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Retention of highly qualified wildland firefighters in the Western United States

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ABSTRACT

Federal agencies responsible for wildland fire management face increasing needs for personnel as fire seasons lengthen and fire size continues to grow, yet federal agencies have struggled to recruit and retain firefighting personnel. While many have speculated that long seasons, challenging working conditions, and low wages contribute to recruitment and retention challenges, there has been no empirical investigation of these claims. We assemble a unique dataset on the federally funded Interagency Hotshot Crews in the Western United States, which are comprised of highly qualified firefighters, from 2012 to 2018 to analyze the factors that affect firefighter retention. Using a Cox proportional hazard model, we find that a higher workload, a proxy for higher earnings, and cumulative experience over the course of an employee's career both have a significant positive impact on retention. The wage of alternative occupations had no significant effect on retention. Retention decreases over the study period.

1. Introduction

Retention among the federal fire suppression workforce in the United States is a growing concern. Climate change is lengthening wildland fire seasons (Flannigan et al., 2013) and increasing the demand for fire suppression resources (Belval et al., 2020; Abatzoglou et al., 2021; Belval et al., 2022; Coop et al., 2022) while retention is declining (Safo, 2021; Quinton, 2021; Wigglesworth, 2022; Sacks, 2022; Interagency Hotshot Crew Review Team, 2023; Granberg et al., 2022). In addition, the lack of qualified personnel is cited as a barrier to fuels management and risk reduction activities (Reams et al., 2005; Schultz et al., 2019; Interagency Hotshot Crew Review Team, 2023), a core priority of United States Forest Service's approach to mitigating large destructive fires (United States Forest Service, 2022). Numerous explanations have been proposed for the decline in retention in recent years, including long seasons, challenging working conditions, and low wages. Low wages are often cited as a critical reason for recruitment and retention challenges (United States Government Accountability Office, 2022; Davidson, 2022; Safo, 2021; Quinton, 2021; Sacks, 2022; Granberg et al., 2022; Interagency Hotshot Crew Review Team, 2023). Yet, there has been no empirical research on the veracity of these proposed explanations for the declining recruitment and retention of wildland firefighters.

Our objective is to investigate whether retention in the elite ranks of the federal firefighting workforce in the Western US is affected by prior season workload (a proxy for wages), local wages of alternative occupations, and experience. Economic theory suggests that labor supply in a given industry increases in its own wages and decreases in the wages of competing industries. Our analysis builds on this insight to study whether existing Interagency Hotshot Crew (IHC) members remain in the IHC workforce or exit, given changes in workload and wages of outside occupations. We construct a panel data set of individual IHC members that includes the number of days they were assigned to large incidents each year and the local wages of alternative occupations based on their home forest. We fit a Cox proportional hazard model to estimate the marginal effects of an individual's workload, competing occupation wages, and experience on the probability that they exit the IHC workforce. Our results provide important evidence for policy discussions on the role of wages and workload in IHC workforce development.

Previous empirical work has explored factors that impact retention for federal employees in the US; most of these studies rely upon data from the Federal Employee Viewpoint Survey (e.g., Nguyen and Tuan, 2022; Byrne et al., 2017; McCarthy et al., 2020; Hassett, 2022; Kim and Fernandez, 2017; Asencio, 2016; Lee, 2020; Leider et al., 2016). These studies provide insights into the impact of factors such as workplace

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environment, culture, pay satisfaction and employee engagement turnover intention. However, beyond considering self-reported pay satisfaction, these studies are unable to link responses to employee compensation. In addition, they examine turnover intention but cannot determine if an employee left the federal government within a given period. None of these retention studies have specifically examined wildland firefighters. In contrast to these retention studies that ask individuals about their intention to remain or leave a job, our approach is based on the observed decisions of actual IHC members.

Previous studies have found that the workforce composition for the US Forest Service (the agency by which most IHCs are employed) is lacking in diversity relative to the US population as a whole (Westphal et al., 2022) as well as relative to the places employees are located (Locke et al., 2023) and that race and gender play a role in career progress (Sachdeva et al., 2023). Other workforce studies note that contractors have come to play a larger role in wildland fire suppression tasks recently (Deak et al., 2023; Huber-Stearns et al., 2019), though the contractors may not be optimally located for initial suppression response (Huber-Stearns et al., 2019) and communities with a higher number of contractors and more diverse economy are more likely to capitalize on the contracting workforce in the event of a large fire (Nielsen-Pincus et al., 2018). None of these workforce composition and contracting studies look specifically at federally employed firefighters, nor do they specifically look at retention beyond linking gender and race to career length (Sachdeva et al., 2023).

Low wage is often cited as a key reason for attrition of federal wildland firefighters (United States Government Accountability Office, 2022), which would be consistent with theoretical frameworks and empirical findings of studies of other occupations (e.g. Kang et al., 2015, 2021; Adams, 1963; Herzberg et al., 1959; Hirschman, 2004; Leider et al., 2016; Metro et al., 2021; Whitford and Lee, 2015). However, studying firefighter pay is difficult because the wage structure of federal wildland firefighters is complex, and a complete set of data on annual compensation is not available to researchers. However, firefighter dispatch data is archived and contains information on where individuals were assigned and for how long (Belval et al., 2020). While the wildland firefighting pay structure is complex, it is highly correlated with days on assignment. Multiple reports have noted that the current wage structure incentivizes individuals to maximize their time on fire assignments during a fire season despite the additional hours being associated with exposure to hazards, additional fatigue, and additional time away from home (Innovation and Organizational Learning, 2022; Granberg et al., 2022; Interagency Hotshot Crew Review Team, 2023). We use these data to estimate workload and wages earned over the course of an individual's career during our study period.

Hazard (or survival) models have been widely used to study retention across a variety of industries. For example, survival modeling has been used to examine factors influencing retention for positions and fields with high turnover rates such as health care workers (Somers, 1996; Bailey et al., 2016; Cho et al., 2012; Singer et al., 1998; Opoku et al., 2015; Chang and Cho, 2022; Pagaiya et al., 2015), child welfare workers (Clark et al., 2013; Rosenthal and Waters, 2006; Madden et al., 2014), teachers in low-income areas (Donaldson and Johnson, 2010), non-profits (Kang et al., 2015), and entry-level jobs (Pierce et al., 2022). In most of these studies, workers exit and do not return to the same employer. In contrast, wildland firefighters will sometimes leave the occupation for one or more seasons and return in the future. We develop a measure of cumulative experience (i.e., human capital) as a covariate in the regression model to account for this.

2. Wildland firefighting background

Wildland firefighting is a physically strenuous job that requires long hours and entails a wide variety of physical and psychological risks. Federal wildland firefighters are routinely dispatched to incidents where they work 16 h per day for multiple days (Desmond, 2009; Aisbett et al., 2012b; Interagency Hotshot Crew Review Team, 2023; Granberg et al., 2022). Recent research highlights the risks associated with these lengthy and stressful assignments, including decreased cognitive function from insufficient sleep (Vincent et al., 2018; Aisbett et al., 2012a), high exposure to smoke and air pollutants in close proximity to fire (Navarro et al., 2021; Adetona et al., 2016; Navarro, 2020), and injury while operating equipment (i.e., chainsaws). Despite many safety protocols, firefighters risk being burned by the fire they are fighting and being struck by falling trees (Britton et al., 2013). Wildland firefighting fatalities have historically occurred at roughly a rate of 58 per 100,000 workers (Campbell and Dalsey, 2012; National Institute for Occupational Safety and Health, 2023). This rate of fatalities places wildland firefighters below the 2021 fatality rates for the top two highly fatal occupations (logging workers and fishing and hunting workers; 82 and 75 fatalities per 100,000 workers, respectively), and is on par with the third highest fatal occupation in 2021 (roofers; 59 fatalities per 100,000 workers) (U.S. Bureau of Labor Statistics, 2022).

