**Do variations in hospital admission rates bias comparisons of standardized hospital mortality rates? A population-based cohort study**

**ABSTRACT**

**Background:** Standardized mortality rates are routinely used as measures of hospital performance and quality. Such metrics may, however, be biased if hospital admission thresholds differ and patient severity is not fully measured.

**Aim:** To examine whether comparisons of hospital mortality rates suffer from selection bias due to variations in hospital admission rates, using the example of variations by day of the week.

**Data:** 12,900,687 emergency department attendances and 3,418,446 unplanned admissions to all acute non-specialist hospitals of the National Health Service in England between 1 April 2013 and 28 February 2014.

**Methods:** Population-based retrospective cohort study. Mortality within 30 days of attendance is modelled as a function of weekend or weekday attendance and hospital-level predictors of admission rates using patient-level risk-adjusted probit and bivariate Heckman selection models. Robustness is supported by the use of different hospital-level predictors.

**Results:** When examining only the admitted population, patients admitted to hospital at weekends have a 0.206 percentage point higher risk of death within 30 days compared to patients admitted during the week. However, patients attending emergency departments at weekends have a 1.390 percentage point lower probability of being admitted to hospital. Once this selection bias is accounted for, the weekend effect in mortality is reduced by two-thirds to a 0.068 percentage point increase in the risk of death.

**Conclusions:** Comparisons of standardized hospital mortality rates following unplanned admissions can be biased by variations in emergency department admission rates, leading to incorrect conclusions about quality. The use of mortality as a performance measure could therefore lead to misleading comparisons if admission rates vary and illness severity is not fully controlled for. Accounting for sample selection bias and dependence between admission and mortality rates is vital if accurate comparisons of hospital performance are to be made.

Key words: Risk-adjustment, hospital quality, mortality, hospital performance, standardized hospital mortality, selection bias

**INTRODUCTION**

Standardized hospital mortality rates are routinely published in several countries including the United States, England, and Canada (Canadian Institute for Health Information, 2017; Gestel et al., 2012; NHS Digital, 2012a). These summary statistics compare the death rate amongst the admitted population to the expected rate, given the admitted population’s characteristics. They have been adopted to monitor hospital performance, and are frequently used as a marker of hospital quality (Gestel et al., 2012).

Many commentators have raised concerns about the use of standardized mortality rates as measures of hospital quality. There are fears that they result in patient selection, with hospitals unwilling to treat the most high-risk patients (Gupta et al., 2017). Furthermore, criticisms have been made regarding the data used for risk-adjustment (Girling et al., 2012). Whilst administrative inpatient datasets contain a wealth of information including primary and secondary diagnoses, they do not include information on the severity of these conditions (Gestel et al., 2012). Unobserved case-mix or severity differences across hospitals will mean that hospitals admitting less severely-ill patients will therefore have lower standardized mortality rates, which could lead to incorrect conclusions about the quality of care provided during hospital admissions (Gestel et al., 2012).

Despite these criticisms, standardized mortality rates remain popular with policy-makers, in part due to their relative ease of computation and availability of data (Gestel et al., 2012). Given the importance attached to hospital mortality rates, accurate measurement and risk-adjustment is vital if correct inferences about performance and quality are to be made.

Laudicella and colleagues illustrate how the comparison of hospital readmission rates may suffer from selection bias when patient characteristics are not perfectly observable, due to differing death rates across hospitals following initial admission (Laudicella et al., 2013). They demonstrate that when mortality rates vary across hospitals, hospitals with lower mortality rates have a greater share of unobservably sicker patients facing risk of readmission. Failure to correct for this leads to underestimation of true performance on readmissions.

There is a similar potential for selection bias in the comparison of mortality rates. This is well known for elective procedures, where there is the potential for patients to select hospitals and hospitals to select patients. Hospitals have some discretion over which patients they admit for treatment, with concerns that some may avoid the most severely ill (Ellis, 1998; Omoigui et al., 1996). Elective patients can also select which hospital to seek treatment from, with this choice in part influenced by hospital quality (Brekke et al., 2014). The possibility for selection bias is less recognised for unplanned admissions as patients may have less opportunity to choose the provider to which they present, with this primarily determined by distance to the closest hospital (Laudicella et al., 2017). However, hospitals do select patients for admission from the pool of patients that present at emergency departments. If the severity threshold for admission varies across hospitals, hospitals with a higher admission threshold will face an unobservably sicker admitted patient population at a greater risk of death.

