The Effect of Shift Structure on Performance

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Abstract

The effect of shift structure on worker performance and productivity has been an issue of increasing interest among firms and regulatory bodies, motivated by the belief that fatigue is a critical mediator. We study this issue using approximately 742,000 emergency trauma and medical incidents attended by 2,381 paramedics in the state of Mississippi between 2001 and 2005, and evaluate the extent to which performance of paramedics towards the end of their shift is impacted by its length. We find that paramedics exhibit poorer performance towards the end of long shifts, compared to their performance towards the end of shorter shifts. In addition, at the end of longer shifts, paramedics perform fewer medical interventions while the speed with which procedures are performed deteriorates significantly. We argue that fatigue is the mediating factor in the observed decline in performance. These findings have implications for workforce organization and call attention to regulation designed to limit extended work hours.

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I. Introduction

Shift work is common in many industries and is universal in those operating around-the-clock. While widespread, the impact of shift structure and length on performance is not well understood. Most firms and organizations function in such a way that labor works in shifts of 12 hours or less on a daily basis, while others have shifts lasting 24 hours or more. Such long shifts reduce commuting and adaption time, and are associated with longer breaks and time off between consecutive shifts. On the other hand, the cumulative effect of night work and extended work hours can lead to fatigue-impaired employees.

Fatigue from long work hours, sleep deprivation, and circadian disruption has been recognized as a substantial cause of serious human errors (Veasey et al. 2002). In the context of health care, policies and procedures aimed at reducing the incidence of medical errors have either been voluntarily implemented by health care organizations or imposed by regulators. In medical education, for example, the Accreditation Council for Graduate Medical Education (ACGME) implemented duty hour restrictions in 2003 for all ACGME-accredited residency programs, following concerns about deaths associated with medical errors in US hospitals (Nasca et al. 2010).[1]

While quantifying the effect of fatigue resulting from long shifts has important implications for policy and safety regulation design regarding shift structure, there is a paucity of research that

[1] In June 2010, the ACGME issued a report calling for an unprecedented 16 hour limit to shift lengths for interns (Nasca et al. 2010).

credibly isolates fatigue as the mediating factor for deteriorations in real time performance among health care workers who work extended hours.

There is a literature on the effects of extended work hours on healthcare providers' cognitive ability. The bulk of this literature follows a within-subject lab-based research design (e.g. subjects with different degrees of sleep loss are evaluated using standardized tests).[2] Veasey et al., (2002) provides a comprehensive review of 33 studies on the effects of sleep loss on resident performance. Most studies fail to compare providers at the same time of day but on different shift lengths, and hence the effects of extended work hours are likely confounded by nighttime work. Moreover, these studies involved a very small number of subjects, with the majority of studies having fewer than 20 subjects. Only 6 of the 33 studies reported the statistical power for the null. In addition, many of the studies had significant numbers of dropouts and health care providers who declined the study, and it is possible that these reasons were confounded with vulnerability to sleep loss.[3]

In more recent work, Lockley et al., (2004) found thirteen out of 20 interns to experience a decrease in the number of slow eye movements during overnight work (from 11 p.m. to 7 a.m.) in longer shifts compared with shorter shifts. Similarly, Arnedt et al., (2005) found reduced

[2] Typical lab-based tests include: special perception tests, auditory serial addition tests, number connection tests, card sorting tests, reaction time tests, hand-eye coordination tests, and divided attention tests. Similarly, lab-based simulations include: simulated triage tasks, simulated intubation, and simulated driving.

[3] The residents who were most vulnerable to the effects of sleep loss may have selectively refused to participate in these studies.

sustained attention and poorer performance on a driving simulator after "heavy" rotations compared with "light" rotations for 34 pediatric residents.

Studies measuring clinical performance on actual patients tend to be more descriptive. For example, Goldman et al., (1972) compared videotapes of actual operations performed by five residents and found a 30% increase in surgical time in 4 of the 5 residents with little sleep. Analysis of large retrospective data, where both shift length and actual performance are observed is quite rare. Haynes et al., (1995) studied 6,371 surgical cases and found no increased risk of complications for patients seen by residents that were on call for 24 hours on the day prior to surgery. Rogers et al., (2004) studied data from logbooks filled by 393 registered nurses over four weeks and found that working more than 12 hours was associated with increased number of reported errors. While both retrospective studies benefited from a relatively large sample size, the analysis is cross-sectional, the timing of complications or errors is not known, and the effects of shift length may be confounded by time of the day.

Finally, a number of studies focused on the effects of extended work hours on risk of injury to residents. Steele et al., (1999) found an increase prevalence of motor vehicle crashes involving medical residents during post-call periods. Ayas et al., (2006) studied 498 cases of percutaneous injuries for interns, who reported fatigue as a contributing factor in 30% of cases. The paper found such injuries to increase with work duration and nighttime work. However, it is plausible that the link between injuries and work duration is confounded by the time of day, as longer shifts are more likely to include nighttime work. Moreover, differences in hospital activity during the night compared with the day could explain the authors' findings.[4]

In this study, we examine the relationship between shift structure and productivity in Emergency Medical Services (EMS), where there is considerable variation in shift structure. Specifically, we analyze paramedic performance in approximately 743,000 emergent medical and trauma incidents by tracking 2,381 paramedics in the state of Mississippi over five years. We first adopt a paramedic fixed-effects difference-in-differences approach and argue that fatigue is likely to be a key contributing factor in the deterioration of paramedic performance toward the end of longer shifts (e.g. a 24 hour shift). We later consider the relationship between time-in-shift (or time on duty) and provide a number of robustness checks that serve to complement the *within*-paramedic analysis.

The main performance measure in this study is a process measure that is widely accepted in the EMS community, total out-of hospital time, which is measured from the moment the ambulance crew is dispatched to a scene to the moment it arrives at the hospital (Carr et al. 2008). We further partition this measure into response time, on-scene time, and transport time. Response time is the most commonly used performance marker in EMS contracting between municipalities and ambulance providers (David and Brachet, 2009; David and Brachet, 2011). In addition, we track the number of pre-hospital interventions performed on-scene and minutes-

[4] "Hospitals may have more phlebotomy and intravenous teams available during the day so that interns would be doing relatively more needlesticks at night. Moreover, admitting and transferring patterns may lead to an increased need for interns to perform needlesticks at night." (Ayas et al., 2006)

per-procedure. While these are all process measures that serve as inputs into a health production function, shorter out-of-hospital time intervals are argued to be an important factor in survival (Feero et al, 1995; Nichol et al, 1996; Sampalis et al, 2002, IOM, 2007).

The practice of working both long and short shifts is prevalent in EMS, with over 93% percent of emergency medical technicians (EMTs) in our sample working both types of shifts. The most common reason for observing within-EMT variation in shift lengths is the practice of shift-splitting and back-to-back shifts (Kuehl, 2002). Conversations with EMS directors in Mississippi confirmed that while EMS companies typically subscribe to a specific shift structure (for example, fire-based EMS providers typically organize service delivery around 24-hour shifts), flexibility in scheduling is widespread.[5] We find that paramedics working longer shifts exhibit poorer performance toward the end of their shift compared to their own performance when working shorter shifts. In addition, estimating a *within*-shift relationship between time on duty at nighttime and performance produced consistent results. Our study contributes to the evidence that performance deteriorates with shift length even in a life-and-death context such as EMS, where there is little room for error. The underlying mechanism is likely fatigue from extended work hours.

[5] For EMTs that worked both long and short shifts, shift-switching occurred rather frequently (every 12 days on average). This is broadly consistent with most EMTs working one long shift and three to four short shifts per week.

II. Data

Our data come from the Mississippi Emergency Medical Services Information System (MEMSIS) and are gathered by the Office of Emergency Planning and Response at the Mississippi Department of Health. MEMSIS provides statewide data, systematically collected through a comprehensive software system enabling real time collection of patient level data by EMS providers and dispatchers.

MEMSIS allows us to track the universe of paramedics' activities between 2001 and 2005, totaling 1,625,000 ambulance runs, including 882,000 inter-facility transfers, in addition to 743,000 trauma and medical incidents. We use all incidents for the purpose of constructing shift schedules, yet to focus on incidents for which time to definitive care is most likely to be important, we limit our attention to EMS incidents for which the initial emergent call was related to trauma (defined as motor vehicle crashes, motorcycle crashes, pedestrian and bicycle injuries, stabbings, assaults, gunshots, or falls) or to a medical emergency (defined as cardiac, gastrointestinal, neurological, psychological, substance abuse, or other) and for which an advanced life support (ALS) unit was dispatched to the scene.[6] We exclude cases of death on arrival as well, because time to hospital's morgue is not important for these incidents. Our final sample is comprised of 155,392 trauma incidents and 587,617 medical incidents, which involve emergency transport to a hospital.

[6] ALS units are more heavily equipped than Basic Life Support units, and offer a wider range of interventions on scene. Inter-facility transfers, which are often non-emergent and scheduled in advance, were excluded.

Construction of Paramedic Shifts

MEMSIS, which is designed primarily for monitoring, billing and clinical evaluation, but not for human resources management purposes, does not contain an explicit indicator of shift structure for paramedics. Therefore, we elicit this information from the data. MEMSIS is organized by patient, with each observation corresponding to a single patient, recording the dates and times at which [1] the emergent call was received, [2] an ALS unit was dispatched to the scene, [3] the unit arrived on-scene, [4] the unit left the scene, and [5] the unit delivered the patient to definitive care. For each patient, the paramedic and driver who were dispatched to the incident are identified by unique (and stable) EMT IDs.

We exploit these features and the fact that MEMSIS records every EMS incident in the state – whether emergent or not – to construct paramedic and driver shifts based on their periods of inactivity, which we identify by their absences from the data. Sorting the data first by EMT ID, then by date and time at which they were alerted for each incident, we define the beginning of a new shift every time ten or more hours have elapsed between consecutive observations of the same paramedic.[7] Once shifts are defined, we measure a lower bound for the shift's duration as the difference between the times of the first and last calls of the shift. For simplicity, we refer to this difference as "shift length" and plot its distributions in the trauma and medical data on which we focus our analysis in the upper panel of Figures 1. For both types of incidents, the mode is around nine hours, and the distributions fall off precipitously thereafter, leveling off

[7] For robustness, we also used eleven and twelve hours between shifts as cutoffs for defining new shifts. The results presented below were not sensitive to these alternative definitions.

somewhat around twelve hours. This leveling largely forms the basis for our categorization of shift types: we define long and short shifts as those lasting longer and shorter than twelve hours, respectively. For simplicity, we refer to long shifts as 24-hour shifts, and short ones as 12-hour shifts, though these are admittedly very approximate characterizations. We use the time elapsed between every incident alerted and the first incident in the shift to construct a measure of time on duty. This measure of time-in-shift varies across incidents within shift, and forms the basis for out *within*-shift analysis.

