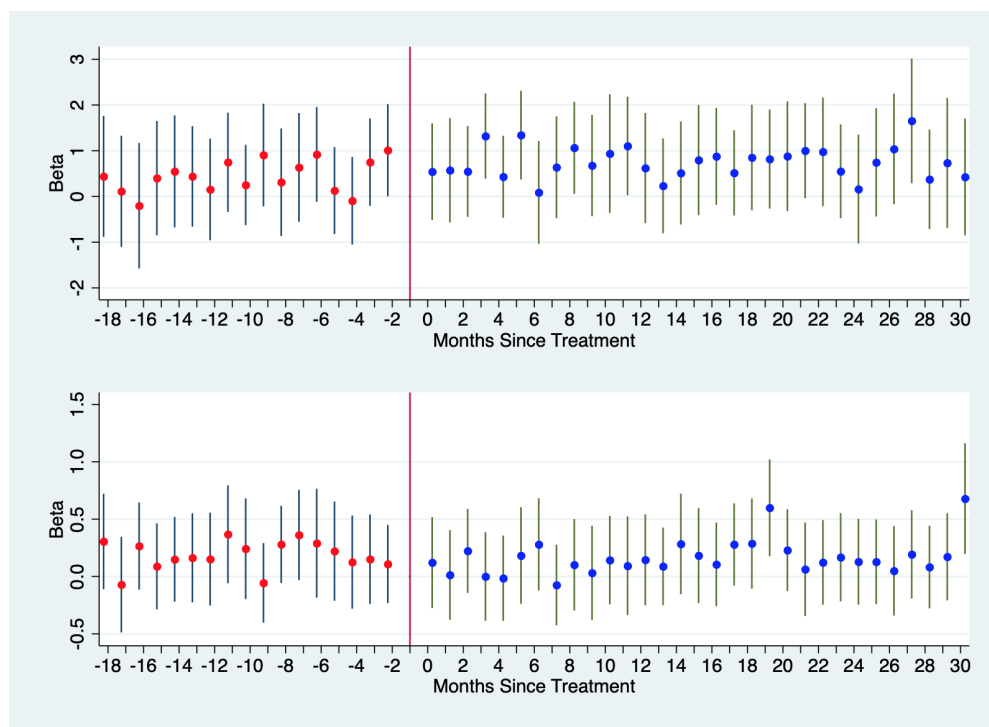
Figure 3.4: *Additional estimates: deaths from cardiovascular disease and strokes*



This figure plots the estimated betas from equation (3.1) in the 18 months preceding treatment and the 30 months following treatment for deaths due to cardiovascular disease (top panel) and strokes (bottom panel). The baseline means for these variables are 54.7 and 11.6 deaths per month in the year prior to first application. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 52,065 monthly observations for the 310 fire departments in the restricted analysis sample. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the NCHS Restricted All-Counties Mortality Data.

The decline in fire incidence alone does not preclude the possibility that increased firefighter employment can still generate net economic benefits in the fire domain. In the second chapter of this thesis, I found that higher employment levels induced by the SAFER hiring grant led to response time improvements on fire responses that could have reduced direct average loss by as much as \$184 per firefighter on structure fire responses. Based on the per-incident compensation costs calculated in the first chapter, this is well below the lower threshold of the average breakeven target of \$422 per incident, which allocates compensation costs evenly across all response types (e.g., fires, EMS events, false alarms). While there are several potential limitations to these estimates, which I discuss in Chapter 2, the discrepancy between marginal loss reductions on fire responses and employment costs is substantial for this group.

Figure 3.5: *Additional estimates: deaths from external causes and sepsis*



This figure plots the estimated betas from equation (3.1) in the 18 months preceding treatment and the 30 months following treatment for deaths due to trauma and other external causes (top panel) and sepsis (bottom panel). The baseline means for these variables are 18.1 and 3.2 deaths per month in the year prior to first application, respectively. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 52,065 monthly observations for the 310 fire departments in the restricted analysis sample. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the NCHS Restricted All-Counties Mortality Data.

In the present chapter, I extend the analysis to EMS responses, to determine whether increased firefighter employment pays for itself via reductions in time-sensitive deaths. I do not find any evidence that grant-induced employment increases result in a decline in these outcomes. One limitation of these estimates is that I am unable to observe whether grant receipt affects the staffing of substitute EMS providers. Moreover, while saving lives is the most economically significant aspect of EMS provision, increased firefighter employment could also lead to improved outcomes for victims of non-fatal events.²⁶ Notwithstanding these caveats, the findings in this chapter suggest a limited scope for direct marginal loss reduction on EMS events.

²⁶However, I do not observe a change in EMS response times among the subset of departments that first applied for a SAFER grant after 2011, when this data is first available in NFIRS.