Despite the many risks associated with wildland firefighting, federal and state agencies employ thousands of people to fight fire in US wildlands each year. Desmond (2009), a former wildland firefighter himself, finds that wildland firefighters are not simply "risk junkies", but rather identify with a community of people with a shared goal. The community values their skill set and knowledge of how to survive in challenging conditions and solve problems. Notably, Desmond (2009) argues that financial incentives are not the primary motivating factor for wildland firefighters in his study and Alkhars et al. (2023) found that camaraderie and a passion for the mission incentivize firefighters to stay in the profession. Nevertheless, firefighters are economic agents that need to earn income and pay has been cited as a key reason for leaving the profession (Interagency Hotshot Crew Review Team, 2023; United States Government Accountability Office, 2022; Alkhars et al., 2023). The empirical question is how wages and working conditions influence wildland firefighter's decision to remain in their occupation.

Interagency Hotshot Crews (IHCs) are the most highly qualified and capable type of firefighting crew in the US wildfire management system (National Interagency Hotshot Crew Steering Committee, 2019a, 2019b; Interagency Hotshot Crew Review Team, 2023). IHCs are able to perform tasks that no other crews are qualified for and thus are in high demand even during quiet fire seasons (Stonesifer et al., 2017; Belval et al., 2020; Interagency Hotshot Crew Review Team, 2023), resulting in the majority of the crew's time during the fire season being spent on assignments away from their home base. Positions on IHCs have historically been considered very desirable due to their high earning potential and membership in a high-status group. Specifically, IHC crew members are able to meet the physical demands of the work, are comfortable in the unique wildland firefighting environment, and are willing to travel extensively during the fire season. We focus on this population because they are a critical firefighting resource, and their dispatch records are the most accurate.

Like all other federal wildland firefighters, IHC crew member wages are highly correlated with the length of time firefighters spend on fire assignments. Fire assignments often include hazard and overtime pay (25% and 50%, respectively), which is paid in addition to their base pay (Interagency Hotshot Crew Review Team, 2023). This wage premium provides a strong incentive to maximize one's workload. Thus, additional time on assignment is associated with both increasing wages as well as additional time during which the firefighters are subject to the stresses and hazards of being on a fire assignment.

Fig. 1 illustrates the pathways through which cumulative experience and days assigned in a given year would be expected to influence retention, based upon results from previous studies and interaction with the IHC program (Interagency Hotshot Crew Review Team, 2023). Cumulative experience captures the accumulation of human capital gained over seasons. The US federal government pay structure rewards this additional experience with higher seniority as well as the ability to move into higher paying jobs that require higher levels of qualifications, both

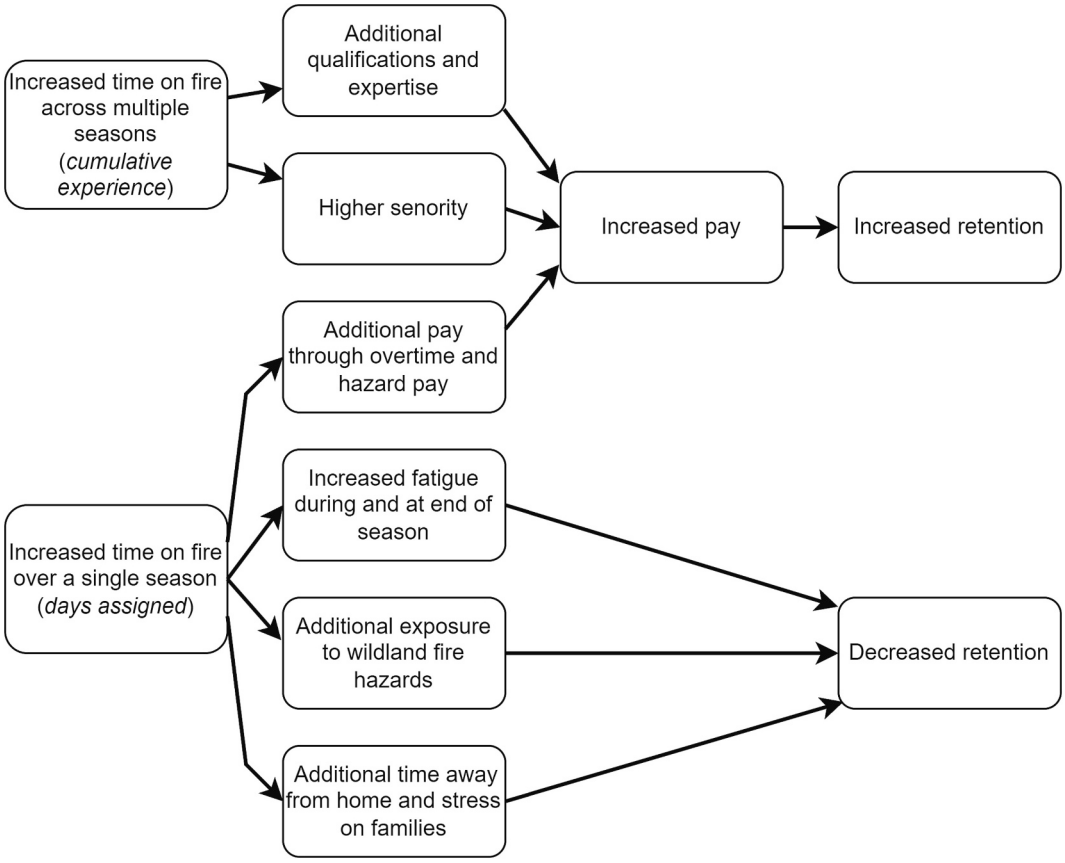

Fig. 1. Pathways through which time on fire assignments might impact retention.

of which result in increased wages. Within a particular season, the number of days assigned increases earnings but also increases time away from home and exposure to wildland fire hazards (Innovation and Organizational Learning, 2022; Interagency Hotshot Crew Review Team, 2023); one previous study found that higher pay is explicitly associated with these additional "burnout factors" (Innovation and Organizational Learning, 2022). While we expect the increased earnings to increase retention, more time away from home and exposure to hazards should decrease retention. Our objective is to estimate the effect of workload, competing wages, and experience on the probability of retention in the IHC workforce. With regard to pay, our empirical model estimates the net effect of the pathways shown in Fig. 1 on retention.

3. Methods and data

3.1. Data

Our analysis focuses on Interagency Hotshot Crews. Composed of 18–25 individuals, the crews (115 existed in 2020) are provided primarily by the US Forest Service (91 crews in 2020), though some are hosted by agencies within the US Department of the Interior (21 crews) and state agencies (3 crews). These crews are used extensively during the US wildfire season (Stonesifer et al., 2017; Belval et al., 2020). IHCs spend an average of 110 days each fire season on wildland fire assignments or related travel (as reported in the Interagency Hotshot Crew Seasonal Summary Report from 2014 to 2019), generally for most of the summer and into the fall.

Our core dataset includes individual-by-year information on the number of days assigned to wildland fire incidents. These data come from the Resource Ordering and Status System (ROSS), a software designed for dispatchers to track personnel on assignments. We calculate the number of days assigned each year and estimate active IHC members each year from 2008 to 2019 based on the number of days assigned. Each individual has a unique identifier, so we can determine whether an individual left the system and whether they returned in future years. For instance, if individual i was assigned in 2015 but not at all in 2016, we code an exit at the end of 2015. While we observe assignments in 2019, we only use 2019 data to determine whether an individual exited at the end of 2018. If an individual is assigned in 2019, they are coded as right censored. The ROSS dispatch records began in 2008. We assume that individuals with assignments in 2008 began in 2008, even though they may have been active IHC members before 2008. Our results are robust to omitting these records where the actual start date is unknown (see Appendix A.2.2 for model results obtained by fitting the model only with data that includes a known start date.)