The middle panel of Figures 1 plots the distribution of the paramedics' hours of inactivity between shifts separately for short and long shifts. These distributions are multi-modal, with (local) modes occurring roughly at multiples of twelve hours. A large proportion of paramedics on shorter shifts have between twelve and twenty four hours off between shifts. The next highest proportions occur in the [36, 48] and [60, 72] hours intervals. In turn, those paramedics starting long shifts are considerably more likely to have been off-duty for longer periods, with a large proportion having been inactive between 48 and 72 hours. These observations are consistent with evidence that paramedics working 24-hour shifts often have two to three days off between shifts.[8]

Finally, the lower panel of Figures 1 plots the distribution of the time at which the first incident of a shift occurred separately for short and long shifts. Whereas the vast majority of first

[8] The typical 24-hour shift schedule provides approximately 260 days off per calendar year, a reason many paramedics have a preference for this shift structure (Kuehl, 2002). Not surprisingly, a 2006 nationwide survey of paramedics found more than 55 percent of respondents reported working 24-hour shifts.

incidents occur between 7 AM and 10 AM for those paramedics starting long shifts,[9] the distribution is bimodal among short shifts, with a large mass between 6 PM and 8 PM. Thus, to provide round-the-clock coverage with short shifts, EMS agencies appear to design an early shift that begins at roughly the same time as those on long shifts, coupled with another that begins in the evening to cover the night. This was also consistent with information collected through interviews with local EMS officials.

Since a beginning of a shift is assigned to the first EMS call following a long break, it is likely measured with error. This measurement error is potentially more severe with greater typical time between incidents. Since the average time between morning incidents is approximately an hour, the true starting point of the shift is likely to precede our assigned starting point by roughly 30 minutes.[10] As we see in Figure 1, there is a mass of shifts with a first incident between 7 AM and 10 AM, suggesting that the dispersion in observed starting time in the morning is real.

The idea behind the ten-hour cutoff between incidents to define a shift is that, given the frequency of incidents in Mississippi, it is unlikely that a paramedic would be on-duty for ten

[9] In the analysis below, we study only those long shifts for which the first call came in the morning (7AM-12PM), such that the end of the shift roughly coincides with the midnight to 6 AM interval. This corresponds more closely to the clinical literature on the circadian cycle, according to which the natural deterioration in cognition, attention, and focus is most severe between 2 AM and 5 AM (Veasey et al., 2002; Lockley et al., 2004; Arendt et al., 2005; Ayas et al., 2006).

[10] Note that the average out-of-hospital time (36 minutes) places a lower bound on the average time between incidents for a given EMT.

consecutive hours without an incident (these incidents include inter-facility transfers, which are more frequent than medical or trauma emergencies). However, this procedure is imperfect, as on-duty paramedics may go inactive for ten or more hours, in which case our procedure will assign them a new shift when in fact they are on the same long shift. Thus, we will inappropriately tend to misclassify such paramedics as being on shorter shifts. Should that be the case, our estimates will be attenuated and might be thought of as lower bounds on the effect of long-shifts. Moreover, inactivity is commonly the result of low call volume, which is highly correlated with local characteristics (e.g. population size and density). A second type of misclassification, albeit less likely, may arise if paramedics have breaks between consecutive shifts that last less than ten hours. In this case, we will inappropriately tend to misclassify such paramedics as being on longer shifts. While possible, such instances are not very likely given the structure of shifts in Mississippi (e.g. no agency fits a schedule that consists of three consecutive eight hours shifts)

Nevertheless, it is not conceptually clear that, for the purposes of studying the effects of the variety of fatigue studied here, misclassifications of the first type represent severe threats to validity: while a paramedic may technically be on a long shift, having at least ten hours uninterrupted by an incident implies that she may be well rested for the calls that she does receive (paramedics often manage their fatigue with naps). In essence, since the effect that we aspire to identify arises from fatigue that results from sustained wakefulness, rather than fatigue from chronic sleep loss, such a paramedic would provide little identifying power if her true shift structure were observable.

We provide summary statistics for medical and trauma runs in our data, broken down by shift structure, in Table 1. In particular, these report the six different dependent variables of interest: total out-of-hospital time and its components (response time, on-scene time, and transport time), number of procedures, and minutes-per-procedure.

Paramedics on 24-hour shifts tend to have shorter out-of-hospital times compared with their 12 hour shift counterparts for both trauma and medical runs (35.17 versus 36.20 minutes for trauma incidents and 35.33 versus 35.86 minutes for medical incidents). These differences arise from longer on-scene and transport times among paramedics on shorter shifts, though they are mitigated by shorter response times in both medical and trauma incidents. In addition, paramedics on 24-hour shifts undertake 0.2 more pre-hospital interventions in trauma incidents than their shorter shift counterparts, and each procedure is performed 1.33 minutes faster. This relationship is reversed for medical incidents, with those on 12-hour shifts initiating 0.1 more procedures and performing them slightly faster than those on longer shifts.

Table 1 also presents summary statistics for key scene, provider, and patient characteristics. Among trauma incidents, those on long shifts see 2.7 percentage points more motor vehicle crashes, but 1.8 percent fewer falls. This helps explain the discrepancies in incident locations: long shifters are 3.6 and 3.1 percentage points more likely to attend scenes on county roads and state/federal highways, respectively, but are 3.5 and 3.2 percentage points less likely to be dispatched to incidents located on city streets and other locations (usually residences and nursing homes), respectively.

III. Analysis

We use a difference-in-differences approach to examine whether shift-to-shift changes in shift structure are associated with changes in underlying paramedic performance during the later segments of their shifts.

In our setting, we conceive of paramedics on long shifts as being in the treatment group and those on short (12 hours or less) shifts as being in the control group. We then define an incident as being treated if it takes place in the last quarter of a paramedic's 24-hour shift. Since the vast majority of 24-hour shifts begin in the morning (see Figure 1), it is specifically defined for incidents occurring between midnight and 7 AM. This definition captures the intuition that fatigue may manifest itself after long durations on call and especially at night (Veasey et al., 2002; Lockley et al., 2004; Arendt et al., 2005; Ayas et al., 2006).

There are several reasons to believe that emergent incidents occurring late at night will differ from those occurring during the day. For instance, a motor vehicle accident at 2 AM on a poorly lit county road will likely pose greater difficulties for paramedics than the same accident occurring at midday. Alternatively, the later accident may be more likely to involve an intoxicated driver, or one who has fallen asleep at the wheel, and is therefore likely to be more severe in both observable and unobservable dimensions. These observations suggest that simple night-versus-day comparisons will be inadequate for studying fatigue, as they will be plagued by unobserved severity and complications. For this reason, the late night deteriorations in performance among paramedics on 24-hour shifts are benchmarked to those of paramedics on 12-hour shifts (who started in the late afternoon/early evening; see Figure 1), who experience the same changes from day to night in the nature and characteristics of scenes as their 24-hour counterparts.

Our application of difference-in-differences is further refined by the fact that we can identify individual paramedics, allowing us to adopt a paramedic fixed-effects approach. Our estimates therefore result from *within-paramedic* comparisons, measuring the deterioration in performance that occurs in the last six hours of a paramedic's 24-hour shifts relative to that which she experiences in the second half of her 12-hour evening/night shifts, conditional on observed differences in incident characteristics. The inclusion of paramedic fixed effects implies that our results are not driven by inherent differences between paramedics who are selected for 24-hour shift work and those working shorter shifts. The upper panel of Table 2 indicates that roughly 30% of both trauma and medical incidents are served by paramedics on 24-hour shifts, and that approximately a quarter of shifts are 24-hour, with a slightly rising trend over time. However, these 24-hour shifts are unequally distributed across provider types. The lower panel of Table 2 indicates that public, fire-based EMS agencies are almost twice more reliant on long shifts compared to hospital-based and private providers, who employ 24-hour shifts between a quarter and a third of the time. This is consistent with the practice of back-to-back shifts for private providers (such as hospitals and private EMS companies) and the practice of shift splitting for public providers (such as municipal fire departments).

The models we estimate are of the following form:

(1) $$y_{isp} = \mathbf{X}'_{isp}\Pi + \text{Hour}'_{\text{isp}}\beta + \phi \times \text{Shift}_{is} + \gamma \times \text{Night}_{isp} + \alpha_i + \varepsilon_{isp}$$

where y_{isp} is a measure of performance for paramedic *i* attending patient *p* during shift *s*; $Hour_{isp}$ is a vector of 23 indicator variables specifying the time of day of patient *p*'s call; $Shift_{is}$ is an indicator for whether the attending paramedic is in a 24-hour shift; $Night_{isp}$ is an interaction term equaling 1 when the attending paramedic is in a 24-hour shift and patient *p*'s call came between midnight and 7 AM; $\mathbf{X}_{\text{isp}}$ are incident, patient, and provider characteristics; and α_i is a paramedic fixed effect.

We first estimate difference-in-difference models for total out-of-hospital time as the dependent variable, then separately for its component parts, first response, on-scene, and transport times, all of which are common EMS process measures. As additional evidence, we also estimate models using the number of pre-hospital procedures performed on-scene by paramedics, as well as the speed of procedures, conditional on at least one such pre-hospital intervention being performed.

All models control for the certification levels of both the driver and the paramedic (indicators for EMT-Driver, EMT-Basic, EMT-Intermediate, EMT-Paramedic), their tenure in years, and their hours of inactivity before the beginning of the current shift.[11] There are minimum volume restrictions for EMTs to be certified at a higher level, and so the majority of providers in our data switched certification level during their tenure. Moreover, while drivers are less likely to change their certification level (predominantly EMT-Driver), paramedics tend to frequently switch drivers. Controlling for hours of inactivity before the beginning of the current shift may indicate both alertness level at the beginning of the shift and the paramedic's typical shift structure. We do not control for the volume of calls that a paramedic received during a shift leading to the time of each incident to which she was dispatched. While one might argue that fatigue operates not only through sustained wakefulness, but also through the quantity of work she engages in, there are (at least) two arguments against controlling for such a variable. One argument is econometric: there is mechanically limited overlap in the support of this measure between 24-hour and 12-hour shifters, with the former group necessarily accumulating more incidents throughout their longer shifts. For instance, the median call volume for a paramedic in her 20th hour of a 24-hour shift is 6 calls, which is the 90th percentile of call volume for a 12-hour shifter in the last hour of her shift. Controlling for volume would thereby place more of the burden on the linear functional form in the estimation. The second argument is more conceptual. Clearly fatigue can accelerate with call volume, which is itself positively related to duration on duty. Long shifts therefore have a dual effect of forcing paramedics to remain awake for sustained periods and of involving them in more incidents on a per-shift basis. By not

[11] Since paramedics are not exclusively responsible for producing first response and transport times, which might be more readily attributed to the driver of the ambulance unit, all of our models control for the driver's shift structure, certification level, tenure in years, and hours of inactivity before the beginning of their current shift.

controlling for call volume within the shift, we are thus identifying a reduced form parameter that combines these two effects.

In addition, all models control for patient characteristics (race, age, gender), the type of incident, the incident location (e.g. residence, state/federal highway, etc.), and a series of indicators for year, month, day of week, and hour of the day. For trauma incidents, we also control for the type (e.g. fracture, burn, laceration, etc) and location (e.g. head, chest, etc) of injury, while for medical incidents we control for medical symptoms. For both trauma and medical incidents we include 30 indicators for procedures performed on scene. These variables primarily control for the severity of trauma and medical scenes, and insure that the effect of the shift length on performance is not confounded by scene characteristics or by reduced patient severity. In the next section, we provide evidence that paramedics on long shifts are not dispatched to less severe incidents, by showing that paramedics' shift lengths are not correlated with scene characteristics and patient acuity.