Whilst previous comparisons have focused on the variations in mortality rates across hospitals, recent developments in England have also seen the publication of mortality comparisons within hospitals, comparing patients admitted on weekends to those admitted on week days (NHS Digital, 2016). This is in response to findings of a so called ‘weekend effect’ where patients admitted to hospital at weekends experience higher death rates than patients admitted during the week, previously observed in the United States (An, 2017; Pauls et al., 2017). We focus on these variations in mortality depending on the day of the week on which patients present at emergency departments as our illustrative example. We use this example to demonstrate the potential biases from which comparisons of standardized hospital mortality rate may suffer, and to illustrate a technique to formally correct for this bias.

Recent evidence has shown that hospitals in England admit fewer patients at weekends, with patients attending emergency departments on weekends significantly less likely to be admitted than their counterparts attending on weekdays, even after adjustment for all observable patient characteristics (Meacock et al., 2017). In this paper we examine this variation in the propensity to admit to illustrate the importance of selection bias in the comparison of hospital mortality rates.

Focusing on England to illustrate the importance of this issue is advantageous because all emergency care is covered by a single payer, the National Health Service (NHS), and healthcare is free at the point of use. This eliminates the potential for hospital choice to be dictated by an individual’s health insurance coverage. In addition, national data are available for the entire population of patients attending emergency departments and admitted to hospital through this route.

**ILLUSTRATIVE EXAMPLE: MORTALITY RATES FOR WEEKEND VERSUS WEEKDAY UNPLANNED HOSPITAL ADMISSIONS**

Patients admitted to hospital in an emergency at weekends have been found to experience higher mortality rates than those admitted during the week (Lilford and Chen, 2015; Pauls et al., 2017). Whilst the focus of our example is England, this phenomenon has also been noted in many other high income countries including the United States and Canada (An, 2017; Bell and Redelmeier, 2001). The findings of this so called ‘weekend effect’ have widely been assumed to reflect poorer quality of care received on admission at the weekends (Bell and Redelmeier, 2001; NHS England, Seven Days a Week Forum, 2013; Schmulewitz et al., 2005). However, previous studies have focused solely on the admitted population. Such inferences regarding care quality may be incorrect if the population of patients admitted to hospital on weekdays and weekends differ in ways not fully captured in standard risk-adjustment models.

The majority of patients admitted to hospital in an emergency in England represent a selection from the pool of patients attending emergency departments (National Audit Office, 2013). This attending patient pool includes patients brought to the emergency department by ambulance, referred to the emergency department by a general practitioner or other healthcare professional, and patients who self-refer. Examining the entire population of patients attending emergency departments, rather than focusing only on the subset who are selected for admission, could provide additional information of importance when interpreting comparisons of admitted patient mortality rates.

There are both supply and demand factors that could potentially influence which patients enter the admitted population, and these may vary between weekdays and weekends. The potential selection mechanisms are illustrated in Figure 1, with the restricted focus of previous mortality rate comparisons contained within the dashed box.

[INSERT FIGURE 1]

Patients access emergency departments at different rates and with different characteristics throughout the week. These characteristics, some of which are unmeasured (such as illness severity), influence a patient’s risk of mortality. When patients attend emergency departments, hospitals decide whether or not to admit them, applying a filter to admissions which may vary according to demand-side factors such as patient severity (Wyatt et al., 2017), and supply-side factors such as the level of staffing in the hospital.