The United States is split into 10 geographic areas for wildland fire management purposes. These areas may have different wildland fire management cultures. Similarly, culture may vary by federal land management agencies (e.g., US Forest Service, Bureau of Land Management). We attribute the individual-level data with crew-level information, including federal agency and the geographic area in which the crew's home base is located. Fig. 2 shows that there are between 2000 and 2500 active members of IHCs each year (all active members are shown in the left bar for each year); approximately two-thirds of IHC members remain in the job each year while one-third of the workforce leaves (the right bar for each year shows the number that left, which is a subset of the active members that year). Vacancies are filled with newly recruited or recruited back members (recruited back refers to crew members who were previously on a crew and left the crew for at least a season before returning). This analysis only focuses on the retention of crew members and not recruitment. The recruitment process is the outreach that is done to convince candidates to apply for a position. The metrics to measure the success of recruitment efforts are the number and quality of applicants. We don't have data on the applicant pool, only on

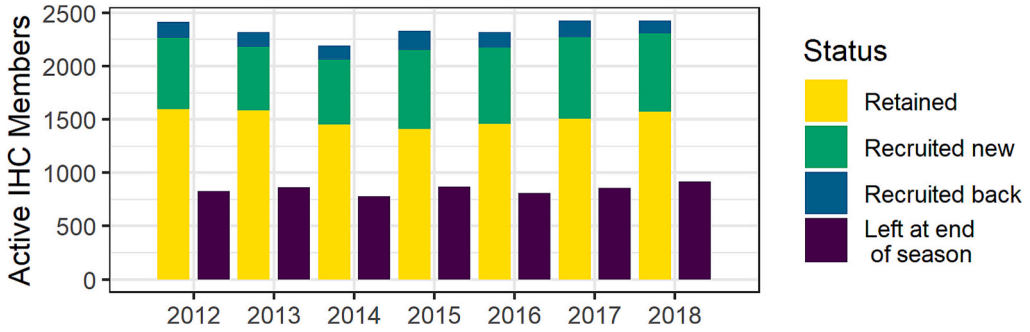

Fig. 2. The bar on the left side of each year shows the number of active IHC members in our data each year, colored by their entry status: retained (yellow), recruited (green) or re-entered (blue). The subset of individuals who left the IHC workforce at the end of each year is shown by the right bar. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

those who were hired. Thus, we leave this question to future work.

Fatalities have occurred on hotshot crews during our period of analysis. To properly account for these personnel, we searched the Wildfire Lessons Learned Documents archive for fatality reports. Because these crew members did not make a choice to leave, we right-censored their final year in the system, which affected six observations in the analysis. We also removed all non-federal crews as well as crews from Alaska (three crews - one of which is state-provided), the Southern Geographic Area (four crews), and the Eastern Geographic Area (one crew), as there are very few crews in these regions, and they have substantially different work environments than those in the Western US.

We also calculate the cumulative number of days an individual works regardless of IHC employment gaps (hereafter referred to as "cumulative experience"). This variable captures the human capital and seniority accumulated over the course of one's career. Additional experience and seniority generally increase the wage rate, which may affect one's decision to remain on their IHC.

Individual earnings data are not publicly reported. We use crew-level survey data collected from each IHC annually and days assigned to large incidents to estimate an individual's annual earning potential. These data include information about crew activities across the season. We refer to our estimates as the maximum crew earning potential (abbreviated in tables as MCEP), as it reflects the potential pay a crew member could have received from working on every reported activity with the crew. We assume a common federal employee pay scale (i.e., general schedule https://www.opm.gov/policy-data-oversight/pay-leave/salaries-wages/2023/general-schedule) level along with information about number of workdays not on a large incident to estimate a base level of earnings. Finally, we use a cost of living adjustment to account for wage differentials across the US. Additional technical details are in appendix A.1.2.

The decision to work in firefighting depends in part on the wage an individual is earning as well as the wages one might earn in an alternative job. The ONet Project is a database sponsored by the US Department of Labor and the Employment and Training Administration that contains detailed information on occupations in the US (National Center for O*NET Development, 2023a). Along with information on tasks and skills required by an occupation, ONet also identifies related occupations based on three factors: what people in the occupations do, what they know, and what they are called (National Center for O*NET Development, 2023). We identify the ten most related occupations (Table 1) and compile wage data representing the potential wages one could earn seeking alternative employment.

We collected wage and employment data from the Bureau of Labor Statistics (BLS) Occupational Employment and Wage Statistics (Bureau of Labor Statistics, U.S. Department of Labor, 2023) for the ten most related occupations to firefighting. These data contain detailed wage and employment information for every occupation classification for all metropolitan statistical areas (MSA) in the US. We calculate the

Table 1
A list of the standard occupation classification codes and occupation names for the ten most related occupations to firefighting as assessed by the ONet Project.

Standard occupation classification code	Occupation Name
53–3011.00	Ambulance Drivers and Attendants, Except Emergency Medical Technicians
29–2042.00	Emergency Medical Technicians
33–2021.00	Fire Inspectors and Investigators
17–2111.02	Fire-Prevention and Protection Engineers
33–1021.00	First-Line Supervisors of Firefighting and Prevention Workers
33–2022.00	Forest Fire Inspectors and Prevention Specialists
47–4041.00	Hazardous Materials Removal Workers
33–9092.00	Lifeguards, Ski Patrol, and Other Recreational Protective Service Workers
19–5011.00	Occupational Health and Safety Specialists
29–2043.00	Paramedics

employment-weighted mean of related occupation wages in each year for each MSA. Weighting the wage by employment accounts for the relative likelihood of finding alternative employment at a given wage. We then merge the wage data with the IHC data by year and MSA, which provides us with a location-specific estimate of competing wages. We also compute a location-specific opportunity cost of working as a hotshot by subtracting the average competing wage estimates developed from the BLS OES data from the crews' maximum crew earning potential. All wage information is deflated to 2012 USD using the consumer price index reported by the BLS (Bureau of Labor Statistics, U.S. Department of Labor, 2023).

A summary of the covariates names, description and data source are provided in Table 2.

3.2. Summary statistics

Our data set consists of 5139 individual IHC members across 94 crews from 2012 to 2018 for a total of 11,447 unique observations

Table 2
Covariates, descriptions, and data sources.

Covariate	Description	Data Source
Days Assigned	Total days on large fire assignment	ROSS
Cumulative Experience	Cumulative days on assignment over individuals tenure	ROSS
Agency	Federal employment agency	ROSS
Geograhpic Area	Federal employment region	ROSS
Competing Wage	Wage of related occupations	BLS; ONET
Maximum crew earning potential (MCEP)	Maximum wage that could have been earned on each crew	Survey

Table 3
Summary statistics.

Covariate	Mean	10th–90th %	Min	Max
Days Assigned	80.18	45–111	29	178
Cumulative Experience (100 days)	2.71	0.64–5.71	0.29	11.88
Competing Wage ($1000)	48.58	30.64–65.10	19.41	88.73
Max Crew Earning Potential ($1000)	49.96	41.04–58.19	5.14	78.59
MCEP - Competing Wage ($1000)	1.37	−16.95–19.44	−44.11	36.11

Obs: 11,447; IHC Crews: 94; Individual IHC members: 5139.