Altogether, I do not find that the employment increases granted to the average SAFER recipient resulted in net (direct) economic gains among the incident types considered, which comprise the majority of fire department activity. However, these estimates do not account for indirect benefits, general equilibrium effects, or the welfare value of marginal performance improvements. Given that fire protection is essentially a form of insurance, risk-averse communities may be willing to pay a premium for a given level of expected marginal loss reduction. A welfare-based criterion would be the more appropriate measure for assessing the optimality of staffing increases.

However, in my view, the most critical next step for future research is not to polish cost-benefit analyses based on the existing operational framework, but to fill the substantial knowledge gap that exists regarding the effectiveness and efficiency of different EMS delivery models in the US (Institute of Medicine, 2007). For example, to the extent that EMS needs are driving firefighter employment growth, rather than single-role paramedics, the significant gap in relative employment costs begs an economic justification. Moreover, while the personnel and apparatus needs for a severe fire are considerably higher than for most conceivable EMS events, the relative investment in fire suppression and EMS resources at many fire departments may need to be reevaluated, given the drastic divergence in event frequency. Finally, as suggested by the findings in Craig *et al.* (2010), there is a need to better understand the impact of provider redundancy on EMS outcomes and explore innovations in the dispatch process that can limit unnecessary resource deployment.

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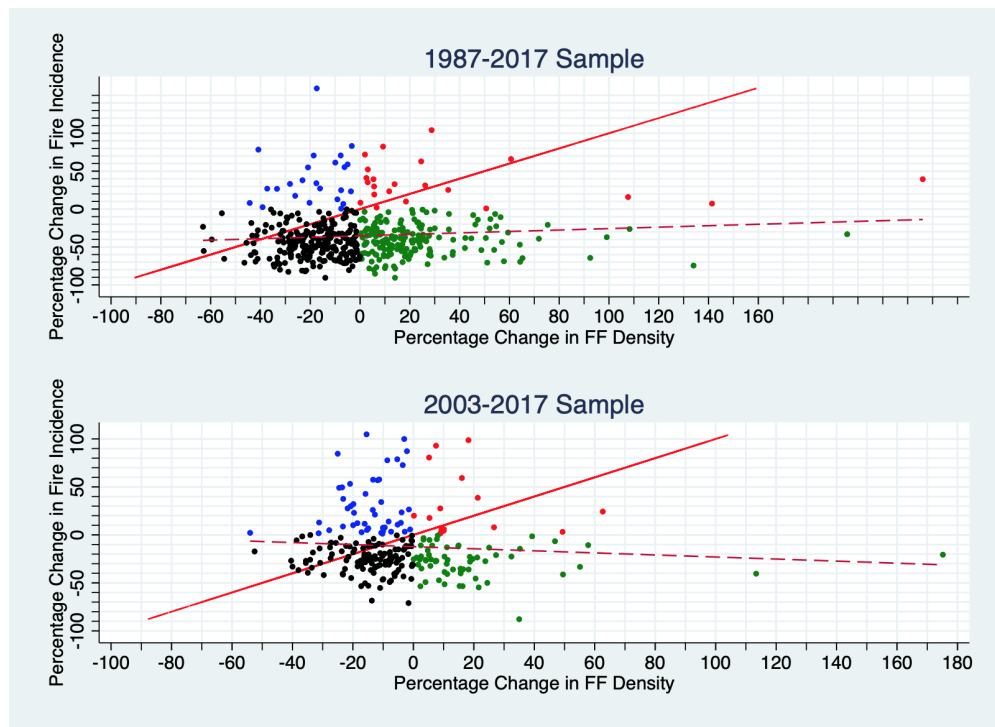
Appendix A

Appendix to Chapter 1

A.1 Supplemental Figures

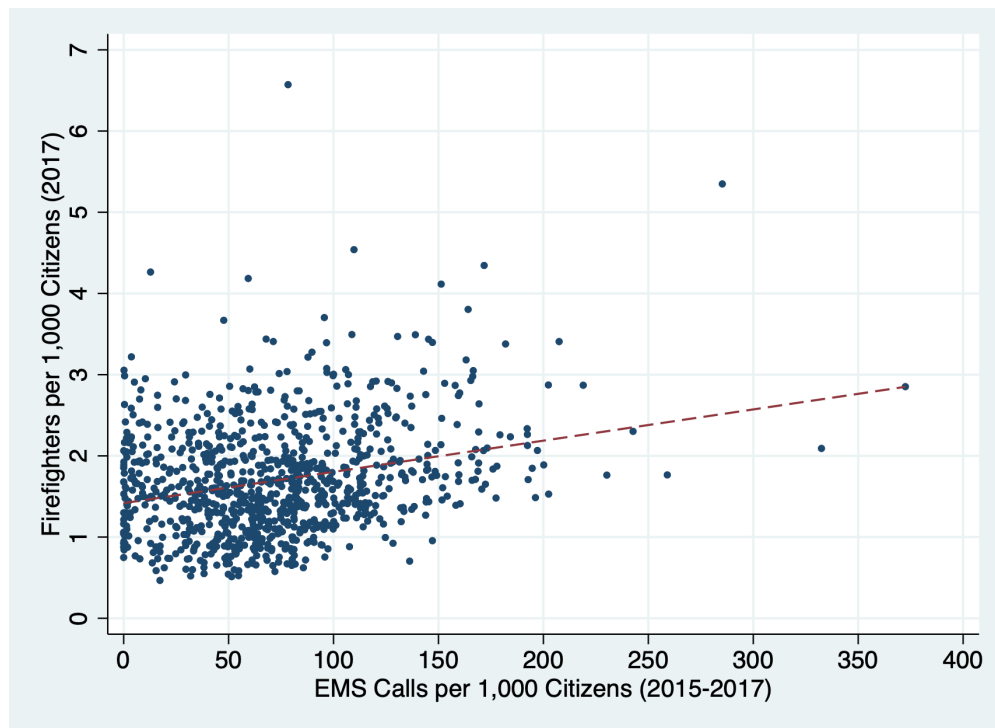
Appendix Figure A.1 replicates Figure 1.13, but based on changes in firefighter density, rather than changes in absolute firefighter employment. Appendix Figure A.2 reproduces Figure 1.25, but based on EMS call density, rather than fire call density.