Once admitted, the hospital provides care to patients. It has previously been assumed that the finding of elevated mortality amongst patients admitted at the weekend reflects poor quality care received at this stage (Black, 2016). However, patient characteristics influence the flow of potential demand for admissions and supply characteristics influence the probability that attending patients will be admitted. If the characteristics of patients attending emergency departments or of those subsequently admitted differ systematically between weekdays and weekends, and the risk-adjustment models previously applied are unable to fully capture these differences, the observed weekend effect could be generated by demand-side factors. If this unobserved heterogeneity between patient populations affects both the probability that patients who attend emergency departments are admitted to hospital, and the probability of mortality once admitted, previous comparisons of mortality rates between patients admitted during the week and those admitted at the weekend may suffer from selection bias. In addition, if admission decisions differ at the weekend, this would also introduce systematic bias into previous estimates of the weekend effect.

The number of unplanned admissions has been shown to be significantly lower at the weekends (Aylin et al., 2010; Meacock et al., 2015, 2017). If this reduction in the volume of admissions reflects a change in the severity composition of patients being admitted at the weekend, then this may be contributing to the observed difference in mortality rates at the weekend. More broadly, this may extend to differences in admission and mortality rates across hospitals.

Meacock et al.(2017) previously suggested a plausible mechanism by which selection bias may be occurring through hospitals’ reduced propensity to admit patients at weekends. The study was, however, only able to examine the issue indirectly (Aylin, 2016), demonstrating that risk-adjusted mortality rates did not differ amongst the wider pool of patients attending the emergency department on weekdays and weekends. We build upon this earlier work to directly test for the presence of selection bias in estimates of the weekend effect, and illustrate a method to formally correct for selection into the admitted patient population. We quantify the magnitude of the bias at the patient level in terms of the unexplained correlation between the residuals of two separate probit regression models for admission and mortality. We then perform a formal statistical adjustment to account for the lower probability of admission on weekends, and assess its impact on the estimated magnitude of the weekend effect in mortality. We compare estimates of elevated weekend mortality rates produced when assessing only the admitted population with a bivariate Heckman selection model estimated on the total population of patients attending emergency departments. Whilst the focus of our illustrated example is the comparison of mortality rates within hospitals by day of admission, the solution offered to the sample selection problem is similarly applicable to comparisons of mortality rates across hospitals.

**METHODS**

**Data**

We use individual patient-level data on emergency department attendance and inpatient records between 1st April 2013 and 31st March 2014. These records are taken from Hospital Episode Statistics, an administrative data set capturing all hospital activity in England (NHS Digital, 2012b). We analyse emergency department attendances from the first 11 months of this period so that each patient can be followed up for 30 days after attendance. We restrict our analysis of emergency department attendances to Type 1 units, which are consultant-led 24-hour services with full resuscitation facilities and designated accommodation for the reception of accident and emergency patients. These exclude single specialty centres, minor injury units and walk-in centres, and account for 99% of unplanned admissions via emergency departments (House of Commons Library, 2015). Associated attendance and admission records were linked using a linkage file provided by NHS Digital, the national information and technology partner to the NHS. This leads us to analyse data on 12,900,687 emergency department attendances and 3,418,446 unplanned admissions.

The emergency department attendance records contain information on the patient’s age, gender, ethnic group, provider attended, date of attendance, incident location (home, work, educational establishment, public place, other), attendance category (first attendance, planned follow-up attendance, unplanned follow-up attendance), and diagnosis (38 major categories).

We analyse attendance records from the 140 non-specialist acute hospital Trusts in England for which the national healthcare information body NHS Digital reports the summary hospital-level mortality indicator (SHMI) (NHS Digital, 2012a). This sample covers all NHS hospitals designed for the reception of general emergency patients in England, and is the sample of hospitals for which mortality rate comparisons are published by the national regulator. We link these records using an encrypted patient identifier to the dates of death of all patients who had died in any hospital in England between 1st April 2013 and 31st March 2014 using inpatient records. This includes both deaths occurring during the initial index admission, and for those who are discharged alive and subsequently readmitted for either an elective or unplanned admission, captures deaths occurring during these subsequent admissions. Deaths occurring on route to, or in, an emergency department are also captured. We focus on deaths within 30 days of attendance. When an individual had multiple emergency department attendances within the last 30 days of life, we drop all but the last attendance record during this period to avoid double counting of deaths.