(Table 3). IHC members are assigned to large incidents for an average of 80 days per year. Hotshot crews are required to be available nationally for fire assignments for a minimum of 90 days per year (National Interagency Hotshot Steering Committee, 2016), though many crews are available longer. During this time period, many crew members were hired as temporary workers whose appointment was not meant to exceed six months per year. The minimum number of days assigned is 29 because we drop all individuals with fewer than 29 assignment days (unlikely to be IHC members). The average cumulative experience of IHC members in the sample is 271 days (or 3.4 80-day seasons) but is as high as 1188. The average maximum crew earning potential is nearly $50,000, which is perhaps unsurprisingly close to our average estimate of competing wages ($48,580). The proximity of these wage estimates reinforces the credibility of the underlying data sources and our processing of the data.

We estimate a Kaplan-Meier survival curve to understand the baseline retention rates and expected career duration (Kaplan and Meier, 1958). Fig. 3 illustrates the baseline IHC survival curve. The survival curve represents the probability that a representative IHC member will remain in the job for another season as a function of the number of years already worked. For example, there is just over a 50% chance that a first-year IHC member will be retained into their second year. An alternative interpretation is that the median IHC member will remain in the job for two years. The slope of the survival curve declines over time as only those individuals with a strong affinity for the job remain on an IHC.

The following section estimates proportional hazard models to better understand how time-varying assignment days, experience, and wages influence the retention probability.

3.3. Econometric model

We develop a Cox proportional hazard (PH) model to study the effects of wages and days assigned on retention rates in IHCs.

The Cox PH model is given by,

$$\lambda(t|\mathbf{x}_{it}) = \lambda_0(t)exp(\beta\mathbf{x}_{it}) \quad (1)$$

where λ is the hazard function, λ_0 is the baseline hazard function, $\mathbf{x}_t$ is a vector of covariates for individual i in year t, β is a vector of coefficients. The baseline hazard function quantifies the probability that an event will occur, given that it has not yet occurred. In the case of workforce retention, the hazard function represents the probability that an IHC member leaves the system in year t conditional on having been in the system for $t-1$ years. The baseline hazard function represents the probability of exit by the reference case, which we describe in more detail below. The covariates modify the baseline hazard function multiplicatively. The regression coefficients represent a proportional adjustment on the baseline hazard rate similar to an odds ratio (Kalbfleisch and Prentice, 2002; Therneau and Grambsch, 2000).

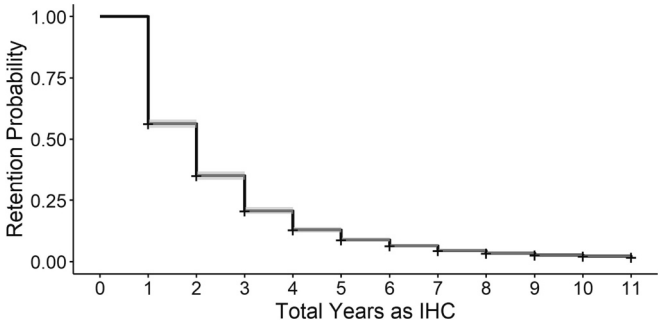

Fig. 3. Estimated Kaplan-Meier curve for IHCs 2012–2018.

We estimate an Andersen-Gill Cox PH model (Cox, 1972; Amorim and Cai, 2015; Austin, 2017) with time-varying covariates (Table 2). We are primarily interested in how opportunity cost and workload affect the probability that someone leaves their IHC. Thus, we include the location-specific competing wages and the number of days an IHC member was assigned to large incidents. We also include the IHC agency and geographic area to account for policy and cultural differences across agencies and regions. We include year fixed effects to account for the severity of the fire season, which may capture traumatic experiences of the IHC members associated with a particular fire season. Cumulative experience is included to account for human capital and seniority on the crew. These time-varying measurements allow us to estimate the effect of these factors on retention over the course of an IHC member's career. The model effectively forms cohorts of IHC members and associates covariates with the share of the cohort that exits in a given year, conditional on having been in the system for at least that many years.

The identification of competing wages and days assigned coefficients relies on several assumptions. Neither competing wages nor days assigned are meaningfully influenced by an IHC member's decision to leave the job or remain. Competing wages are a function of regional labor market conditions, and individual firefighters represent a small share of the potential labor force, so there is little risk of simultaneity or reverse causality. Days assigned are also determined exogenously by the severity of the fire season within the region and around the country. The severity of the fire season determines how many days IHCs are dispatched throughout the year.

While we control for several factors that we expect would influence retention, our list is not exhaustive, so it is possible that we omit variables correlated with retention. However, this should only bias our estimates if these omitted variables are sufficiently correlated with our measures of competing wage and days assigned (Wooldridge, 2015, pg 88). Again, since wages in competing occupations are determined by aggregate supply and demand, we do not expect any correlation with individual IHC members' unobservable characteristics. Similarly, these unobservable preferences for firefighting should not systematically influence the demand for firefighting via the severity of the fire season.

Measurement error is another potential source of endogeneity. Our measure of competing wages is based on occupations with similar skill sets and job requirements as well as empirical evidence of occupations that people move between. However, it may not capture the opportunity cost of all IHC members, particularly because early career IHC members were hired on a seasonal basis during this time period, so they might be able to take advantage of high competing wages in the off-season. We expect that any measurement error in competing wages should bias our coefficient estimates toward zero, making them a conservative estimate of the role of wages in alternative occupations (Angrist and Pischke, 2014).

IHC members that leave their crew may return in future years and leave again. In these cases, we omit the years they are not active in an IHC, and resume their "clock" if and when they rejoin an IHC. This implies that individuals may experience multiple exit events at different times in the data. However, they are considered part of the same cohort as other individuals who started in an IHC in the same year. This approach is consistent with the Andersen-Gill approach to dealing with multiple events (Amorim and Cai, 2015).

We estimate all hazard regressions using the *survival* and *coxph* libraries (Therneau and Lumley, 2015) in R version 4.1.1 (R Core Team, 2013). The dataframe was set up with one row per year per person (i.e.,

(start time, end time] format, see Therneau et al. (2023); and Amorim and Cai (2015).) The baseline survival function was estimated using the *survfit2* function, while Cox PH models were estimated using the *coxph* function. The *survminer* package was used to plot the Kaplan Meier curves using the *ggsurvplot* function and to assess the proportional hazards assumption using the *ggcoxdiagnostics* function (Kassambara et al., 2021).

4. Results

We estimate a series of Cox PH models to quantify the effect of days assigned in the previous year, cumulative experience, and wages of alternative occupations on IHC retention. Table 4 contains the coefficient estimates of the hazard models. Column 1 shows the results of our preferred specification, including Competing Wage ($1000s). Column 2 shows the results of a similar specification using the difference between an IHC Maximum Crew Earning Potential and the Competing Wage (MCEP-Competing Wage). Column 3 returns to using competing wages but also includes crew-specific fixed effects to account for unobserved factors that may cause crew members to leave or remain in the crew. All specifications include fixed effects for the IHC's agency and the geographic area where the crew is based. We cluster standard errors on crew ID to account for within-crew correlation. We confirm that the data satisfy the proportional hazards assumption based on plots of the Schoenfeld residuals in appendix A1.

Standard errors are clustered at the IHC level to account for correlation between crew members for model 1 and 2.

The coefficient estimates of a Cox PH model describe how a one-unit increase in a covariate (e.g., Days Assigned) proportionally shifts the hazard function. The hazard function represents the probability that an individual experiences the event at time t (leaving their IHC) conditional on having remained in the crew up until t. Perhaps counterintuitively, this implies that negative coefficients have a retentive effect while positive coefficients imply an increase in the likelihood that someone leaves their IHC.