In Mississippi, EMS is provided by a network of ambulance services organized at the county or city level. These municipalities contract with EMS providers on a sole-provider basis, such that one agency provides all EMS services within the municipality's boundaries. We identify 86 such contracting municipalities, where 56 different EMS providers operate. About 19% of agencies are community-based (mostly integrated with local fire departments), 27% are hospital-based, and the remaining 54% are large private ambulance companies. EMS agencies integrated into and operated by hospitals may have different approaches to pre-hospital care due to closer medical supervision. Similarly, paramedics working for a large private multi-state company may have access to different training standards, equipment, and operate under more stringent protocols compared to a small, local fire-based agency. In the analysis, we therefore include information about EMS provider type (i.e. private vs. hospital-based vs. fire-based) to account for those instances of switching between provider types, when municipalities change the type of provider with which they contract. The analysis is conducted separately for trauma and medical incidents, which differ in scene, patient age profile, and protocol.[12]

IV. Results

The upper panel of Figures 2 shows the total out-of-hospital time by hour of day for trauma and medical runs in Mississippi between 2001 and 2005. These graphs are unadjusted representations of the difference-in-differences approach described in the statistical analysis section. Specifically, they show mean pre-hospital durations by hour of the day, for paramedics on 24-hour (solid line) and 12-hour (dotted line) shifts. The (unadjusted) difference-in-differences estimate can roughly be read from the charts as the pre- to post-midnight change in performance that occurs among paramedics on 24-hour shifts minus that of paramedics on 12-hour shifts. There is much less variability in total out-of-hospital time in medical incidents, for which there are almost four times as many observations as there are for trauma.[13] Nonetheless,

[12] As discussed above, MEMSIS collects slightly different information for trauma and medical incidents. For example, the trauma file includes data on the type of injury and the injured body part while the medical file includes data on medical symptoms.

[13] Note that more than half of trauma incidents involve motor vehicle crashes, which may occur far from urban centers (and therefore require longer travel times) and in complex environments in terms of lighting, weather, and

both charts suggest some deterioration in performance late at night among both short- and long-shifters, though this decline appears steeper among 24-hour paramedics.

The late-night reversals of performance may be mediated by factors other than fatigue. We therefore consider two additional performance indicators that are arguably more sensitive to paramedic fatigue: the number of pre-hospital procedures performed on-scene and minutes per procedure, with the latter conditioned on at least one procedure being performed. The middle and lower panels of Figure 2 present the number and speed of procedures by hour of day separately for trauma and medical incidents. In the case of trauma, the 24-hour shifters initiate almost 0.3 more procedures during the daytime than their short-shift counterparts, but this gap closes quickly starting around 7 PM and reverses, such that, by midnight, the long-shifters perform 0.1 fewer procedures per incident. Although these differences are unadjusted cell means, they are consistent with fatigue accounting for the decline in paramedic performance.

To produce a covariate-adjusted version of Figure 2, we followed the specification in (1) separately for incidents during each one hour-block and using all covariates described above as well as paramedic fixed-effects. Figure 3 plots the coefficients on the shift length dummy (24-hour shift = 1; 12-hour shift = 0) and standard errors for each within-hour regression. The trend lines track within-EMT differences in performance between 24-hour and 12-hour shifts, and are consistent with the ones presented in Figure 2. For example, the out-of-hospital time trend line

accessibility to victims (and therefore require more time spent on scene). This is another reason for the greater variability in total out-of-hospital time for trauma incidents compared with medical ones.

is mostly below zero between 7 AM and midnight and is above zero between midnight and 6 AM, consistent with the late-night reversal patterns observed in the covariate-unadjusted plots.

Random Assignment

To explore the possibility of nonrandom assignment of paramedics to incidents, we regress patient demographics, call type, medical symptoms, trauma injury and scene characteristics on paramedic shift structure according to specifications that mirror those of the difference-in-difference analysis. In Table 3, we report the coefficients on the indicator for treatment (24 hour shift) and the interaction term (24 hour shift x late at night). The upper panel reports results for medical incidents and the lower panel reports results for trauma incidents. Both panels report results for three models: the first includes paramedic and hour of day fixed effects, as well as driver shift structure; the second adds controls for time off between the end of the previous shift and the start of the current one; the third model includes controls for the EMT's tenure. In a few instances (e.g. medical incidents occurring on county roads or trauma incidents involving patients in the "other race/ethnicity" category), the coefficient on the interaction between shift structure and incidents occurring between midnight and 6 AM has some statistical significance, yet the magnitudes of the coefficients are extremely small. The results suggest that paramedic shift structure is unrelated to most patient and scene characteristics across models. This is not surprising, as the unpredicted nature of emergencies and the importance of delivering patients to hospitals quickly require the dispatch of units to rely solely on proximity.

Difference-in-Differences Analysis

Table 4 provides the results of the difference-in-differences analysis, first cross-sectionally with no additional controls, then with upwards of 200 scene, patient, and EMT characteristics (as discussed in Section III), and then with paramedic fixed effects. This level of saturation makes it highly unlikely that systematic differences across scenes which are correlated with shift length are responsible for the deterioration in EMT's performance towards the end of long shifts, compared to their performance towards the end of shorter shifts. For each model, we report the coefficient estimate on the interaction between an indicator for whether the paramedic is working a 24 hour shift and an indicator for whether the call occurs between midnight and 7 AM (i.e. γ in equation (1)). In addition, we also report the estimate of ϕ, the coefficient on the 24-hour shift "treatment" indicator.

The interaction term in the first row of Table 4 indicates that trauma and medical patients appear to experience delays between a minute and three minutes in total out-of-hospital time when a paramedic on a long shift is dispatched to their scene relative to when that same paramedic is scheduled for a 12-hour shift, both between midnight and 7 AM. Breaking total out-of-hospital time into its components reveals that paramedics on 24-hour shifts appear to be just under a minute slower in getting to the scene of medical or trauma emergencies between midnight and 7 AM. For instance, conditional on incident characteristics, it takes paramedics when they are on 24-hour shifts on average 1.07 additional minutes to arrive to the scene of a trauma incident towards the end of their shift, compared with when they are on shorter shifts. These paramedics also take an additional 1.1 minutes transporting trauma patients to a hospital.

Nonetheless, the results along the margins of time markers may be difficult to interpret as being solely attributable to fatigue. For example, EMS agencies may accommodate the longer shifts by allowing on-call paramedics to be asleep when they receive late night calls, which may lead to a slower reaction due to sleep inertia.[14] Although this is clearly a legitimate cost of long shifts, it is not fatigue from sustained wakefulness per se that drives it.

While the difference in time spent on-scene towards the end of a long versus a short shift is indistinguishable from zero, the number and speed of procedures performed on-scene are also affected in trauma and medical incidents. Paramedics on 24-hour shifts engage in 0.17 (or 8.5%) fewer procedures during trauma incidents in the closing hours of their shifts. In essence, no discernible difference in on-scene time is achieved by performing pre-hospital interventions more infrequently towards the end of long shifts. To distinguish whether these results are driven by the extensive vs. intensive margins of pre-hospital interventions, we study the number of procedures conditional on initiating at least one procedure. The results in Table 4 indicate that the intensive margin appears to be driving the results: conditional on performing at least one procedure, paramedics on long shifts engage in 0.21 (or 10%) fewer interventions.[15]

[14] Sleep inertia is defined as incomplete arousal from sleep. It is associated with performance deficits and impaired decision making (Bruck and Pisani, 1999). Yet, very little is known about the effects of sleep inertia in health care providers (Veasey et al., 2002).

[15] In more than 96% of cases, there is a single emergency medical technician certified as EMT-paramedic and a driver (certified as either an EMT-driver or an EMT-basic). In less than one percent of incidents, the unit is composed of two paramedics. Since only the paramedic is certified to perform the procedures recorded in our data, this measure – number of procedures – is a margin along which fatigue can be more credibly attributed to the paramedic.

Consistent with this result, we find the typical procedure to take 24 additional seconds (0.391 x 60) to complete for paramedics towards the end of a 24-hour shift.

It is worth noting that the effect on the number of pre-hospital procedures, while detected for medical incidents, is of smaller magnitude. Ex ante, this may make sense since EMS responses to medical emergencies are standardized to a much greater degree than in trauma incidents. Paramedic training and certification dictates specific responses and interventions for cardiac events, for instance, whereas trauma incidents are much more unpredictable and less standardized. As such, there is more room for paramedic discretion in treating trauma patients.

Robustness

The difference-in-differences approach provides a useful and simple framework for studying the effects of shift structure. It is not, however, without shortcomings. First, the magnitudes of the effects are attributable not only to performance deficits between midnight and 7 AM, but also to gaps in performance earlier in the day. Second, identification comes from the timing of calls (midnight to 7 AM), rather than from the duration of shifts directly. Lastly, performance deficits from longer shifts may operate in dimensions other than just mean pre-hospital times. We address these issues below.

Matching on covariates

Observations based on covariate-unadjusted charts (Figure 2) as well as covariate-adjusted charts (Figure 3) highlight differences in performance between short- and long-shifters at baseline. It appears that 24-hour shifters are more expeditious during business hours than their 12-hour counterparts. For trauma incidents, paramedics on long shifts are almost 2 minutes faster at delivering trauma patients to the hospital around noon or 1 PM. For medical incidents, this gap is approximately 48 seconds. However, while the long-shifters are on average quicker during the day, this relationship is reversed late in their shift (midnight-to-7 AM). These disparities suggest that there is non-negligible selection into 24-hour shifts, and that controlling for unobserved paramedic heterogeneity may be important.

To address this issue we use two matching strategies. The first addresses cross-sectional variation across EMTs on 12 and 24-hour shifts, while the second addresses variation solely within EMTs on 12 and 24-hour shifts.

To mitigate cross-sectional composition effects, we match 12-hour shifters and 24-hour shifters on three different quality related dimensions: tenure, certification level, and time elapsed before the beginning of a new shift. Tenure is computed using data going back to 1991.[16] EMTs on 24-hour shifts have slightly longer tenure then those on 12-hour shifts (7.68 years versus 7.28 years), and therefore may be more adapted to shift work and more experienced. In turn, this may explain their superior performance early into the shift. EMT certification is a clear marker of experience and competence. While most EMTs in our data (over 96%) are certified as paramedics, some are certified as EMT-Basic or EMT-Intermediate. Similar to tenure, EMTs on

[16] Data prior to 2001 allows for identifying individuals for the purpose of calculating tenure, but do not include essential controls, such as procedures, symptoms and injury indicators. These variables are available from 2001 on.

24-hour shifts are slightly more likely to be paramedics compared to their 12-hour counterparts (see Table 3). Finally, while we cannot observe sleep patterns, we might think that longer breaks between shifts provide better opportunities to mitigate sleep loss.[17] EMTs on 24-hour shifts had longer intervals between shifts compared with those on 12-hour shifts (approximately 43 hours versus 37 hours), which may imply that EMTs coming into a 24-hour shift are more refreshed than 12-hour shifters. As none of the three variables vary within shift, we use propensity score matching to pair short and long shifts for paramedics with similar tenure, certification level and time off duty before the beginning of the shift. We then identify all incidents that took place during the matched shifts. The resulting matched samples consist of 80,373 trauma incidents and 303,311 medical incidents.

The upper panel of Table 5 reports the results from this analysis on our three main performance measures. The results are similar to those obtained using the full sample. Figure A.1 (in the appendix) replicates Figure 2 for the matched sample. By and large, this figure is similar to Figure 2.