We adjust for socio-economic deprivation using the Index of Multiple Deprivation 2010 score for the patient’s Lower-level Super Output Area (LSOA) of residence (Department for Communities and Local government, 2015). This is a relative measure of deprivation based on an individual’s area of residence. England is divided into 32,844 LSOAs, with a mean population of 1,500. The LSOA of residence is originally derived from an individual’s postcode. Residents of countries other than England and those with missing LSOA codes were assigned to separate categories.

The admission records also contain a pseudonymised identifier for the consultant in charge of the patient’s care (Bloor et al., 2012). A consultant is a senior hospital-based doctor who has completed all of his/her specialist training, with a minimum of eight years of training after medical school. Consultants accept ultimate responsibility for the care of all of the patients referred to them (Royal College of Physicians, 2015), and all patients are admitted under the care of an allocated consultant upon hospital admission (NHS Digital, 2018). This information is used to construct one of the hospital-level variables that determines the probability of admission. It should be noted that when this code appears on a patient’s record, it may refer to the individual consultant or a consultant-led team of doctors (Health & Social Care Information Centre, 2013).

**Statistical analysis**

We observe two binary outcomes for each patient: whether the patient’s attendance results in an admission () and whether the patient dies within 30 days of their attendance ().

First, to replicate the standard approach to mortality rate comparisons, we begin by focusing on the mortality of the admitted population. We estimate a probit regression for the probability of mortality conditional on being admitted and a vector of explanatory variables () including an indicator of whether the patient was admitted on a weekend:

where is the normal c.d.f. and . The vector of explanatory variables are as follows: age, gender, ethnic group, provider, incident location, attendance category, diagnosis, area deprivation, and a binary variable indicating whether the admission took place at the weekend. This analysis is performed to estimate the magnitude of the difference in mortality rates between weekday and weekend admissions when we do not account for selection bias.

Second, we estimate the probability of admission to hospital for all those attending emergency departments as a function of the same set of explanatory variables to investigate whether this varies between weekdays and weekends:

Finally, we assess the importance of the admission selection decision by estimating a bivariate Heckman selection model (Heckman, 1979; Laudicella et al., 2013):

assuming that the errors are independent of and and distributed as a bivariate standard normal with correlation coefficient .

We use two variables in only the admission equation (exclusion restrictions, ) to improve the identification of our model (Puhani, 2000). These are variables that explain an individual’s probability of admission to hospital given that they attend the emergency department, but not an individual’s probability of dying given that they are admitted, other than through the impact on admission probability.

We present the main results estimated using both exclusion restrictions jointly. In subsequent sensitivity analysis the exclusion restrictions are included individually to assess the robustness of our results to different specifications of the selection models. Results are reported in terms of average marginal effects, that is, the average across all patients of the changes in the probability of admission or mortality associated with one-unit changes in the explanatory variable of interest. All analyses were performed using Stata 14.

***Exclusion restrictions***

We construct two potential exclusion restrictions; one capturing demand-side pressures and one representing supply-side constraints:

* + 1. Typical volume of demand on this provider on this day of the week relative to other days of the week.

We construct an indicator of the extent to which each of the 140 emergency departments experiences fluctuations in relative demand (represented by the volume of attending patients) across the seven days of the week. We calculate the average number of emergency department attendances at each hospital on each day of the week. We then divide by the maximum value for each hospital to create an index that reflects the relative variation in emergency department attendance volumes for each hospital across the days of the week. This generates an index of demand taking seven values for each hospital – a value of 1 in each hospital on the day of the week with the highest demand and the extent to which each hospital’s demand is typically reduced on every other day of the week compared to this.

We propose that these typical variations in the number of patients attending the emergency department across the week influence the probability of being admitted to hospital given that a patient has attended, but is uncorrelated with an individual patient’s inherent risk of mortality conditional on their measured characteristics. By using the average demand on a given day across the year as opposed to the level of demand on the exact date, we avoid potential correlation between levels of demand and individuals’ risk of mortality, for example due to a large accident or disease outbreak occurring in the area.

The decision to admit patients attending the emergency department is to some extent at the discretion of hospital staff, who are likely to adopt higher thresholds for admission on days that are typically busy. A priori, we hypothesised that the probability of admission would typically be lower on days that were typically busier for hospitals.