The survival function is equal to one minus the cumulative hazard function, or the probability that an IHC member has not exited by time t (Kalbfleisch and Prentice, 2002). In addition to our coefficient table, we present our results as shifted survival curves. These survival curves provide a clear sense of the coefficient magnitude and allow us to translate the coefficient into a median length of tenure on an IHC (see Fig. 5). To examine possible heterogeneity within the Days Assigned, Cumulative Experience, and Competing Wages variables, we binned the variables into deciles (days assigned and cumulative experience) or logical categories (competing wages; $10,000 bins). We re-estimate model 1 using the binned categorical version of our three covariates of interest: Days Assigned, Cumulative Experience, and Competing Wage. Fig. 4 shows the estimated coefficients and confidence intervals for the Hazard Ratios for the set of binned variables.

Table 4
Cox PH regression results.

	1	2	3
Days Assigned	−0.011***	−0.011***	−0.011***
	(0.003)	(0.003)	(0.002)
Cumulative Experience (100 days)	−0.164***	−0.163***	−0.148***
	(0.003)	(0.003)	(0.002)
Competing Wage ($1000)	0.001		−0.002
	(0.003)		(0.002)
MCEP-Competing Wage ($1000)		0.001	
		(0.003)	
Year 2013	0.118	0.123	0.127*
	(0.003)	(0.003)	(0.002)
Year 2014	−0.155+	−0.159+	−0.200**
	(0.003)	(0.003)	(0.002)
Year 2016	0.102	0.096	0.082
	(0.003)	(0.003)	(0.002)
Year 2017	0.233**	0.227**	0.230***
	(0.003)	(0.003)	(0.002)
Year 2018	0.312***	0.311***	0.324***
	(0.003)	(0.003)	(0.002)
Fixed Effects			
Agency	x	x	x
GACC	x	x	x
Crew			x
Num.Obs.	11,447	11,447	11,447
BIC	58,741.5	58,740.6	59,197.2

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001.

We find that both Days Assigned and Cumulative Experience reduces the hazard of leaving an IHC whereas we find no statistically significant effect of Competing Wage (wage of alternative occupations). Specifically, an additional day assigned to a wildfire incident reduces the hazard rate by -0.011 with 95% CI $[-0.014, -0.008]$. Cox PH model coefficients can be transformed into relative risk ratios where the coefficient is exponentiated. An additional Day Assigned is associated with a relative risk of 0.99 ($exp(-0.011)$) compared with someone who was assigned one fewer day, all else equal. In other words, the additional Day Assigned increases the probability of retention by 1%. This estimate is very stable across alternative model specifications, including crew-level fixed effects (column 3). Fig. 5a puts the regression results in perspective, comparing the survival curves at the median Days Assigned (82 days) to someone who experiences the 90th percentile Days Assigned (111 days), holding all else equal. The median duration of employment increases by 32%, from 2.83 years for the median IHC member to 3.73 years for that same member who is assigned at the 90th percentile. Days Assigned is directly observable in the data and captures both the costs associated with workload (e.g., stress, time away from family) and earnings. Our results suggest that the earnings effect dominates the costs.

We find that an additional 100 days of Cumulative Experience reduces the hazard rate by 0.164 with 95% CI $[-0.167, -0.161]$, and has a relative risk of 0.848 compared with a similar IHC member with 100 fewer days of Cumulative Experience. Again, this estimate is robust across alternative specifications in columns 2 and 3. Fig. 5b compares the median IHC member (212 days Cumulative Experience) to one with the 90th percentile Cumulative Experience (571 days). We find that someone with the 90th percentile Cumulative Experience has a median duration as an IHC member 64% longer than the median IHC member (4.65 years compared to 2.83 years).

Finally, we consider the role of one's Competing Wage on retention. Economic theory suggests that a higher wage in alternative occupations in the same labor market would lead to an increased hazard rate or lower retention. Our coefficient is positive but very small and not statistically different from zero. Column 2 shows the results of an alternative specification using the difference between an IHC member's own Maximum Crew Earning Potential and their Competing Wage (MCEP-Competing Wage). The advantage of this covariate is that it puts competing wages in context relative to one's own earning potential. The disadvantage is that our measure of one's earning potential is an estimate based on crew-level assumptions and may introduce measurement error. Fig. 4 shows the relative risk coefficient estimates of a model with Competing Wages binned in $10,000 increments to illustrate the heterogeneity of our effect estimate. Indeed, we find that the probability of exit increases by a factor of 1.32 when IHC members face very high competing wages ($85,000 - $95,000) relative to the lowest range of $15,000 to $25,000, though the confidence intervals do include zero.[1]

We find that retention has been falling across all IHCs in our sample

[1] We define Competing Wage bins based on even increments of $10,000 rather than deciles as with Days Assigned and Cumulative Experience. The Competing Wage estimates were fairly concentrated around the mean, so the bin widths were small around the mean and large in the tails. We were interested in the effects at the upper tail in the case of Competing Wages.

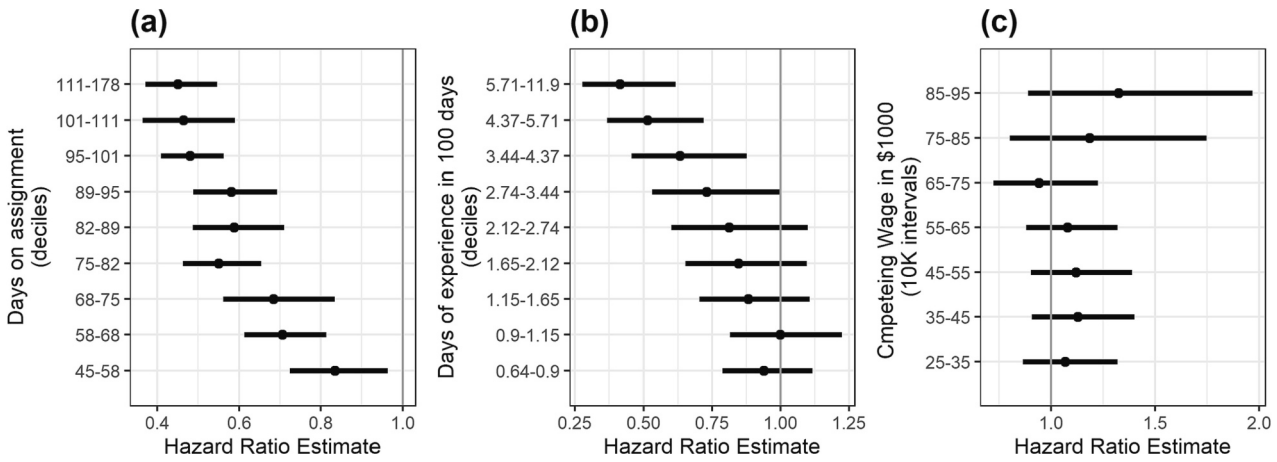

Fig. 4. Hazard ratio estimates for model 1 with binned variables: Days Assigned (deciles), Cumulative Experience (deciles), and Competing Wage ($10,000 intervals).