Our second matching strategy seeks to reduce discrepancies in performance within-EMTs. In this case, the desirability of variables that primarily vary across paramedics is limited. In particular, we rule out certification level which rarely varies within EMT. Similarly, tenure is

[17] Some of the clinical studies surveyed in Veasey et al., (2002) recorded information on sleep patterns between shifts, focusing on longer term sleep loss (for example, the effect of having fewer than 6 hours of sleep per night on average during a one week period). It has been documented that the severity of neurobehavioral impairment is similar in both short-term sleep loss and chronic sleep restriction.

ruled out since, by construction, variation within EMTs captures the passage of time and forces the matching process to couple shifts that are closer in time. There is no obvious reason why we would think this is a desirable feature for the purpose of matching. Unlike tenure and certification level, time between shifts varies across shifts and can plausibly account for within-EMT variation in performance earlier into the shift. If the same EMT is more likely to be well-rested going into a 24-hour shift than she is going into a 12-hour shift, that could account for the discrepancies in performance at the beginning of shifts.

We matched long and short shifts using propensity score matching with a mix of exact matching on EMT ID and 1-to-1 nearest neighbor propensity score matching without replacement for time between shifts. Our matched sample consists of all incidents that correspond to the matched shifts where about a third of 24-hour shifts are on a common support. The resulting matched samples consist of 28,243 trauma incidents and 115,302 medical incidents.

The lower panel of Table 5 reports the results for our three main performance measures for the matched sample within EMTs. For total out-of-hospital time, the results are similar in magnitude and statistical significance to those obtained for the full sample. However, the upper panel of Figure A.2 shows greater similarity between 12 and 24-hour shifters in the beginning of their shifts. For minutes per procedure, we find different results for trauma and medical runs. While for trauma the effects are smaller and for the most part statistically insignificant, the results for medical incidents suggest a 20 second increase in the time it takes a 24-hour shifter to complete a procedure towards the end of her shift (see lower panel of Figure A.2). Finally, we no longer find an effect for number of procedures when using this matched sample.

Within–shift analysis

To complement the within-EMT between-shifts approach, Table 6 repeats the specifications in equation (1) for total out-of-hospital time and number of procedures, replacing the interaction between the "late night" dummy and the for 24-hour shift dummy with an interaction between the "late night" dummy and time-on-duty (which measures the time since the beginning of the shift). Since time-on-duty varies within shift, Table 6 offers, in addition to the cross-sectional and EMT fixed-effects analysis, a shift fixed-effects analysis.

The two methods exploit different sources of variation, one being *within*-paramedic variation in shift structure, the other being *within*-shift variation in time-on-call. The identification in the latter case comes from both long shifts and late short shifts that include incidents in both the early (7 AM to midnight) and late (midnight to 7 AM) periods. Based on the lower panel of Figure 1, a typical late short shift would start at 7 PM and end by 7 AM. Identification relies on a comparison of incidents within a given shift, some occurring prior to midnight and others occurring between midnight and 7 AM. The hour of day dummies capture performance changes across time, the time-on-duty variable capture the effects of prolonged shifts, and the [time on duty x late night] interaction captures the differential effect of prolonged shifts during the midnight to 7 AM period.

The within-EMT fixed effects results in Table 6 are smaller in magnitude compared to those in tables 4 and 5. For example, according to Table 4, a paramedic moving from a 12-hour to a 24-hour shift increases total out-of hospital time between midnight and 7 AM by 1.15 minutes (69 seconds) for a medical incident and by 2.26 minutes for a trauma incident. According to Table 6, adding 12 additional hours of time-in-shift (the typical difference in time-on-duty between long and late short shifts) increases total out-of hospital time between midnight and 7 AM by 45 seconds (0.063 x 12) for a medical incident and by 1.06 minutes (0.088 x 12) for a trauma incident.

The within-shift fixed effects results are smaller in magnitude compared to the within-EMT fixed effects ones and only statistically significant in the case of total out-of-hospital time for medical incidents in the full sample. In the cross-sectional matched sample, the within-shift fixed effects results for total out-of-hospital time are statistically significant for both medical and trauma incidents and are virtually identical to the within-EMT fixed effects results.

While this methodology is appealing, it is far more sensitive to measurement errors, discussed in section II. The difficulty with undertaking such an analysis is that the precise starting point of shifts is not observed. Measuring the beginning of a shift with error is a potentially important source of bias when separating time-of-day effects from time-in-shift effects and less so when the beginning of the shift is used for the purpose of broadly defining long and short shifts.

Quantile analysis

Here we explore the possibility that the performance deficits from longer shifts operate in dimensions other than just mean pre-hospital times. Specifically we posit that sustained wakefulness might shrink the conditional distribution of our outcome measures. To this end we employ quantile regression methods, which serve to describe how being on a 24-hour shift late at night affects the entire distribution of total out-of-hospital time and minutes-per-procedure. Table 7 reports the results from quantile regressions estimated cross sectionally at seven different percentiles (0.05, 0.15, 0.25, 0.5, 0.75, 0.85, and 0.95).[18] Standard errors for the coefficient estimates are obtained using bootstrapping, which provide robust results (Koenecker and Hallock, 2001; Hao and Naiman, 2007). The results indicate that operating in a 24-hour shift late at night compresses the upper tails of the conditional total out-of-hospital time and minutes-per-procedure distributions.[19] For example, being on a 24-hour shift late at night increases the 95th percentile of total out-of-hospital time for trauma by 6 minutes and for medical incidents by 2.3 minutes, which in both cases is approximately double the median and mean effects. Moreover, being on a 24-hour shift late at night increases the 95th percentile of minutes-per-trauma-procedure by 2 minutes and the 95th percentile of minutes-per-medical-procedure by 45 seconds, approximately three times the median and mean effects for trauma incidents and close to five times the median and mean effects for medical incidents.

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[18] EMT fixed effects models, while desirable, are computationally impractical.

[19] The bootstrap standard errors are estimated under the assumption of conditional homoscedasticity and no within-cluster correlation. Therefore, the reported standard errors are likely to understate the true variability of the estimates. Confidence intervals are robust to using Censored Least Absolute Deviations (CLAD) estimator (Powell, 1984) which is robust to heteroscedasticity and is consistent and asymptotically normal for a wide class of error distributions.

Discussion

While this is primarily a measurement paper, the impact of shift structure on workers' performance is an issue that has received increasing attention by regulatory bodies in manufacturing and service industries.

As we state in the introduction, shift work is common in many industries and is universal in those operating around-the-clock. Oil, natural gas, pipelines, foundries, steel mills, paper, and printing industries schedule shifts to meet increasing global demand and to take advantage of sophisticated and expensive technology. In other industries, such as media, communications, electric utilities and nuclear power generation, around-the-clock operation and delivery dictates the organization of the workload. Similarly, police and fire departments, emergency rooms, and ambulance services require around-the-clock expert assistance, often on a moment's notice, in situations where lives may be at stake. High degrees of preparedness and service can also be found in just-in-time warehousing, marine and ports services, where employees work in shifts.

Shift work is also common in many industries with less than 24/7 coverage. In manufacturing, continuous processes exist to manage demand fluctuations. For instance, automotive, electronics, semiconductor, and pharmaceutical industries all organize large parts of their labor force into shifts. Similarly, most retailers organize work in shifts. In aviation, public transit, railroads, trucking and shipping, shift work results from extended travel durations and government regulation regarding vehicle operation.

While shifts are at the heart of human resources practices, a review of the literature reveals that the evidence on the effect of longer shifts on, for example, hospitals' performance is mixed. In our study, we offer an evaluation of the effect of shift structure and shift length on workers' performance, by using objective process measures capturing speed and activity, to examine the effect of shift structure on paramedic performance. Our study is, to our knowledge, the largest scale observational study to estimate the effect of shift structure on workers' performance, using a dataset that is collected in real time by paramedics responding to calls. We found that paramedics working longer shifts exhibit poorer performance towards the end of their shift (midnight to 7 AM), as measured by pre-hospital intervals, number of pre-hospital interventions, and minutes per procedure compared to their own performance when working 12 hour (or less) shifts. Our results are robust to using samples based on matching paramedics working in different shift structures on covariates, to alternative sources of variation (within-shift versus within-paramedic), and to characterizing the effect of long shifts on different quantiles of the conditional performance distribution. Our results are consistent with the hypothesis that fatigue plays a role in the decline of the performance of paramedics at the end of 24 hour shifts.

There are several possible limitations to our study. Since EMS are designed to reach and safely transport patients with time sensitive injuries (e.g. excessive blood loss from penetrating trauma) or medical emergencies (e.g. stroke or heart attack), speed is a well-accepted marker of paramedic performance. Yet, it remains an input into patient outcomes such as mortality, disability, and morbidity. While desirable, we are unable to observe survival directly. Arguably, outcome markers such as patient mortality may be better in evaluating the ultimate effect of longer shifts. Since detailed inpatient data is not available for Mississippi during our sample period, we were unable to evaluate the process measure itself in our data.

Ultimately, a firm's choice of shift structure is the result of balancing business requirements (Mayshar and Halevy, 1997), employee desires (Kostiuk, 1990), and regulatory objectives (Coleman, 1995). One of these objectives is minimal health and safety standards for employees working extended hours, such as the 2010 recommendations by the ACGME to cap shift length at 16 hours for interns (Nasca et al., 2010). While over 80 percent of employees work a daytime schedule, more than 21 million wage and salary workers in the U.S. (17.7 percent) work alternate shifts that fall at least partially outside of the daytime shift range (McMenamin, 2007).[20]

So why do people work extended hours? Neoclassical theory would suggest that individuals will work longer hours (for example, back-to-back shifts) to supplement their income when their marginal rate of substitution between leisure and income is below the wage rate.[21] Consistent with this argument, wage differentials were found to affect workers' shift choice (Lanfranchi et al., 2002; Presser, 2003). In particular, there is evidence of self-selection in the

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[20] Similar findings were reported for Canada (Williams, 2008) and European countries (Le Bihan and Martin, 2004).

[21] In addition, there is some evidence for a "shift premium" (Lanfranchi et al., 2002).

choice to work extended hours, as workers with low potential daytime salary were found to be more likely to choose night work to supplement their earnings (Kostiuk, 1990).

Consistent with findings of compensating differentials, the health and safety consequences for employees working extended hours are likely to be internalized. However, as we find in this paper, working longer shifts may impose a negative externality on others. In health care, the concern is that extended work hours could negatively impact patients' health and well-being. To counterbalance such effects, health care providers are held legally responsible for the harm they impose on patients due to professional negligence. Evidence suggests that health care providers react to malpractice pressure by offering more procedures and tests, a behavior often labeled "defensive medicine" (Kessler and McClellan, 1996). However, there is no evidence that health care institutions react to such pressure by shortening shifts or discouraging the practice of back-to-back shifts.

The notion of increasing marginal utility of leisure (with the number of hours worked) is central to the underlying tradeoff between the utility from consumption and the utility from leisure. Nevertheless, holding labor supply constant, diminishing marginal utility of income does not suggest that individuals would prefer to work shorter shifts. For example, imagine that work hours per week are the relevant interval for labor supply decisions. Clearly, individuals working 48 hours per week can do so in two 24-hour shifts or in four 12-hour shifts, depending on their preferences and the flexibility offered by firms (Altman and Golden, 2007).[22]

[22] Because EMS in Mississippi is organized based on sole provider contracts, paramedics residing in a given contracting area may not have much flexibility in affecting the shift structure.