* + 1. Consultant availability

As a proxy for the number of consultants available to admit patients, we count the number of unique consultant identifiers appearing on unplanned admission records in each hospital on each date. For each hospital, we then construct a measure of the extent to which the complement of consultants available to admit patients varies across days of the week. We calculate the average number of consultants admitting patients on each day of the week at each hospital. We divide by the average value for Wednesday in each hospital to reflect the proportionate reduction in availability of consultants. This generates an index of availability taking seven values for each hospital – a value of 1 in each hospital on a Wednesday and the extent to which each hospital’s complement of admitting consultants is typically reduced on every other day of the week compared to this. Wednesday was chosen as the reference as this was the day of the week with the highest average number of admitting consultants.

This is intended to capture the rota pattern of consultants at each provider across days of the week. We propose that the typical variation across hospitals in consultant availability throughout the week influences the probability that a patient will be admitted to hospital given that they attend the emergency department, but is uncorrelated with an individual’s inherent risk of mortality conditional on their observable characteristics. Whilst it could be hypothesised that levels of consultant presence could impact on the probability of mortality amongst those admitted, a recent study in England demonstrated that elevated weekend mortality was not associated with variations across hospitals in the extent to which senior doctors were present on Sundays compared with Wednesdays (Aldridge et al., 2016), supporting the validity of this exclusion restriction. A priori, we hypothesised that the number of consultants available would be positively associated with an individual’s probability of admission.

**RESULTS**

Descriptive statistics on the characteristics of the patients attending emergency departments and of the population subsequently admitted are shown in Table I. Of the emergency department attendances we examine, 9,236,122 occurred on a week day and 3,664,565 on a weekend. The patient characteristics are broadly similar between those attending on weekdays and weekends. However, the proportion of patients attending emergency departments who are subsequently admitted to hospital is lower at weekends (25.26%) than on week days (26.99%). This is an absolute difference of -1.73 percentage points and a relative difference of -6.4%.

The average volume of attendances index is similar on weekdays (0.910) to weekends (0.902) but there is more variability between hospitals on weekends (SD=0.058, IQR 0.861 to 0.944) compared to weekdays (SD=0.052, IQR 0.875 to 0.926). The average consultant availability index is much higher on weekdays (0.933) than weekends (0.707), and again there is more variability between hospitals at weekends (SD=0.083, IQR 0.654 to 0.760) than weekdays (SD=0.061, IQR 0.896 to 1.000).

Table II provides our first estimate of the impact of being admitted to hospital at the weekend on mortality from a probit model estimated on the admitted patient sample. Results are reported in terms of average marginal effects, that is, the average across all patients of the changes in the probability of mortality associated with a one-unit change in the explanatory variable of interest. We find that, amongst the population selected for admission, weekend admission is associated with a significantly higher risk of death of 0.206 percentage points.

Table III shows the determinants of hospital admission amongst the sample of patients attending emergency departments. Results are reported in terms of average marginal effects. We find that, conditional on all observable characteristics including diagnosis, patients attending emergency departments at the weekends have a 1.390 percentage point lower probability of being admitted to hospital than their counterparts attending during the week. When our exclusion restrictions are added to the admission model, the magnitude of this weekend effect on admission probability is reduced slightly to a 1.181 percentage point reduction. Both of the exclusion restrictions predict the probability that an individual will be admitted to hospital given emergency department attendance significantly, and the signs of the coefficients are in line with our a priori hypotheses. We find that patients attending a hospital on a day that is typically a busier day for this hospital have a lower probability of being admitted. Conversely, attending the emergency department on a day when the hospital typically tends to have more consultants present increases an individual’s probability of admission to hospital.

Table IV shows the results from the bivariate Heckman selection model. Results are again reported as average marginal effects. The residual correlation coefficient is positive and statistically significant, indicating that the unobservables that positively predict the admission probability also positively predict the probability of death. Once this selection into the admitted population is accounted for, the weekend effect is reduced in magnitude to a 0.068 percentage point increase in the risk of death. Two thirds of the elevated mortality risk associated with weekend admission found when examining only the admitted patient population can therefore be explained by selection bias.