Figure A.1: All-career fire department FF density growth vs. fire growth: 1987-2017 and 2003-2017



Change in fire incidence is based on the percentage change between the 5-year averages of annual fire incidence in 1987-1991 and 2013-2017. The sample is restricted to municipal all-career fire departments that served a population of at least 20,000, employed at least 20 firefighters, and responded to at least 20 fire calls in the start year. The top panel is restricted to departments with sufficient NFIRS data to account for the period 1987-2017 ($N = 465$); the bottom panel is restricted to a separate group of 246 departments with more limited NFIRS data (2003-2017). Observations are color-coded by quadrant. The solid line represents the 45-degree line; the dashed line shows a linear fit of the data. *Source:* Author's calculations from the National Fire Incident Reporting System and the U.S. Census Bureau Annual Survey of Public Employment and Payroll.

Figure A.2: Firefighter density (2017) vs. EMS density (2015-2017) for all-career departments



This figure plots firefighter density in 2017 (firefighters per 1,000 citizens) relative to EMS density, as averaged over the period 2015-2017. The sample consists of 945 all-career fire departments with a population of at least 20,000 and that employ at least 20 firefighters in 2017. The plotted line represents a linear fit, with an estimated slope coefficient of 0.004. *Source:* Author's calculations from the U.S. Census Bureau Annual Survey of Public Employment and Payroll, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

Appendix B

Appendix to Chapter 2

B.1 Supplemental Tables and Figures

As discussed in Section 2.3, Appendix Table B.1 provides the coefficient estimates and standard errors for the baseline regression of equation (2.1) on response times.

Appendix Figure B.1 reproduces the baseline response time plot (Figure 2.3), but in this case for a constructed categorical response time variable with four bins: 0-2 minutes (coded 1), 2-4 minutes (coded 2), 4-6 minutes (coded 3), and greater than 6 minutes (coded 4). The baseline mean for this variable is 2.69 in the year prior to first treatment.

Appendix Figures B.2 and B.3 reproduce Figures 2.9 and 2.10 for the entire universe of 2004-2017 NFIRS data, rather than just the SAFER analysis sample.

B.2 Exponential Property Loss Estimates

The rest of this appendix provides an illustration of how the property loss estimates from Section 2.4 would change if loss is assumed to grow exponentially with time, rather than linearly. While the empirical estimates from this paper and Challands (2010) suggest more of a linear relationship between response time and property loss, the heat output of a fire is typically modelled as growing exponentially up to the point of flashover. Therefore, Ramachandran (1986) and others have also used an exponential framework to model the total area damaged by fire. For example, the total floor area