Without the ability to conceptually link shift structure with labor supply decisions, neoclassical theory provides little guidance for understanding employees' preferences for organizing their work schedule. One such link could come from the idea that shorter shifts provide greater flexibility for altering the number of hours worked in a given week (e.g. through the practice of back-to-back shifts). This would certainly apply if individuals held a single job. However, anecdotal evidence suggests that paramedics working 24-hours shifts have two or three days off between shifts and are more likely to hold a second job (Kuehl, 2002). Therefore, the link between shift structure and labor supply decisions is not obvious.[23]

Finally, EMS often relies on volunteers; this may suggest that there are non-pecuniary benefits to working as a paramedic (e.g. serving the community, saving lives, or from thrills embedded in the delivery of emergency care). Non-pecuniary benefits were found to be associated with labor supply (Lazear, 1991; Freedman, 1997; Akerlof and Kranton, 2005; Farzin, 2009), but there is no reason to think that these are associated with workforce scheduling.

While more research is needed and while recognizing the inevitable need for health care professionals to work long hours in some circumstances, it appears that greater attention to the design of work schedules may entail benefits to patients relying on emergency medical services.

[23] From a measurement perspective, concerns regarding such selection (and others discussed earlier in the paper) highlight the importance of our *within* paramedic approach.

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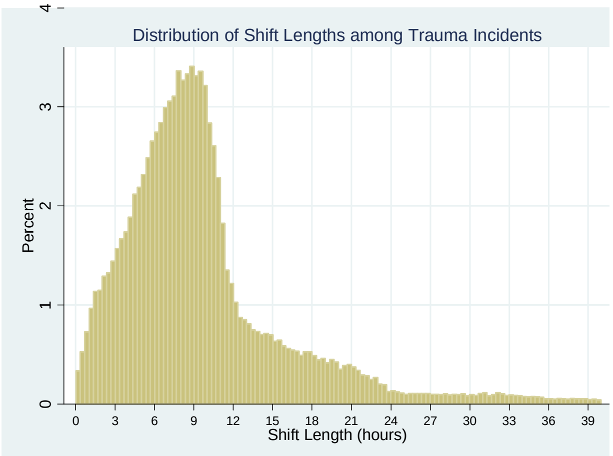
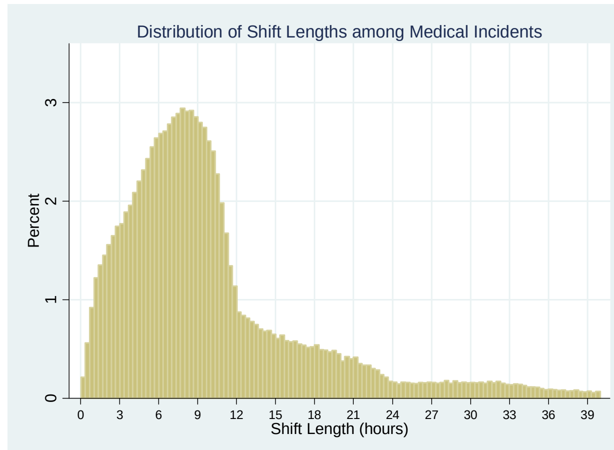
Figure 1: Distributions of shift lengths, hours of inactivity, and beginning of shift.

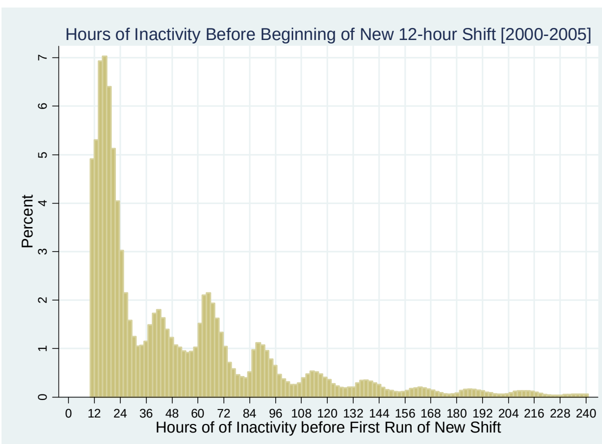
Shift length (Trauma)



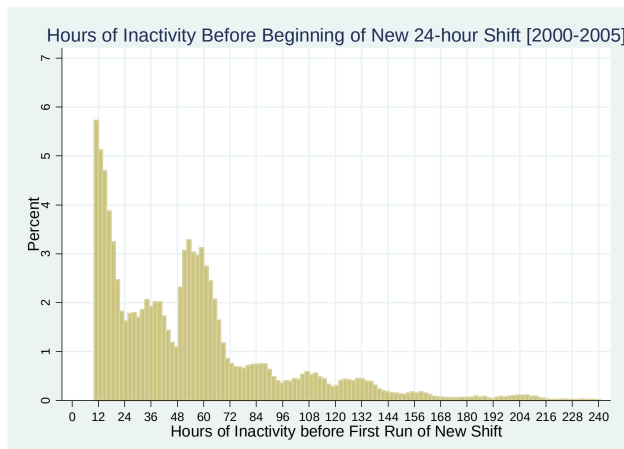
Shift length (Medical)



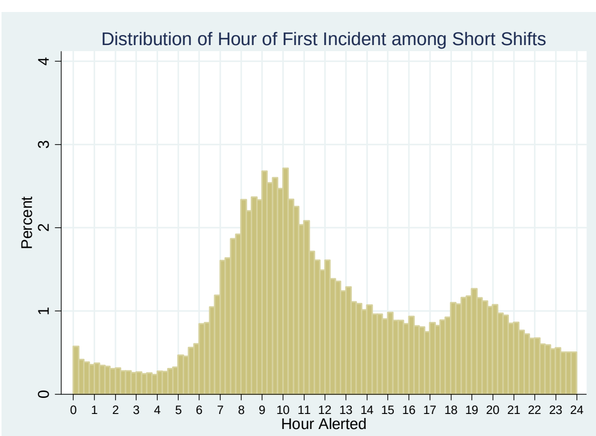
Hours of inactivity (12-hour shifts)



Hours of inactivity (24-hour shifts)



Hour of first incident (12-hour shifts)



Hour of first incident (24-hour shifts)

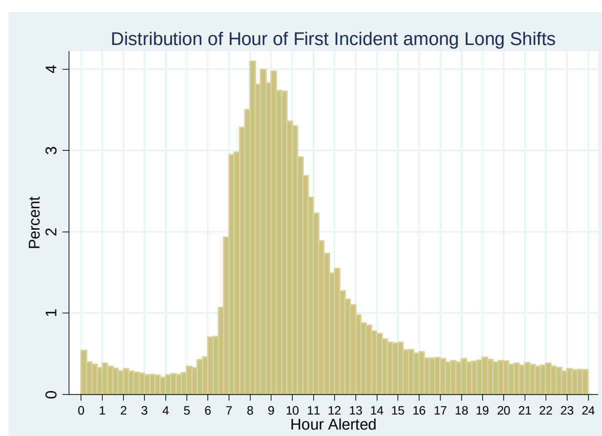


Figure 2: Total Out-of-Hospital Time, Number of Procedures, and Minutes per Procedure by Shift Length and Hour of Day for Trauma and Medical Incidents, Mississippi 2001-2005

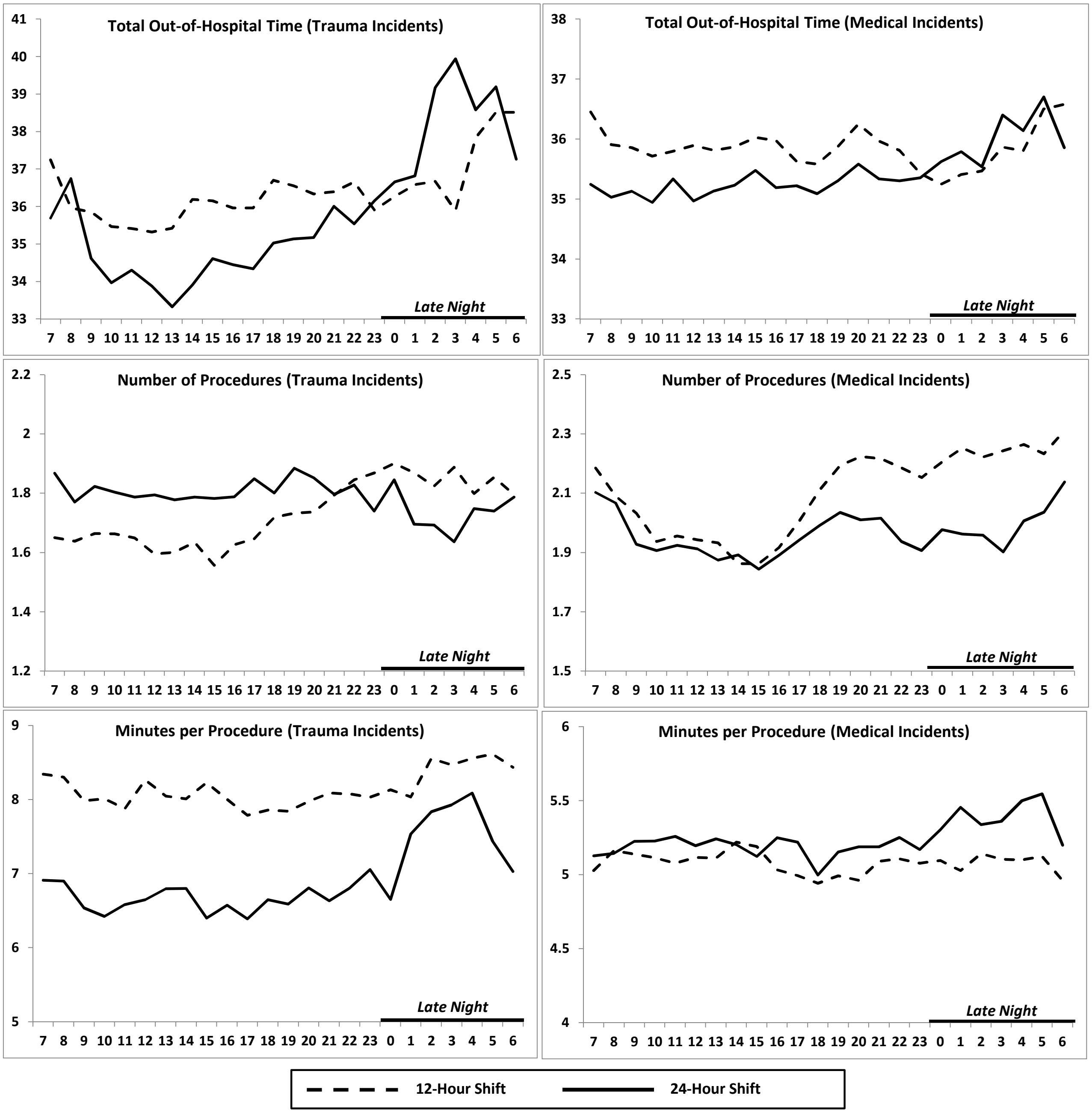
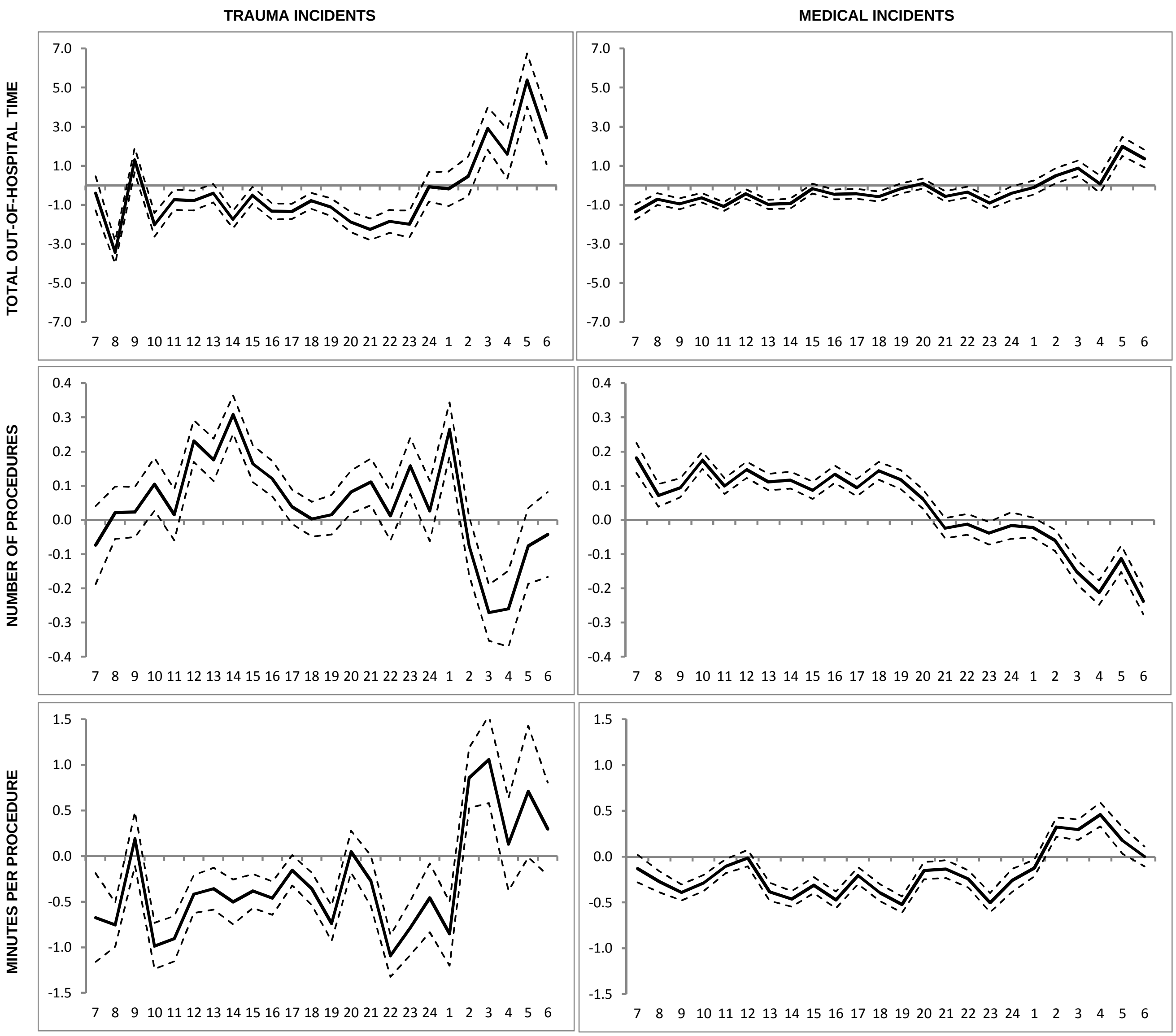