Table IV also presents the results of the sensitivity analysis where the exclusion restrictions are used individually rather than jointly. The results are stable across the different specifications, with the magnitude of the effect on weekend attendance unchanged. When only the typical volume of attendances at the same provider is used to identify the models, attending on a weekend is associated with a 0.068 percentage point increase in the risk of death. When only the level of consultant availability is used, attending on a weekend is associated with a 0.072 percentage point increase in mortality risk. The residual correlation coefficient is positive and statistically significant across specifications, indicating that the unobservables that increase admission probability also increase the probability of death. This sensitivity analysis confirms that, regardless of the exclusion restrictions used to identify the models, two thirds of the elevated mortality risk associated with weekend admission can be explained by selection into the admitted population.

**DISCUSSION**

Standardized mortality rates are routinely used as a measure of hospital performance and quality. However, the resulting inferences regarding quality of care may be incorrect if the admitted populations differ in ways not fully captured by standard risk-adjustment models. Differences in admission policies or practices may therefore influence the validity of standardized mortality comparisons.

Using the example of mortality rates for weekday versus weekend unplanned admissions, we illustrate how such comparisons may suffer from selection bias, and propose a solution to correct for this sample selection problem. We confirm that patients attending emergency departments at the weekends have a lower probability of being admitted, conditional on their observable patient characteristics. The residual correlation between the errors in the admission and mortality equations is positive and significant, indicating that the unobservable characteristics that increase admission probability also increase the probability of mortality. This means that ignoring the correlation between admission and mortality results in material sample selection bias in the estimate of the association between weekend admission and mortality. The patients admitted at the weekend represent a more severely ill population than those admitted during the week, and this difference in severity is not adequately captured by standard risk-adjustment variables available in hospital inpatient records.

We then demonstrate a solution to the sample selection problem, which has previously been applied to the estimation of hospital readmission rates (Laudicella et al., 2013). In our example, the magnitude of the mortality rate difference between weekday and weekend admissions is reduced by two thirds once selection into the admitted population is accounted for. Being admitted at the weekend is found to be associated with a 0.068 percentage point increase in the risk of death, from a baseline of 4.037% on a weekday. Applied to the volume of weekend admissions of 925,687 over the 11 month period we examine, this equates to 629 excess deaths above the level we would expect if the same patients were admitted to hospital during the week. This is compared to an estimate of 1,902 excess deaths that would be produced using standard risk-adjustment methods not accounting for selection bias. This calculation illustrates the material difference that accounting for selection bias can make.

***Strengths and limitations***

In this study we examined the total population of patients attending emergency departments rather than just the subset of patients who were subsequently admitted to hospital. The single payer structure of the NHS in England eliminates the potential for hospital choice to be dictated by an individual’s health insurance coverage, and so provides a good setting in which to illustrate the importance of this phenomenon. Linked individual patient-level data was available for the entire population of patients attending emergency departments and admitted to hospital through this route nationally.

The selection models we have employed rely in part on the validity of the exclusion restrictions used in the admission equation. The variables we used as exclusion restrictions are proxies for important aspects of demand or supply, but cannot fully capture all influences on the admission decision. We undertook sensitivity analyses to check that our results are robust to different specifications of the selection model, and not dependent on the particular exclusion restrictions used.

We did not have information on deaths occurring out of hospital, which would generate bias if the proportion of all deaths that occur in a hospital is different for weekday versus weekend admissions. We do, however, have data on out-of-hospital deaths for an earlier year (1st April 2010 to 31st March 2011) which allows us to investigate the potential influence of this omission. Analysis of this earlier data shows a small bias towards finding higher death rates for patients admitted at the weekend as a slightly higher proportion of deaths within 30 days of admission occur in hospital for weekend admissions (81.3%) than for weekday admissions (80.1%). The direction of this bias means that including out-of-hospital deaths in this analysis would further reduce the detected weekend effect towards zero, reinforcing our findings.