Table B.1: Baseline response time estimates

Months Since Treatment	Coefficient	Std. Error	95% CI	Months Since Treatment	Coefficient	Std. Error	95% CI
-18	-3.7	3.72	[-10.9, 3.6]	7	-7.4**	3.40	[-14.1, -0.8]
-17	-4.5	3.61	[-11.5, 2.6]	8	-7.7**	3.44	[-14.4, -0.9]
-16	-3.3	3.44	[-10.0, 3.5]	9	-7.0**	3.39	[-13.6, -0.3]
-15	-5.8	3.26	[-12.2, 0.6]	10	-6.9	3.46	[-12.7, 0.8]
-14	-1.6	3.36	[-8.2, 5.0]	11	-7.9	3.56	[-14.9, -0.9]
-13	-1.8	3.76	[-9.2, 5.5]	12	-6.0	3.62	[-13.1, 1.1]
-12	-0.3	3.52	[-7.2, 6.6]	13	-7.9**	3.93	[-15.6, -0.2]
-11	-3.9	3.63	[-11.0, 3.2]	14	-6.8	3.72	[-14.1, 0.5]
-10	-2.0	4.24	[-10.3, 6.3]	15	-8.5**	4.11	[-16.5, -0.4]
-9	-5.6	3.27	[-12.0, 0.8]	16	-9.9**	4.03	[-17.8, -2.0]
-8	-3.8	2.97	[-9.6, 2.0]	17	-10.7**	4.22	[-18.9, -2.4]
-7	-0.2	3.06	[-6.2, 5.8]	18	-13.9***	4.40	[-22.5, -5.3]
-6	-0.8	2.98	[-6.6, 5.1]	19	-10.0**	4.87	[-19.5, -0.4]
-5	-1.0	3.01	[-6.9, 4.9]	20	-11.5***	4.18	[-19.7, -3.3]
-4	1.1	2.75	[-4.3, 6.5]	21	-12.2***	3.96	[-20.0, -4.5]
-3	-0.0	2.21	[-4.4, 4.3]	22	-11.8***	4.20	[-20.1, -3.6]
-2	-0.2	2.47	[-5.0, 4.7]	23	-10.6***	4.14	[-18.8, -2.5]
0	-2.8	2.34	[-7.4, 1.8]	24	-4.3	4.86	[-13.9, 5.2]
1	-2.8	2.80	[-8.2, 2.8]	25	-7.9	4.70	[-17.1, 1.3]
2	-4.4	2.90	[-10.1, 1.3]	26	-6.9	4.71	[-16.1, 2.4]
3	-5.8	3.26	[-12.2, 0.6]	27	-6.8	4.67	[-16.0, 2.3]
4	-6.4	3.29	[-12.9, 0.0]	28	-9.4**	4.59	[-18.4, -0.4]
5	-9.7***	3.25	[-16.1, -3.3]	29	-8.5	4.35	[-17.0, 0.0]
6	-6.9**	3.21	[-13.2, -0.6]	30	-6.5	4.44	[-15.2, 2.2]
N				249,392			
Clusters (# FDs)				1,801			
R-Sq.				0.72			

This table presents the baseline regression estimates from the regression of equation (2.1) on response times. The table is restricted to the 18 months preceding treatment and the 30 months following treatment. The baseline mean for the response time variable, which is winsorized at 30 minutes, is 341 seconds. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

damaged T minutes since ignition is assumed to evolve according to the equation below, where $A(o)$ is the area initially ignited and β is the growth parameter of the fire.

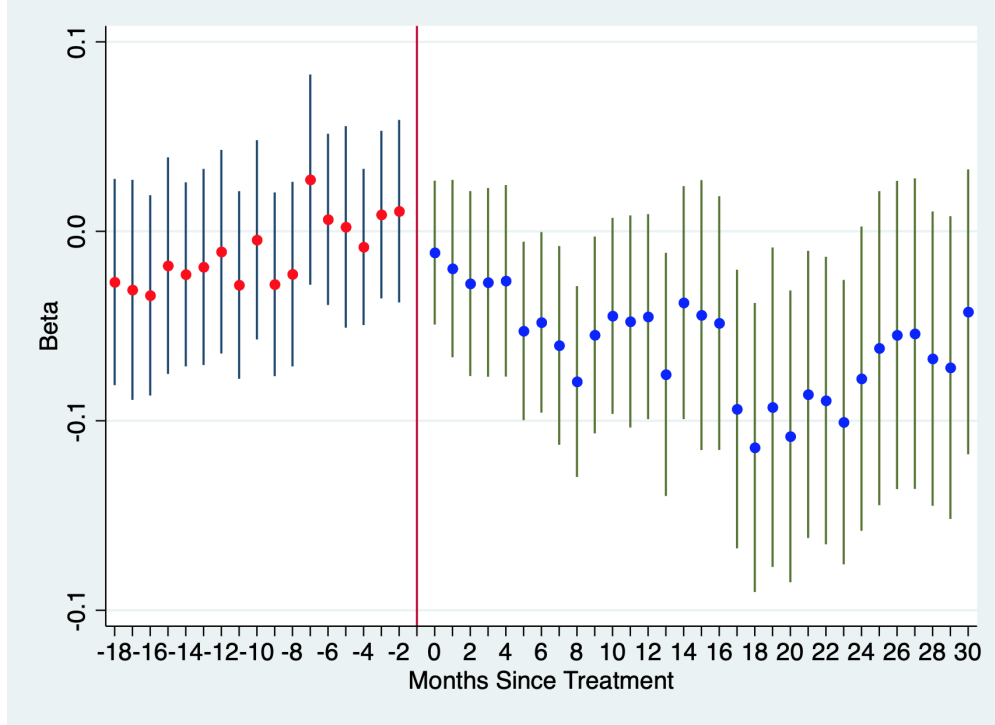
$$A(T) = A(o) \times \exp(\beta T)$$

This model might be further augmented to distinguish between the response time of the first arriving unit (T_R) and the time between arrival and water first hitting fire (T_W), when it might be assumed the fire has reached its maximum growth:

$$A(T) = A(o) \times \exp(\beta_R T_R + \beta_W T_W)$$

In this section, I apply this model to the NFIRS data for the SAFER analysis sample, under the