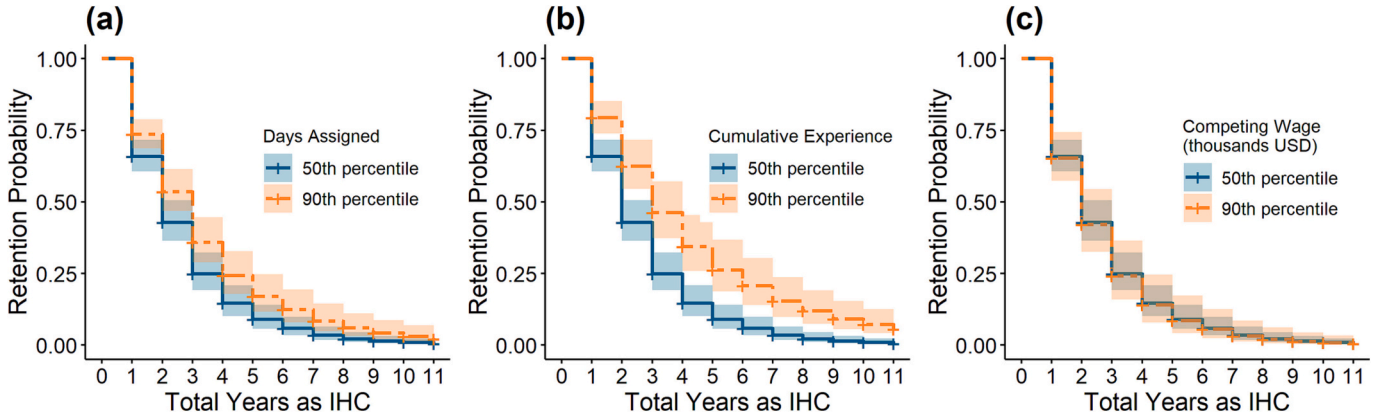

Fig. 5. Estimated Kaplan-Meier curves for IHCs 2008–2019 for predicted values using the Cox PH model 1 formulation (see Table 2). A baseline run (blue lines) was estimated with continuous values held at their median value; the year was held at 2015, agency was held at USFS, geographic area was held at Southern California. Then, a new survival curve was estimated by changing only days assigned (a), cumulative experience (b), or competing wage (c) to its 90th percentile value (orange lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

period (2012–2018), despite our efforts to control for monetary explanations for turnover. For instance, the relative risk of exit from an IHC is larger in 2018 compared to 2015 (the reference year) by a factor of 1.37. In contrast, the years prior to 2017 are not statistically different than 2015. These results are robust to alternative specifications, including crew-level fixed effects. These results point to a trend of falling retention starting in 2017.

We assess the robustness of our results to several alternative specifications. Table A2 in the Appendix shows that our key results on Days Assigned and Cumulative Experience are robust to: omitting California, omitting Competing Wage, including MCEP and omitting Competing Wage, omitting individuals with start dates before 2008, and omitting Days Assigned.

5. Discussion

Our results are generally consistent with the frameworks that specify that pay generally should have a significant impact on retention (e.g., Adams, 1963; Herzberg et al., 1959; Hirschman, 2004; Whitford and Lee, 2015), as well as with empirical results that pay has an impact on retention from other fields. One of our key findings is that individuals who had a high workload (Days Assigned) in the past year are more likely to return for another season. Days Assigned captures the effect of both the annual earnings associated with more days assigned as well as the physical and psychological stresses. Our results suggest that the net effect of more days assigned has a retentive effect, which suggests that the additional annual earnings have a powerful effect on the decision to remain on the IHC. An IHC member in the "Senior Firefighter" position can make up to $512 per day, including hazard and overtime pay while on a fire assignment.[2] The average IHC member in our dataset is assigned 82 days per year, which translates into almost $42,000, a substantial share of their annual earnings. The 90th percentile of Days Assigned is 111 days, which could translate into $56,000 or an additional $14,000 relative to the average. Our binned estimates in Fig. 4a suggest that these earnings associated with the 90th percentile Days Assigned reduce the probability of exit by over 50%. Similarly, we find that more cumulative experience gained over multiple seasons increases retention. As we discuss in Fig. 1, more firefighting experience translates into higher seniority levels as well as the ability to move into higher-paying jobs that require higher levels of qualifications. These factors likely combine to increase retention. While our results show that more

[2] A firefighter employed at a GS5 step 2 (a typical "senior firefighter" position) in 2023 whose duty station resides in the "Rest of US" locality will make $148 when working 8 h while not assigned to a fire (i.e., a day at the station). That same firefighter will make at least $446 over a single day on an assignment (working a 16-h day where 8 of the hours are counted as overtime, a typical day on a large fire) and could make up to $512 per day (when all 16 h are counted as overtime because they are working on their scheduled days off).

cumulative experience and days assigned increase retention, we do not directly estimate the effect of wages.

Our results suggest that under the wage structures in place from 2012 to 2018, the marginal earnings associated with additional days assigned serve as a strong incentive to remain on an IHC. Our data precedes recent legislation providing a short-term increase in wildland firefighter wages implemented in 2021 (DeFazio, 2021). This law was implemented using a set of temporary pay increases "in pay equal to $20,000 or 50% of their annual base salary (including locality pay and special rate supplements), whichever is less" (USDA Press, 2022). Increasing base (non-assignment) wage rates should increase annual earnings and may mitigate the strong incentive of additional earnings associated with assignments. However, the extent of this effect depends on the individual's marginal utility of income and the shape of their labor supply curve. If IHC members can substantially increase their earnings via additional assignments, our results suggest that they will continue to accept high workloads.

A recent review of fatalities and injuries (Innovation and Organizational Learning, 2022) found that the current wildland fire pay structure incentivizes firefighters to take on additional risk in the form of more and longer assignments. The President's 2024 proposed budget would "establish a special base rate salary table for all federal wildland firefighters that will permanently increase their pay; create a new premium pay category that provides all incident responders with additional compensation for all hours they are mobilized on an incident" (USDA Press, 2023). Maintaining the wage premium on incidents may increase the risk of injury and contribute to burnout; however, our results suggest that the wage premium on incidents coupled with more days on assignment can increase retention. Future work should strive to understand whether the retentive effect of more assignment days diminishes as base pay is increased.

The impact of competing wages on retention is less clear than that of days assigned and cumulative experience. The impact of competing wages, as well as the difference between maximum potential crew earnings and competing pay, is not statistically associated with retention rates. When we examine the heterogeneity of that effect by using binned data rather than a linear effect in the model, we find limited evidence that the upper bin ($85 K–90 K) is associated with exit. There are several possible explanations for the lack of statistical association between competing wages and retention. First, our measure of competing wages is based on occupations that wildland firefighters transition between in general. Individual skills and preferences may vary, implying that their choice set for alternative occupations is different from the occupations we use to generate the competing wage. Second, we do not observe an individual's earnings directly, which may vary across IHC members due to experience, so the competing wage may be relatively high to some and low to others on a crew. The statistical consequence may be similar to measurement error in which the coefficient estimates attenuate toward zero.

We find decreasing rates of retention over time (year fixed effect coefficients). Specifically, these fixed effects capture annual trends common to all IHCs conditional on days assigned, cumulative experience, and competing wages. These fixed effects may reflect agency policies or broad macroeconomic trends. For example, fire activity increased throughout our study period compared to the previous decade. These results are consistent with increased media coverage and scrutiny of unfilled positions occurring more recently (United States Government Accountability Office, 2022; Davidson, 2022; Safo, 2021; Quinton, 2021; Sacks, 2022). In addition, the results of the Federal Employee Viewpoint Survey, when aggregated by agency, show a decrease in the overall employee engagement and satisfaction score from 2017 through 2019 for Forest Service employees (Partnership for Public Service, 2022) and show that the Forest Service lags behind comparable agencies regarding employee engagement and satisfaction. While these results represent the entire Forest Service and thus include a wider sample than just IHC members, they do show a decline within the agency by which most IHC members are employed. In addition, the gap between the Forest Service and comparable agencies regarding satisfaction with pay widened substantially between 2016 and 2019.