Figure 3: Coefficient Estimates and Standard Errors for *within* -EMT Differences in Performance across Long and Short Shifts



A plot of the coefficients and standard errors from equation (1) separately for each one-hour block.

Table 1: Summary Statistics for Trauma and Medical Incidents

	Trauma Incidents					Medical Incidents				
	24-Hour Shift		12-Hour Shift			24-Hour Shift		12-Hour Shift		
Variable	**Mean**	**S.D.**	**Mean**	**S.D.**	**t-stat**	**Mean**	**S.D.**	**Mean**	**S.D.**	**t-stat**
Total Out-of-Hospital Time	35.17	16.92	36.20	16.08	-10.69	35.33	17.61	35.86	16.87	-10.44
Response Time	8.25	6.15	7.88	5.90	10.54	8.88	6.93	8.39	6.69	24.25
On Scene Time	14.23	8.41	14.81	8.41	-11.83	12.92	7.79	13.35	8.14	-18.86
Transport Time	12.69	9.75	13.51	9.49	-14.78	13.53	11.32	14.12	10.60	-17.85
Number of Procedures	2.14	2.28	1.95	2.14	14.83	1.95	2.25	2.06	2.39	-15.55
Minutes per Procedure	6.74	5.48	8.07	6.36	-31.46	5.22	4.38	5.08	4.54	7.66
Patient Demographics										
White	0.544	0.498	0.568	0.495	-8.38	0.540	0.498	0.560	0.496	-13.68
Black	0.419	0.493	0.401	0.490	6.60	0.439	0.496	0.421	0.494	12.51
Other	0.036	0.187	0.031	0.173	4.99	0.021	0.143	0.019	0.137	4.34
Age	42.41	24.72	42.42	24.12	0.37	56.24	24.93	56.02	24.76	2.93
Female	0.556	0.497	0.552	0.497	1.55	0.581	0.493	0.567	0.495	9.47
EMT characteristics										
Time between shifts	43.12	21.77	37.39	24.87	38.56	43.38	21.98	37.86	25.04	72.59
EMT - Basic	0.017	0.127	0.023	0.150	-11.26	0.032	0.177	0.037	0.188	-13.50
EMT - Intermidiate	0.001	0.021	0.001	0.237	-15.10	0.001	0.024	0.007	0.083	-29.61
EMT - Paramedic	0.982	0.132	0.966	0.185	21.39	0.967	0.216	0.956	0.230	13.91
Public / Fire-based	0.342	0.474	0.115	0.319	101.31	0.311	0.463	0.121	0.326	168.57
Hospital-based	0.210	0.407	0.278	0.448	-21.90	0.235	0.424	0.342	0.474	-73.84
Private corporation	0.448	0.497	0.607	0.488	-57.12	0.454	0.498	0.537	0.499	-58.11
Incident type										
Motor Vehicle crash	0.549	0.498	0.522	0.500	9.59					
Gunshot	0.015	0.122	0.015	0.121	0.36					
Fall	0.305	0.460	0.322	0.467	-6.62					
Motorcycle	0.013	0.113	0.011	0.102	3.59					
Pedestrian	0.016	0.124	0.018	0.132	-3.01					
Cutting / Stabbing	0.022	0.148	0.024	0.152	-1.59					
Assault	0.081	0.272	0.059	0.285	-5.59					
Cardio						0.249	0.432	0.266	0.442	-13.40
Gastrointestinal						0.117	0.321	0.136	0.343	-20.45
Neuro						0.148	0.355	0.163	0.370	-14.31
Genitourinary						0.015	0.120	0.013	0.113	4.96
Psych / Substance abuse						0.038	0.191	0.063	0.243	-41.75
Constitutional						0.271	0.445	0.301	0.459	-22.68
Other (Medical)						0.162	0.369	0.057	0.232	106.26
Incident location										
City Street	0.189	0.392	0.224	0.417	-15.11					
County Road	0.115	0.319	0.079	0.269	20.32					
Highway	0.255	0.436	0.224	0.417	12.52					
Other (Trauma)	0.441	0.497	0.473	0.499	-11.26					
Residence						0.639	0.480	0.611	0.488	10.16
Healthcare facility						0.212	0.409	0.234	0.424	-9.33
Road/Highway						0.034	0.181	0.032	0.176	1.97
Other (Medical)						0.115	0.319	0.123	0.329	-4.37
Number of observations	41,052		114,340			159,392		428,225		

Table 2: The Percent of Incidents and Shifts Attended by an EMT on a 24-Hour Shift by Year and across Firm Types

	TRAUMA		MEDICAL	
Year	% Incidents Served by a Paramedic on a 24-Hour Shift	% of Paramedic Shifts that are 24-hour	% Incidents Served by a Paramedic on a 24-Hour Shift	% of Paramedic Shifts that are 24-hour
2001	23.4%	20.7%	24.0%	18.4%
2002	27.2%	24.3%	27.2%	21.4%
2003	29.2%	25.9%	29.3%	22.6%
2004	29.3%	25.7%	29.4%	22.6%
2005	32.0%	27.8%	32.4%	24.4%
Total	28.2%	24.8%	28.5%	21.9%

	% Trauma Incidents Attended by a Paramedic on a 24-Hour Shift			% Medical Incidents Attended by a Paramedic on a 24-Hour Shift		
Year	Public / Fire-Based	Hospital-Based	Private For-Profit Corp.	Public / Fire-Based	Hospital-Based	Private For-Profit Corp.
2001	42.6%	19.3%	19.0%	37.7%	18.4%	22.2%
2002	43.9%	20.8%	24.9%	42.1%	21.1%	25.6%
2003	44.8%	23.5%	26.5%	41.9%	22.1%	28.9%
2004	43.9%	23.6%	26.8%	42.7%	23.9%	28.2%
2005	46.9%	27.9%	28.9%	46.1%	25.5%	32.1%
Total	44.4%	22.9%	25.3%	42.0%	22.2%	27.7%

Table 3: Random Assignment Regressions with Paramedic and Hour of the Day Fixed Effects

Medical Incidents	**Patient Demographics**				**Location**		**Incident Type (Medical)**						**Sympthoms**
(N=521,087)	**White**	**Black**	**Other Race**	**Female**	**County Road**	**Highway**	**Drowning**	**Smoke**	**Poison**	**Overdose**	**Breathing Diff**	**Chest Pain**	**Hemorrhage**
Model [1]													
Treatment	0.0000	-0.0007	0.0007	0.0020	-0.0003	-0.0001	0.0001	-0.0001	-0.0001	0.0001	0.0010	-0.0002	-0.0008
	[0.0026]	[0.0026]	[0.0008]	[0.0025]	[0.0004]	[0.0007]	[0.0002]	[0.0001]	[0.0002]	[0.0004]	[0.0018]	[0.0014]	[0.0005]
Treatment x Post	0.0079	-0.0063	-0.0016	0.0093	-0.0022	-0.0002	-0.0010	0.0006	-0.0002	0.0006	0.0073	0.0073	0.0019
	[0.0072]	[0.0072]	[0.002]	[0.0079]	[0.0013]*	[0.0017]	[0.0007]	[0.0006]	[0.0006]	[0.0017]	[0.0059]	[0.0046]	[0.0017]
Model [2]													
Treatment	-0.0001	-0.0007	0.0007	0.0021	-0.0003	0.0000	0.0001	-0.0001	-0.0001	0.0000	0.0010	-0.0002	-0.0008
	[0.0026]	[0.0026]	[0.0008]	[0.0025]	[0.0004]	[0.0007]	[0.0002]	[0.0001]	[0.0002]	[0.0004]	[0.0018]	[0.0014]	[0.0005]
Treatment x Post	0.0078	-0.0063	-0.0016	0.0092	-0.0022	-0.0002	-0.0010	0.0006	-0.0002	0.0006	0.0071	0.0073	0.0019
	[0.0073]	[0.0072]	[0.002]	[0.0079]	[0.0013]*	[0.0017]	[0.0007]	[0.0006]	[0.0006]	[0.0017]	[0.0059]	[0.0046]	[0.0017]
Model [3]													
Treatment	0.0000	-0.0007	0.0008	0.0021	-0.0003	-0.0001	0.0000	-0.0001	-0.0001	0.0000	0.0012	-0.0001	-0.0008
	[0.0026]	[0.0026]	[0.0008]	[0.0025]	[0.0004]	[0.0007]	[0.0002]	[0.0001]	[0.0002]	[0.0004]	[0.0018]	[0.0014]	[0.0005]
Treatment x Post	0.0078	-0.0062	-0.0015	0.0093	-0.0022	-0.0002	-0.0010	0.0006	-0.0002	0.0006	0.0073	0.0074	0.0019
	[0.0072]	[0.0072]	[0.002]	[0.0079]	[0.0013]*	[0.0017]	[0.0007]	[0.0006]	[0.0006]	[0.0017]	[0.0059]	[0.0046]	[0.0017]