Figure B.1: *Categorical response time outcome*



This figure plots the estimated betas from equation (2.1) in the 18 months preceding treatment and the 30 months following treatment for a constructed categorical response time variable with four bins: 0-2 minutes (coded 1), 2-4 minutes (coded 2), 4-6 minutes (coded 3), and greater than 6 minutes (coded 4). The baseline mean for this variable is 2.69 in the year prior to first treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. The regression sample consists of 249,392 monthly observations for the 1,801 fire departments in the analysis sample defined in Figure 2.1. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

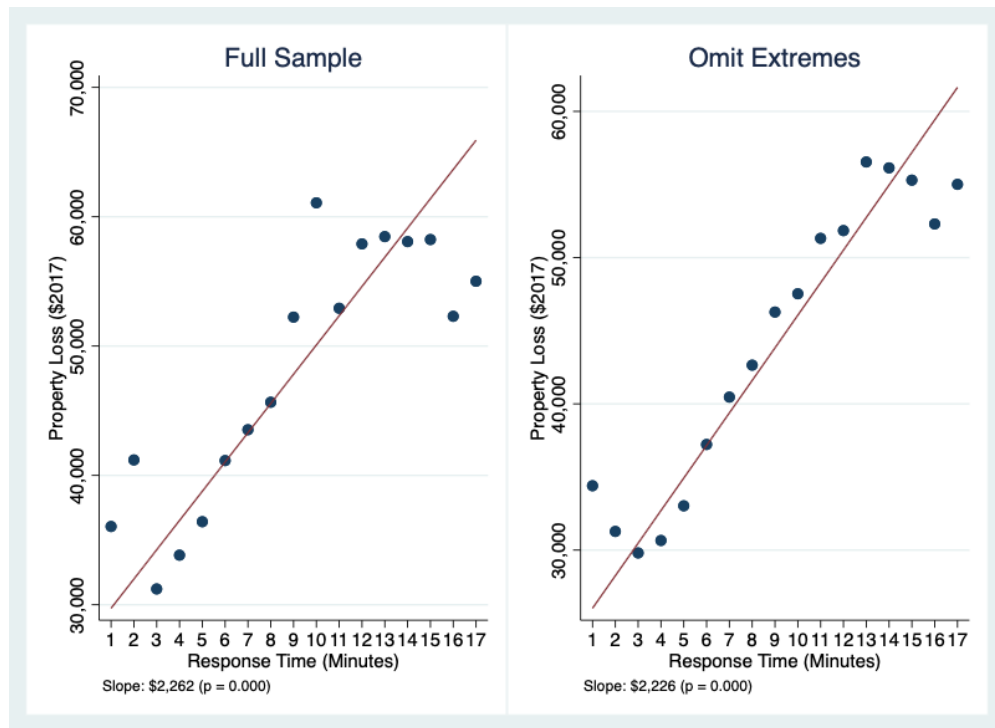
assumption that the dollar loss from fire grows exponentially. Making the further assumption that $\beta_R = \beta_W = \beta$, the estimated loss reduction attributable to a response time change of $\Delta R < 0$ for a fire incident observed post-treatment to have reported loss of $\$L$ is given by

$$\Delta \text{Loss} = \$L[\exp(\beta(-\Delta R)) - 1] \quad (\text{B.1})$$

I calculate ΔLoss for every fire incident reported by grant recipients in the two years following treatment, applying the sample-based bounds of -9.8 seconds and -17.7 seconds for ΔR , which correspond to the mean baseline response time estimate and the lower end of the 95 percent confidence interval, respectively.

I also apply four different estimates for β . I first use the mean and maximum estimates for β

Figure B.2: Relationship between structure fire property loss and response times: full NFIRS sample