There are many logical reasons for challenges in the retention of wildland firefighters. The health risks and occupational stresses are well documented (Navarro, 2020; Britton et al., 2013; Vincent et al., 2018; Adetona et al., 2016; Jung et al., 2021; Koopmans et al., 2022; Aisbett et al., 2012a; McLennan et al., 2017; Desmond, 2009). Prediction of potential annual salary can be challenging as fire activity, and thus, fire assignments can vary substantially by season, leading to a high variation in salary from year to year. Some working conditions are generally expected to only get worse over time, as fire severity increases the need for firefighters over a longer period on fires with more severe fire behavior. Current policy proposals focus primarily on increasing pay rather than improving workplace conditions. However, empirical studies have found other factors such as workplace environment, supervisor support and support resources (Nguyen and Tuan, 2022; Byrne et al., 2017; Hassett, 2022; Asencio, 2016; Jacquet et al., 2008), leadership (Wright et al., 2012), employee engagement and empowerment (McCarthy et al., 2020; Kim and Fernandez, 2017), burnout and lack of work-life balance (Yu, 2019; Madhavappallil et al., 2014; McCarty and Skogan, 2013), and mission change (Ihrke, 2004) to also substantially impact job satisfaction and turnover intent. Public servants may have an additional source of job satisfaction linked to the feeling that they are serving the public good (Perry and Wise, 1990; Naff and Crum, 1999; Homberg et al., 2015). None of these factors were tested in this research, and future work to understand how such factors influence retention in wildland firefighters would be valuable.

One limitation of this work is that the data is restricted to events occurring prior to 2019. This is because the ROSS was replaced in March 2020 with the Interagency Resources Ordering Capability (IROC). While IROC tracks data very similar to ROSS, there were challenges when IROC was first implemented that led to missing roster data for the beginning of the year. While similar data to the ROSS data can be collected for 2021 and 2022, there is a gap in data in 2020 that would be challenging to overcome. Data directly from Human Resources could help bridge this gap, if available. Including more recent years in the data would allow for valuable analyses of the impacts of events occurring during 2020 and 2021, such as the COVID-19 pandemic and related vaccination requirements and pay increases implemented in 2021 due to an executive order and 2022 as mandated by the Bipartisan Infrastructure Law. In addition, state firefighting forces such as CalFire have increased the size of their wildland firefighting workforce. As some of these state positions have a higher base pay rate than their federal counterparts, the increase in federal salaries required to meet or exceed state pay could be substantial.

Our study focuses solely on members of an IHC, which is a fairly unique set of wildfire suppression personnel. IHCs are primarily federally funded crews based in the Western US which are officially designated as national resources with requirements regarding a minimum time the crew must be available to go anywhere in the US (National Interagency Hotshot Crew Steering Committee, 2019a). Because of their required availability and unique capabilities, IHCs are one of the most highly used fire suppression resources in the US. Hotshots understand the nature of the job and plan to work extensively throughout most of the summer. The work is challenging and dangerous, which creates strong social bonds between members of the IHC community (Desmond, 2009) as well as a strong sense of organizational membership, though high levels of turnover can affect this crew cohesion. Consequently, our results may not generalize to the rest of the wildland firefighting community. We expect the effects of our measured covariates to be most muted in the IHC community. Future work should study the effect of workload and economic factors on retention in the broader wildland firefighting community.

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Disclaimer

The findings and conclusions in this report are those of the author(s) and should not be construed to represent any official USDA or U.S. Government determination or policy.

Author agreement statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere. We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. He/she is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

Signed by all authors as follows: Erin Belval, Jude Bayham, and Shayne Magstadt.

CRediT authorship contribution statement

Erin J. Belval: Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Jude Bayham:** Conceptualization, Methodology, Software, Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Shayne Magstadt:** Methodology, Software, Formal analysis, Data curation, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Code and most data is freely available as noted in "Data Availability". Personnel assignment data cannot be shared. The competing wage data from the Bureau of Labor Statistics and the general schedule pay scale information are publicly available. However, the individual-level IHC personnel data is not publicly available. We do provide the code used to process all the data and fit the models at https://github.com/jbayham/ihc_retention.

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Appendix A. Appendix

A.1. Additional data details

A.1.1. Assignment data

Resource orders for crews in ROSS are structured such that there can be a roster of personnel attached to each “root” request for a crew. The roster includes a unique identifier for each firefighter on the crew; this ID remains constant across years, even when firefighters move between employment opportunities, including between agencies. Rosters may change throughout the year as firefighters may not be dispatched to every assignment. Therefore, we are able to use the database to identify the set of firefighters dispatched as a part of an IHC for even a single assignment each year and to track the number of days they were assigned to fires as a part of an IHC.

Crews must have at least 18 firefighters on their roster to accept a fire assignment. When crews are short because of injuries or personal leave, firefighters who were not hired as an IHC member may be pulled from other assignments on their management unit or hired on a short-term “Administratively Determined” basis to fill in and allow the IHC to work on an incident. Because these personnel are not hired as IHCs, we screen them out of the data by only counting those who have gone out for 28 days or more on assignments as an IHC crew member.[3]

The IHC data is somewhat unique in the retention literature in that there are gaps in the data during which IHC crew members are not at risk due to one or more years absent from IHC employment (i.e., the crew members who re-enter). Thus, the data is comprised of a set of recurrent events. Following the example of Amorim and Cai (2015), we structure the data such that there are gaps in the risk interval (see Table A1) in the appendix to see an example. We considered the temporary leave an exit, and their subsequent return brought them back into the risk pool at the number of years since we observed their initial entry. See Table A1 for an example of how the data is structured for entry into the *coxph* function. Person 1 is observed working on fires as a hotshot in 2012, 2013, and 2014: they have one exit associated with their tenure on IHCs. Person 2 is observed assigned to a fire as a hotshot in 2016, 2017, 2018, and 2019; they have no exits associated with their tenure on IHCs. Person 3 is observed working on fires as a hotshot in 2013, 2015, 2016, and 2017; there are two exits associated with their tenure on IHCs. Note the missing observation for Person 3 for year 2014: we have no information on that person that year beyond that they are not on an IHC so they are removed from the analysis during that period.

Table A1
Example structure of the data.

(*continued on next page*)

[3] The 28-day threshold was developed through consultation with the 2021 chair of the IHC Steering Committee.

Table A1 (*continued*)

Person ID	Year	T_{start}	T_{end}	Exit flag
Person ID	Year	T_{start}	T_{end}	Exit flag
1	2012	0	1	0
1	2013	1	2	0
1	2014	2	3	1
2	2016	0	1	0
2	2017	1	2	0
2	2018	2	3	0
3	2013	0	1	1
3	2015	2	3	0
3	2016	3	4	0
3	2017	4	5	1

We tested the independent and identically distributed assumption of the Andersen-Gill model by fitting a frailty model: because the results were nearly identical to the Andersen-Gill models, the independent and identically distributed assumption is met, and thus, we do not explicitly account for within-individual correlation. We cluster standard errors on crew ID to account for within-crew correlation. We confirmed the proportional hazards assumption visually for all tested models (see the appendix for plots of Schoenfeld residuals for the preferred model specification).

A.1.2. Wage calculations

We do not observe an individual's earnings. Instead, we estimate a maximum crew earning potential for each crew from surveys completed by each IHC after each season. The IHC Steering Committee collects annual reports from each IHC regarding the number of days crews spent working on each of the activities the crew was engaged in across the past season. These reports are archived from 2012 to 2021 and are available from the IHC Steering Committee. While there is some missing data each year from crews that fail to submit their data (4.5% of the data is missing across the 2012–2019 data), this is a comprehensive data set that allows us to estimate a maximum crew earning potential salary for each crew as it includes information on work done off fire assignment and allows us to account for both overtime and hazard pay. The maximum crew earning potential calculation using these data was developed in consultation with the chair and a member of the IHC Steering Committee. For this study, the maximum crew earning potential calculation assumes the base pay for a GS-5, step 2 employee working 13 weeks of the year and specifically accounts for the locality pay associated with the crews' duty stations. The maximum earning potential is calculated using historical hourly wages from the Office of Personnel Management (Office of Personnel Management, 2023), then deflated to 2012 dollars. This metric provides us with relative measures of wages between each crew each year, as well as providing a point of comparison against local competing wages.