Trauma Incidents	**Patient Demographics**				**Location**		**Incident Type (Trauma)**					**Trauma Type and Injured I**	
(N=143,708)	**White**	**Black**	**Other Race**	**Female**	**County Road**	**Highway**	**MVC**	**Gunshot**	**Fall**	**Assault**	**Dislocated Arm**	**Back Pain**	**Burn (Face)**
Model [1]													
Treatment	0.0039	-0.0038	-0.0001	0.0036	-0.0017	-0.0021	0.0030	0.0000	-0.0016	0.0022	-0.0019	-0.0058	0.0000
	[0.006]	[0.006]	[0.002]	[0.0055]	[0.0042]	[0.0055]	[0.0059]	[0.0012]	[0.0053]	[0.0029]	[0.0016]	[0.004]	[0.0003]
Treatment x Post	0.0187	-0.0055	-0.0132	-0.0075	-0.0064	-0.0022	-0.0072	-0.0041	0.0147	-0.0012	0.0015	0.0157	-0.0002
	[0.0162]	[0.0159]	[0.0074]*	[0.0163]	[0.0123]	[0.0145]	[0.0182]	[0.0058]	[0.0151]	[0.0138]	[0.0046]	[0.0112]	[0.001]
Model [2]													
Treatment	0.0036	-0.0036	0.0000	0.0036	-0.0018	-0.0021	0.0030	0.0000	-0.0016	0.0022	-0.0020	-0.0058	0.0000
	[0.006]	[0.006]	[0.002]	[0.0055]	[0.0042]	[0.0056]	[0.0059]	[0.0012]	[0.0053]	[0.0029]	[0.0016]	[0.004]	[0.0003]
Treatment x Post	0.0185	-0.0053	-0.0132	-0.0081	-0.0063	-0.0022	-0.0075	-0.0041	0.0148	-0.0010	0.0015	0.0157	-0.0002
	[0.0163]	[0.0159]	[0.0074]*	[0.0163]	[0.0123]	[0.0145]	[0.0182]	[0.0058]	[0.0151]	[0.0138]	[0.0046]	[0.0112]	[0.001]
Model [3]													
Treatment	0.0036	-0.0036	0.0000	0.0037	-0.0017	-0.0022	0.0030	0.0000	-0.0016	0.0022	-0.0019	-0.0056	0.0000
	[0.006]	[0.006]	[0.002]	[0.0055]	[0.0042]	[0.0055]	[0.0059]	[0.0012]	[0.0053]	[0.0029]	[0.0016]	[0.004]	[0.0003]
Treatment x Post	0.0184	-0.0053	-0.0132	-0.0080	-0.0062	-0.0022	-0.0076	-0.0041	0.0149	-0.0010	0.0015	0.0161	-0.0002
	[0.0162]	[0.0159]	[0.0074]*	[0.0163]	[0.0123]	[0.0145]	[0.0182]	[0.0058]	[0.0151]	[0.0138]	[0.0046]	[0.0112]	[0.001]

Note: All models control for Paramedic, contract area, and hour of day fixed effects, as well as for the driver's shift structure. Standard errors are clustered at the paramedic level. Model [1]: No controls fc between End of Last Shift and Start of Current One or EMT Tenure. Model [2]: Controls for Time Off between End of Last Shift and Start of Current One. Model [3]: Controls for Both Time Off between End Start of Current One and EMT Tenure. Similar results were obtained using age categories, year, month, and day dummies, as well as for additional call, location, destination, trauma type, and medical sy results are not reported due to space constraints and are available from the authors.

Table 4: Difference-in-Differences Analysis on the Full Samples of Trauma and Medical Incidents

Outcome		Trauma Incidents: No controls	Trauma Incidents: With controls	Trauma Incidents: With EMT FEs	Medical Incidents: No controls	Medical Incidents: With controls	Medical Incidents: With EMT FEs
Full sample							
Out-of-Hospital Time	T	-1.457 ***	-1.930 ***	-0.989 ***	-0.726 ***	-0.480 ***	-0.656 ***
		(0.101)	(0.109)	(0.159)	(0.056)	(0.060)	(0.086)
	T x Post	2.677 ***	3.063 ***	2.261 ***	1.010 ***	1.153 ***	0.792 ***
		(0.335)	(0.307)	(0.287)	(0.154)	(0.147)	(0.136)
Response Time	T	0.208 ***	0.005	-0.046	0.328 ***	0.180 ***	0.027
		(0.037)	(0.041)	(0.064)	(0.022)	(0.024)	(0.036)
	T x Post	1.115 ***	1.119 ***	1.071 ***	0.674 ***	0.639 ***	0.575 ***
		(0.120)	(0.115)	(0.115)	(0.059)	(0.058)	(0.057)
On Scene Time	T	-0.588 ***	-0.877 ***	-0.444	-0.322 ***	-0.229 ***	-0.367 ***
		(0.050)	(0.054)	(0.081)	(0.025)	(0.027)	(0.039)
	T x Post	0.068	0.364 **	0.084	-0.177 **	-0.046	-0.068
		(0.182)	(0.169)	(0.162)	(0.075)	(0.070)	(0.068)
Transport Time	T	-1.076 ***	-1.059 ***	-0.499 ***	-0.731 ***	-0.431 ***	-0.315 ***
		(0.060)	(0.066)	(0.095)	(0.036)	(0.039)	(0.056)
	T x Post	1.493 ***	1.580 ***	1.106 ***	0.513 ***	0.559 ***	0.282 ***
		(0.182)	(0.174)	(0.158)	(0.095)	(0.091)	(0.083)
Number of Procedures	T	0.219 ***	0.063 ***	0.096 ***	-0.111 ***	-0.031 ***	0.123 ***
		(0.014)	(0.014)	(0.020)	(0.007)	(0.007)	(0.009)
	T x Post	-0.294 ***	-0.257 ***	-0.173 ***	-0.169 ***	-0.122 ***	-0.072 ***
		(0.042)	(0.038)	(0.036)	(0.021)	(0.017)	(0.016)
Number of Procedures	T	0.290 ***	0.117 ***	0.137 ***	-0.229 ***	-0.061 ***	0.085 ***
Conditional on at Least		(0.016)	(0.016)	(0.022)	(0.008)	(0.008)	(0.011)
One	T x Post	-0.308 ***	-0.272 ***	-0.212 ***	-0.191 ***	-0.170 ***	-0.100 ***
		(0.048)	(0.044)	(0.042)	(0.024)	(0.021)	(0.019)
Minutes per Procedure	T	-1.395 ***	-0.881 ***	-0.337 ***	0.151 ***	-0.041 ***	-0.289 ***
		(0.041)	(0.046)	(0.070)	(0.019)	(0.021)	(0.031)
	T x Post	0.511 ***	0.497 ***	0.391 ***	0.191 ***	0.159 **	0.119 **
		(0.146)	(0.142)	(0.139)	(0.052)	(0.050)	(0.049)
N		150,104	150,104	150,104	554,749	554,749	554,749
N (conditional on >1 procedure)		105,046	105,046	105,046	318,446	318,446	318,446

Notes: T = 1(24-hour shift); Post = 1(Midnight to 6AM). Standard errors are clustered at the paramedic level. "*", "**", and "***" indicate significance at the 10%, 5%, and 1% levels, respectively.

All models control for the certification levels of the driver and paramedic (indicators for EMT-Driver, EMT-Basic, EMT-Intermediate, and EMT-Paramedic), their tenure in years, and their hours of inactivity before the beginning of the current shift. All models also control for patient demographics (indicators for race, gender, and 12 age categories), location of incident (street, clinic, physician's office, farm, hospice, hospital, county road, industrial site, nursing home, office, public place, residence, restaurant, school, highway, other location), and hour of day, day of week, month of year, and year indicators. We also control for the driver's shift structure in the same (difference-in-differences) manner as the paramedic, though only the latter's coefficients are reported. Trauma models additionally control for indicators of type of trauma (falls, gunshot wounds, cuts or stabbings, assaults, motor vehicle crashes, and motorcycle and pedestrian accidents), and injury characteristics (70 interactions of injured body part and injury type). Medical models control for indicators of incident type (e.g. cardiac event, drowning, poisoning, etc) and 32 indicators of patient symptoms.

Table 5: Difference-in-Differences Analysis on the Matched Samples for Trauma and Medical Incidents

		Trauma Incidents			Medical Incidents		
Outcome		**No controls**	**With controls**	**With EMT FEs**	**No controls**	**With controls**	**With EMT FEs**
Matched sample (across EMTs)							
Out-of-Hospital Time	T	-1.430 ***	-1.490 ***	-0.510 **	-1.451 ***	-0.946 ***	-0.554 ***
		(0.122)	(0.133)	(0.214)	(0.068)	(0.072)	(0.113)
	T x Post	2.834 ***	3.123 ***	2.321 ***	0.856 ***	0.873 ***	0.361 **
		(0.401)	(0.368)	(0.355)	(0.189)	(0.179)	(0.168)
Number of Procedures	T	0.207 ***	0.028	0.054 **	-0.067 ***	-0.041 ***	0.105 ***
		(0.016)	(0.017)	(0.026)	(0.009)	(0.008)	(0.012)
	T x Post	-0.305 ***	-0.271 ***	-0.143 ***	-0.166 ***	-0.119 ***	-0.081 ***
		(0.051)	(0.046)	(0.044)	(0.026)	(0.021)	(0.019)
Minutes per Procedure	T	-1.398 ***	-0.895 ***	-0.200 **	0.034	-0.047 *	-0.296 ***
		(0.052)	(0.058)	(0.095)	(0.024)	(0.025)	(0.041)
	T x Post	0.721 ***	0.661 ***	0.425 **	0.175 ***	0.142 **	0.116 *
		(0.179)	(0.174)	(0.176)	(0.065)	(0.062)	(0.061)
N		80,373	80,373	80,373	303,311	303,311	303,311
Matched sample (within EMTs)							
Out-of-Hospital Time	T	-0.669 ***	-1.059 ***	-0.801 ***	-0.621 ***	-0.778 ***	-0.718 ***
		(0.213)	(0.207)	(0.202)	(0.112)	(0.112)	(0.108)
	T x Post	2.157 ***	2.362 ***	1.704 ***	0.936 ***	0.983 ***	0.530 *
		(0.714)	(0.657)	(0.625)	(0.315)	(0.298)	(0.281)
Number of Procedures	T	0.147 ***	0.086 ***	0.078 ***	0.223 ***	0.102 ***	0.096 ***
		(0.028)	(0.027)	(0.025)	(0.014)	(0.012)	(0.011)
	T x Post	-0.017	-0.021	0.043	-0.043	-0.045	-0.026
		(0.084)	(0.075)	(0.071)	(0.041)	(0.033)	(0.031)
Minutes per Procedure	T	-0.578 ***	-0.448 ***	-0.350 ***	-0.488 ***	-0.414 ***	-0.314 ***
		(0.085)	(0.087)	(0.087)	(0.040)	(0.039)	(0.039)
	T x Post	0.523 *	0.496	0.289	0.419 ***	0.436 ***	0.340 ***
		(0.309)	(0.304)	(0.300)	(0.104)	(0.101)	(0.098)
N		28,243	28,243	28,243	115,302	115,302	115,302

Notes: T = 1(24-hour shift); Post = 1(Midnight to 6AM). Standard errors are clustered at the paramedic level. "*", "**", and "***" indicate significance at the 10%, 5%, and 1% levels, respectively. See Table 5 notes for the full list of controls.