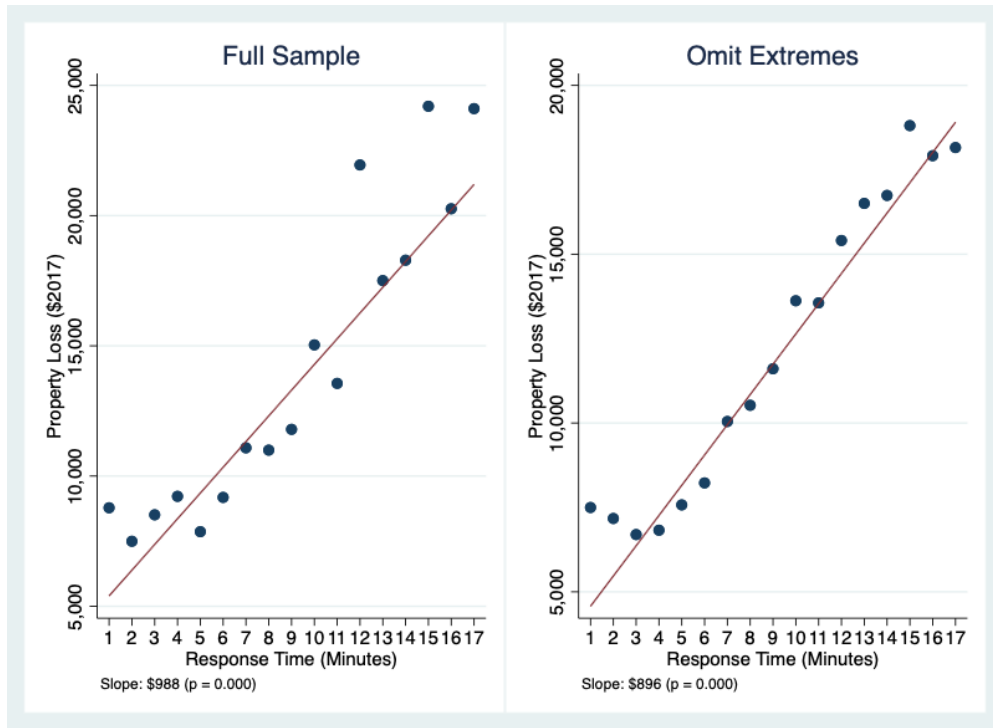
This figure presents bin scatters of reported property losses (in 2017 dollars) for structure fire calls relative to response times, based on the universe of 2004-2017 NFIRS data. Of the 4,433,812 observed structure fire incidents (excluding the provision of mutual aid), I restrict both panels of this figure to the 1,620,345 with non-zero reported property loss. The left panel includes all incidents; the right panel excludes the 167 structure fires with reported loss in excess of \$10 million (0.01% of the sample). The estimated slope coefficients of \$2,262 and \$2,226 are highly significant ($p = 0.000$). This figure can be compared to Figure 2.9, which shows the same relationships for the SAFER analysis sample. *Source:* Author's calculations from the National Fire Incident Reporting System.

(0.045 and 0.075) calculated in Ramachandran (1986) based on a statistical sample of U.K. fire data.¹

I then apply the considerably more aggressive estimates of $\ln(2)/2$ and $\ln(2)$, which correspond to the loss from fire doubling in size every two minutes and every minute, respectively. These rates are consistent with the “slow” and “medium” rates of fire development discussed in 3D Firefighting (2007), and the “doubles every minute” assumption is commonly used in firefighting forums. Based on the findings in Section 2.4 and from other statistical studies of property loss relative to response times, these assumptions do not seem to provide an accurate representation of how the dollar loss from fire grows with time (although they may be appropriate for modelling the heat output from fire). Nonetheless, I still provide estimates using these inputs to gauge the sensitivity of the results.

¹Note again that these β estimates are based on the area of fire damage, rather than the dollar loss from fire.

Figure B.3: Relationship between non-structure fire property loss and response times: full NFIRS sample



This figure presents bin scatters of reported property losses (in 2017 dollars) for non-structure fire calls relative to response times, based on the universe of 2004-2017 NFIRS data. Of the 7,641,315 observed non-structure fire incidents (excluding the provision of mutual aid), I restrict both panels of this figure to the 1,545,017 with non-zero reported property loss. The left panel includes all incidents; the right panel excludes the 50 fires with reported loss in excess of \$10 million (0.003% of the sample). The estimated slope coefficients of \$988 and \$896 are highly significant ($p = 0.000$). This figure can be compared to Figure 2.10, which shows the same relationships for the SAFER analysis sample. *Source:* Author's calculations from the National Fire Incident Reporting System.

For each treated department, I calculate annual averages of the estimated loss reduction per incident and then calculate summary statistics across the full sample. Appendix Table B.2 reports these department-level estimates separately for all fires, structure fires, and non-structure fires for each of the β inputs. The three sets of columns correspond to the median, mean, and 90th percentile estimates, respectively. The first column in each set presents estimates that treat incidents with \$0 of reported loss as true zeros; the second column averages only over incidents with non-zero reported property loss. The range in each cell is based on the mean response-time estimate (9.8-second reduction) and the lower end of the 95 percent confidence interval (17.7-second reduction). The mean estimates are directly comparable to the results in Table 2.2 corresponding to the linear model.

The mean estimates based on the β parameters from Ramachandran (1986), which are obtained

Table B.2: *Estimated property loss reductions (per incident) attributable to grant receipt: exponential model*