A.2. Additional modeling details

A.2.1. Confirming the proportional hazards assumption holds

We use the *survminer* package to visually assess the proportional hazards assumption using Schoenfeld residuals with the *ggcoxdiagnostics* function. The Schoenfeld residuals should be independent of time in order to conform to the proportional hazards assumption; thus, a plot showing deviation from a horizontal line along the $y = 0$ axis implies a violation of the assumption. The results can be seen in Fig. A1. While some models did fail statistical tests of the proportional hazards assumption (using the *cox.zph* function), it is likely due to our large sample size or having a continuous explanatory variable in the model rather than an underlying problem with the proportional hazards assumption (Clogg and Shihadeh, 1994).

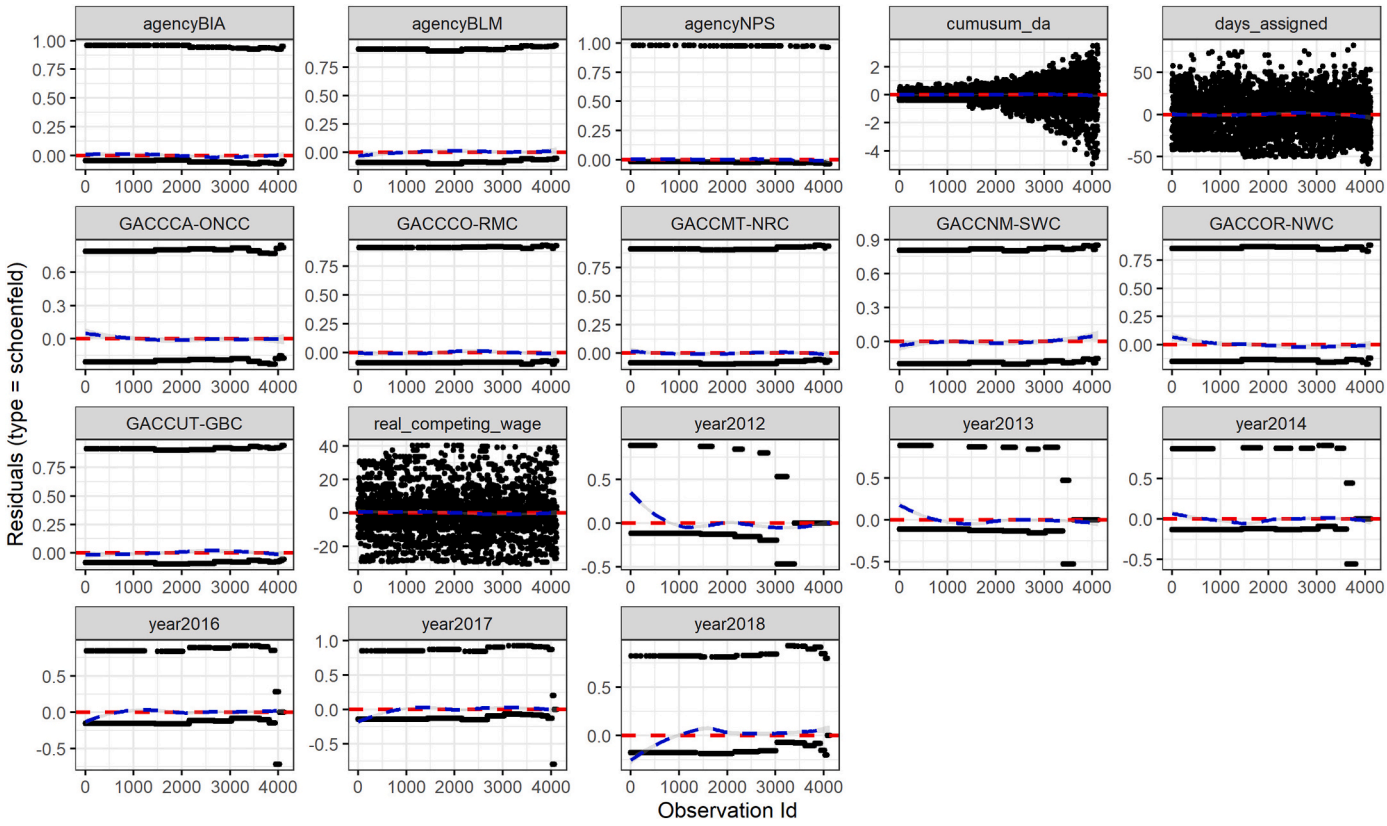

Fig. A1. Schoenfeld residuals for our preferred model specification (model 1) produced to visually assess the proportional hazards assumption.

A.2.2. Alternative model specifications

We tested several models that we did not show in the paper. Each of these models tests the robustness of our results; coefficient estimates are shown in Table A2. Column 1 is our preferred specification from the paper, included as a reference. Column 2 omits any crew members from California to ensure that the high number of crews in California, a state with a relatively high minimum wage, is not driving results. Column 3 excludes competing wages from the model entirely. Column 4 uses the maximum crew earning potential alone without being differenced from competing wages. Column 5 assesses whether individuals with unknown start dates (prior to 2008) influence the results due to crew members starting before 2008 (we cannot know how much human capital they accumulated prior to 2008, and our dataset is short in comparison with a career). Column 6 omits Days Assigned to assess the impact on competing wages.

We find that our coefficient estimates are consistent across columns 1 through 5. However, we do find that omitting Days Assigned (column 6) increases the magnitude of the Cumulative Experience coefficient, suggesting some collinearity between the two covariates.

Table A2
Cox PH regression results: robustness checks.

	Model 1	(2) No California	(3) No Competing Wage	(4) MCEP and No Competing Wage	(5) Start date after 2008	No Days Assigned
Days Assigned	−0.011***	−0.012***	−0.011***	−0.011***	−0.010***	
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	
Cumulative Experience (100 days)	−0.164***	−0.178***	−0.164***	−0.166***	−0.145***	−0.280***
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Competing Wage ($1000)	0.001	−0.001			0.001	0.001
	(0.003)	(0.002)			(0.003)	(0.002)
MCEP ($1000)				0.008*		
				(0.004)		
Year 2013	0.118	0.067	0.120	0.118	0.156+	0.042
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Year 2014	−0.155+	0.046	−0.157+	−0.146	−0.150	−0.127
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Year 2016	0.102	0.053	0.101	0.081	0.071	−0.076
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Year 2017	0.233**	0.318**	0.233**	0.200**	0.207**	0.029
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Year 2018	0.312***	0.332***	0.314***	0.279***	0.271**	0.112
	(0.003)	(0.002)	(0.001)	(0.004)	(0.003)	(0.002)
Fixed Effects						

(*continued on next page*)

Table A2 (*continued*)

	Model 1	(2) No California	(3) No Competing Wage	(4) MCEP and No Competing Wage	(5) Start date after 2008	No Days Assigned
Agency	x	x	x	x	x	x
GACC	x	x	x	x	x	x
Crew						
Num.Obs.	11,447	6971	11,447	11,447	9002	11,447
BIC	58,741.5	32,058.6	58,732.4	58,731.2	51,075.9	58,907.0

+ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Standard errors are clustered at the IH Crew level to account for correlation between crew members.

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