Table 6: Difference-in-Differences Analysis using Time-on-Duty for all Samples

Outcome		Trauma Incidents			Medical Incidents		
		With controls	**With EMT FEs**	**With shift FEs**	**With controls**	**With EMT FEs**	**With shift FEs**
Full sample							
Out-of-Hospital Time	H	0.004	0.011	0.017	-0.009 *	0.006	-0.007
		(0.010)	(0.009)	(0.025)	(0.005)	(0.005)	(0.007)
	H x Post	0.110 ***	0.088 ***	0.045	0.089 ***	0.063 ***	0.055 ***
		(0.022)	(0.020)	(0.057)	(0.010)	(0.009)	(0.014)
Number of Procedures	H	-0.003 ***	-0.002	-0.002	-0.005 ***	-0.003 ***	-0.003 ***
		(0.001)	(0.001)	(0.003)	(0.001)	(0.001)	(0.001)
	H x Post	-0.004	-0.005 **	0.001	-0.004 ***	-0.001	-0.002
		(0.003)	(0.002)	(0.007)	(0.001)	(0.001)	(0.002)
Number of observations		150,153	150,153	150,140	554,749	554,749	554,718
Matched sample (across EMTs)							
Out-of-Hospital Time	H	-0.059 ***	-0.003	-0.004	-0.031 ***	0.005	-0.002
		(0.010)	(0.009)	(0.009)	(0.005)	(0.005)	(0.008)
	H x Post	0.110 ***	0.093 ***	0.092 ***	0.083 ***	0.051 ***	0.051 ***
		(0.027)	(0.025)	(0.025)	(0.012)	(0.011)	(0.018)
Number of Procedures	H	0.002	0.000	-0.002	-0.001 *	-0.001 *	0.001 **
		(0.001)	(0.001)	(0.004)	(0.001)	(0.001)	(0.001)
	H x Post	-0.003	-0.003	0.008	-0.004 ***	-0.001	-0.002
		(0.003)	(0.003)	(0.008)	(0.001)	(0.001)	(0.002)
Number of observations		80,373	80,373	80,373	303,311	303,311	303,311
Matched sample (within EMTs)							
Out-of-Hospital Time	H	-0.046 ***	-0.012	-0.012	-0.027 ***	0.001	-0.002
		(0.015)	(0.014)	(0.050)	(0.008)	(0.008)	(0.013)
	H x Post	0.041	0.036	-0.022	0.064 ***	0.051 ***	0.039
		(0.047)	(0.044)	(0.133)	(0.021)	(0.019)	(0.030)
Number of Procedures	H	0.007 ***	0.004 **	-0.001	0.004 ***	0.001	-0.001
		(0.002)	(0.002)	(0.005)	(0.001)	(0.001)	(0.001)
	H x Post	-0.004	-0.005	0.014	-0.002	-0.001	-0.002
		(0.005)	(0.005)	(0.013)	(0.002)	(0.002)	(0.003)
Number of observations		28,243	28,243	28,039	115,302	115,302	115,302

Notes: H = Hours since start of shift; Post = 1(Midnight to 6AM). Standard errors are clustered at the paramedic level. "*", "**", and "***" indicate significance at the 10%, 5%, and 1% levels, respectively. See Table 5 notes for full list of contros.

Table 7: Effect of being on a 24-Hour Shift between Midnight and 7 AM on Quantiles of Out-of-Hospital Time and Minutes per Procedure.

Trauma Incidents		**Quantiles**						
		0.05	**0.15**	**0.25**	**0.5**	**0.75**	**0.85**	**0.95**
Out-of-Hospital Time	T	-2.521 ***	-2.473 ***	-2.076 ***	-1.934 ***	-1.623 ***	-1.153 ***	-0.351
		(0.513)	(0.319)	(0.224)	(0.411)	(0.165)	(0.241)	(0.326)
	T x Post	0.691 ***	1.082 ***	2.025 ***	3.381 ***	4.148 ***	4.969 ***	6.127 ***
		(0.113)	(0.224)	(0.503)	(0.420)	(0.432)	(0.395)	(0.870)
Minutes per Procedure	T	-0.209 ***	-0.303 ***	-0.428 ***	-1.103 ***	-2.026 ***	-3.002 ***	-3.118 ***
		(0.036)	(0.023)	(0.033)	(0.031)	(0.048)	(0.166)	(0.307)
	T x Post	0.191 ***	0.183 ***	0.344 ***	0.755 ***	1.014 ***	1.333 ***	2.017 ***
		(0.059)	(0.058)	(0.058)	(0.126)	(0.140)	(0.348)	(0.511)
N		150,104	150,104	150,104	150,104	150,104	150,104	150,104

Medical Incidents		**Quantiles**						
		0.05	**0.15**	**0.25**	**0.5**	**0.75**	**0.85**	**0.95**
Out-of-Hospital Time	T	-0.627 ***	-0.615 ***	-0.516 ***	-0.493 ***	-0.404 ***	-0.287 ***	-0.087
		(0.194)	(0.120)	(0.085)	(0.155)	(0.062)	(0.091)	(0.123)
	T x Post	0.260 ***	0.407 ***	0.762 ***	1.273 ***	1.561 ***	1.870 ***	2.306 ***
		(0.054)	(0.107)	(0.241)	(0.201)	(0.207)	(0.189)	(0.417)
Minutes per Procedure	T	0.058	0.073	-0.026 *	-0.019	-0.065 ***	-0.051 ***	-0.061 ***
		(0.054)	(0.051)	(0.014)	(0.061)	(0.009)	(0.010)	(0.014)
	T x Post	0.041 *	0.059 ***	0.102 ***	0.212 ***	0.321 ***	0.433 **	0.748 *
		(0.022)	(0.016)	(0.026)	(0.053)	(0.099)	(0.206)	(0.398)
N		554,749	554,749	554,749	554,749	554,749	554,749	554,749

Notes: T = 1(24-hour shift); Post = 1(Midnight to 6AM). The estimated variance-covariance matrix of the estimators is obtained through bootstrapping. "*", "**", and "***" indicate significance at the 10%, 5%, and 1% levels, respectively. See Table 5 notes for list of controls.

Figure A.1: Sample based on matching shifts on time elapsed before the beginning of a shift

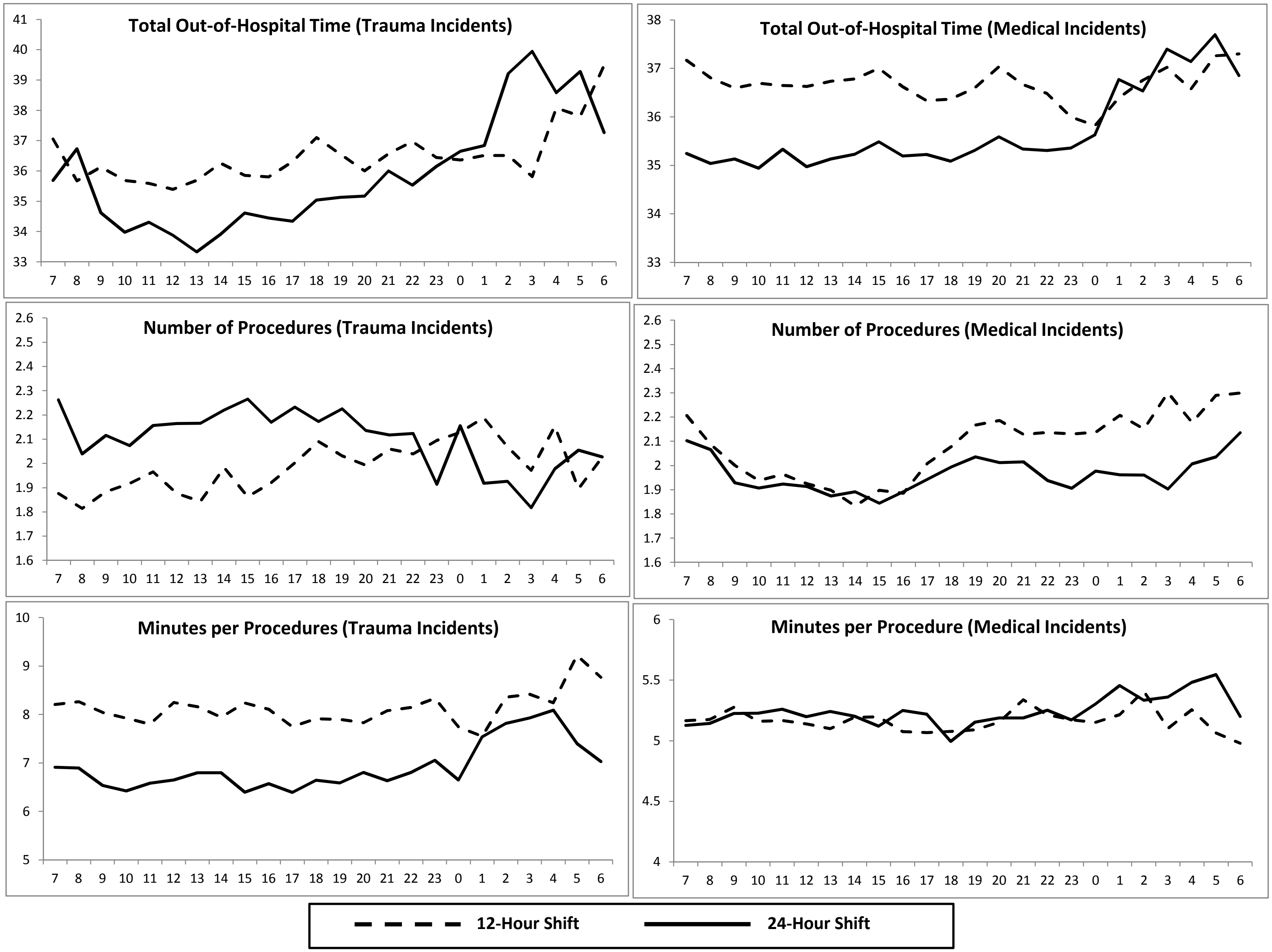


Figure A.2: Sample based on matching shifts on EMT ID (exact match) and time elapsed before the beginning of a shift