	Median		Mean		90th Percentile	
	Include 0s	Exclude 0s	Include 0s	Exclude 0s	Include 0s	Exclude 0s
$\beta = 0.045$						
Avg. Loss Reduction per Fire	[33, 59]	[132, 239]	[51, 92]	[218, 395]	[103, 187]	[409, 741]
Per Structure Fire	[79, 143]	[196, 355]	[126, 228]	[322, 584]	[271, 492]	[636, 1,154]
Per Non-Structure Fire	[7, 12]	[40, 72]	[16, 29]	[92, 167]	[29, 52]	[133, 241]
$\beta = 0.075$						
Avg. Loss Reduction per Fire	[55, 99]	[220, 400]	[85, 154]	[364, 662]	[172, 313]	[683, 1,241]
Per Structure Fire	[131, 239]	[327, 594]	[210, 383]	[538, 978]	[453, 823]	[1,063, 1,932]
Per Non-Structure Fire	[11, 20]	[66, 121]	[26, 48]	[154, 279]	[48, 88]	[222, 403]
$\beta = \ln(2)/2$						
Avg. Loss Reduction per Fire	[258, 477]	[1,039, 1,924]	[401, 742]	[1,719, 3,183]	[813, 1,506]	[3,225, 5,971]
Per Structure Fire	[621, 1,150]	[1,544, 2,860]	[994, 1,840]	[2,542, 4,706]	[2,139, 3,961]	[5,021, 9,297]
Per Non-Structure Fire	[53, 98]	[314, 581]	[124, 230]	[726, 1,344]	[228, 421]	[1,047, 1,940]
$\beta = \ln(2)$						
Avg. Loss Reduction per Fire	[530, 1,005]	[2,139, 4,055]	[825, 1,564]	[3,538, 6,708]	[1,674, 3,174]	[6,637, 12,584]
Per Structure Fire	[1,278, 2,423]	[3,178, 6,026]	[2,045, 3,879]	[5,321, 9,918]	[4,402, 8,347]	[10,333, 19,592]
Per Non-Structure Fire	[108, 206]	[646, 1,225]	[256, 485]	[1,494, 2,833]	[468, 888]	[2,156, 4,087]

This table presents estimates of grant-induced property loss per incident for grant recipients during the first two years of treatment, using the exponential model. Results are shown separately for all fires, structure fires, and non-structure fires, as well as for different rates of assumed fire growth (beta). The three sets of columns correspond to the median, mean, and 90th percentile estimates, respectively. The first column in each set presents estimates that treat incidents with \$0 of reported loss as true zeros; the second column averages only over incidents with non-zero reported property loss. The range in each cell is based on the mean response-time estimate (9.8-second reduction) and the lower end of the 95 percent confidence interval (17.7-second reduction). The mean estimates are directly comparable to the results in Table 2.2, corresponding to the linear model. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.

from a statistical analysis of U.K. fires, overlap nicely with the linear ranges presented in Table 2.2. For structure fires, the average loss reduction per incident attributable to the grant ranges between [\$126, \$383] if including incidents with \$0 reported loss and [\$322, \$978] if averaging only over incidents with non-zero reported loss. To obtain a rough approximation for the implied marginal impact per firefighter, these estimates can again be divided by the relative mean hiring increase (6) found in the first stage.

The estimates based on a two-minute and one-minute assumed doubling time are substantially higher. The average mean loss reduction per structure fire attributable to the grant can be as high as \$3,879 if including fires with zero reported property loss and \$9,918 if excluding them. This implies a crude range for average marginal firefighter loss reduction per structure fire of about \$650 to \$1,650. While there is little evidence statistically to support using these latter assumptions for modelling the dollar loss from fire, I include these estimates to illustrate how sensitive the results could be to these

modelling assumptions.

Appendix C

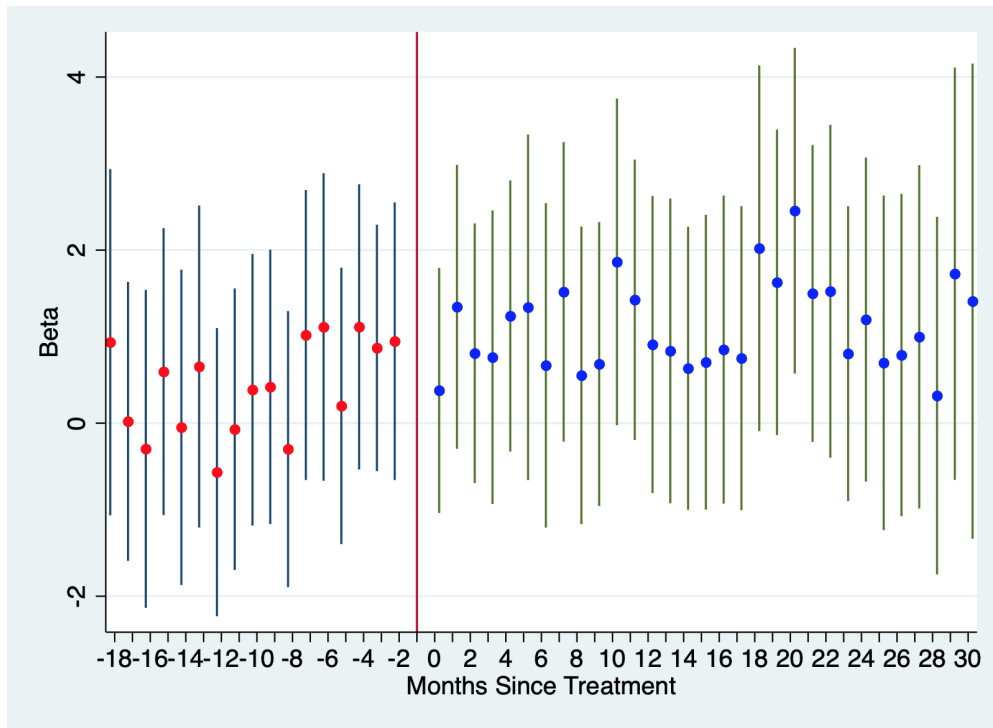
Appendix to Chapter 3

C.1 Supplemental Figures

As discussed in the text, Appendix Figure C.1 reproduces the baseline estimate of equation (3.1) for time-sensitive deaths, but restricts the sample to those that occur at the decedent's home, in an outpatient or emergency room hospital setting, or upon arrival to a hospital. These settings may be more likely associated with a fire department response. I again find no evidence of a grant-induced reduction in time-sensitive deaths.

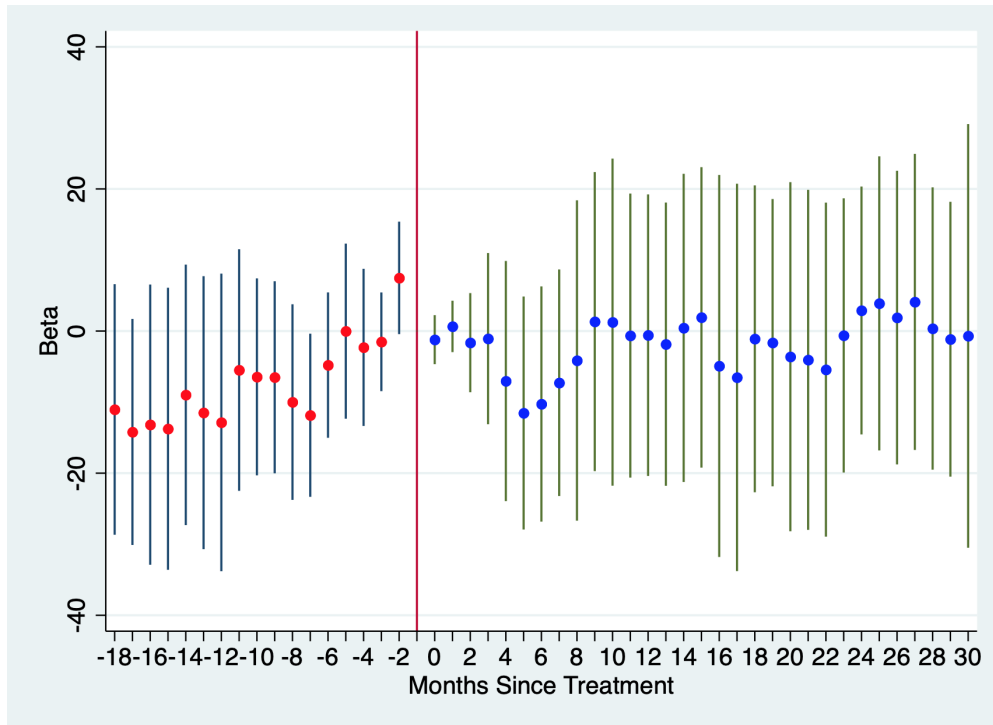
Appendix Figure C.2 repeats the response time analysis from the previous chapter, but for EMS outcomes. Due to limitations of the NFIRS data, the sample is necessarily restricted to the 277 departments that first applied for a SAFER grant on or after January 1, 2012. Unlike for fire responses, I do not find evidence of a decline in EMS response times for this selected group. However, there may be a slight pre-trend for this group preceding treatment, which could affect interpretation of the treatment period estimates.

Figure C.1: *Time-sensitive death estimates: restricted place of death*



This figure plots the estimated betas from equation (3.1) in the 18 months preceding treatment and the 30 months following treatment for the time-sensitive deaths variable, but restricted to deaths that occur in an outpatient or emergency room setting, upon arrival to the hospital, or at the decedent's home. These places of death may be more likely associated with an emergency fire department response than others, such as hospice deaths or inpatient hospital deaths. The baseline monthly mean for this variable is 35.0 in the year prior to first treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the NCHS Restricted All-Counties Mortality Data.

Figure C.2: *Response time outcome: 2012-2017 sample*



This figure plots the estimated betas from equation (3.1) in the 18 months preceding treatment and the 30 months following treatment for the response time variable (winsorized at 30 minutes). The sample consists of the 277 departments in the SAFER analysis sample that first applied after 2012 (100 recipients, 177 denied departments). The baseline mean for this variable is 324.7 in the year prior to first treatment. The marker labels provide the coefficient estimate and the lines represent 95% confidence intervals. Grant recipients have a 6-month grace period following treatment to fill the allocated positions. *Source:* Author's calculations from FEMA grant data, the USFA Fire Department Registry, and the National Fire Incident Reporting System.