***Comparison with previous literature***

Meacock et al.(2017) previously highlighted the possibility that estimates of the weekend effect may suffer from selection bias. The study found that after adjustment for observable patient characteristics, individuals attending emergency departments on weekends were significantly less likely to be admitted than their counterparts attending on weekends. This result indirectly suggested that the population of patients admitted to hospital on weekends would be on average sicker than those admitted during the week, in ways that would not be fully captured by standard risk-adjustment models. Here we build upon this earlier work in a number of ways.

We directly test the theory proposed in Meacock et al. (2017) and confirm the presence of selection bias in estimates of the weekend effect when examining only the admitted population. We quantify the magnitude of this selection bias at the patient-level and formally examine the mechanisms by which this selection bias can occur, considering both demand and supply-side influences. We then implement a formal statistical adjustment to account for this selection bias. The Heckman approach offers a solution to the issue of selection bias in the absence of data on the severity of patients’ condition(s), and so could be applied more widely to other comparisons of mortality rates amongst admitted populations.

Meacock et al. (2017) highlighted the importance of separating patients by their route of admission to hospital, illustrating that those entering hospital through the emergency department and those directly admitted by primary care physicians represent two distinct patient groups. In this paper we have focused only on patients admitted through the most common route; the emergency department. The methods illustrated here could similarly be applied to account for selection into the admitted population for direct admissions using pre-admission data on patients’ attendance at primary care services. This is an area for future research.

***Policy implications***

Our results have important implications for the use of standardized mortality statistics as an indicator of hospital quality. Judging hospitals on their mortality rates may lead to incorrect conclusions about performance if the selection bias caused by variations in admission thresholds is not accounted for. Hospitals with low admission thresholds will on average have lower mortality rates. However, they may be admitting patients to hospital unnecessarily, causing inefficiencies within the system. The use of mortality as a performance measure could therefore lead to a perverse situation where hospitals face the possibility of being penalised for efficient admission management if severity of illness is not fully controlled for within these metrics. Accounting for the sample selection bias and dependence between admission and mortality rates is therefore vital if correct inferences are to be made from the comparison of hospital mortality rates.

Laudicella and colleagues have previously demonstrated the dependencies between survival rates following hospital admission and subsequent hospital readmission rates (Laudicella et al., 2013, 2017). We show that there is similar potential for selection bias in the comparison of hospital mortality rates, with these influenced by hospital admission rates in ways not fully accounted for by standard risk-adjustment models. Hospitals influence both the volume and composition of the patient population that they admit, and so making performance comparisons across only the admitted population can result in misleading conclusions regarding the quality of care provided. Regulators should pay attention to admission rates alongside mortality rates. If such performance metrics are to be used they should cover all stages of the hospital treatment process, from the point at which individuals first seek care. Similar models to those estimated here could be used to account for selection bias in comparisons of mortality rates across hospitals. These models offer a solution in the absence of richer data capturing the severity of patients’ conditions, collection of which would also improve risk-adjustment methods.

Careful consideration is required over the choice of exclusion restrictions when implementing such selection models. These variables should affect the initial selection stage of the model (in our case, the admission decision) but should not affect the outcome of interest (in our case, mortality) directly. For this reason, we used variables that reflected conditions at the ‘front door’ of the hospital. Factors such as bed capacity and hospital crowding are also likely to influence the probability of admission, but it is probable that they will also reflect the quality of care provided to patients during their stay in hospital. Their inclusion could therefore pick up part of the causal mechanism of interest when the purpose of hospital mortality rate comparisons is to make inferences about hospital quality. It is therefore important to consider where factors lie on the causal pathway of interest to ensure that the analysis does not inadvertently control for elements of the phenomenon of interest. Bed occupancy is an important dimension of hospital quality and therefore should not be controlled for in such analyses.

Our analysis may have implications for the evaluation of policy changes designed to reduce the pressure on emergency departments. The proposal to relax the waiting times targets applied to emergency departments in England, for example, may alter the mix and volume of patients admitted to hospital. This could lead to potentially misleading impacts on hospital mortality rates if these changes in admission decisions are not fully accounted for. Finally, our findings also have important potential consequences for the evaluation of current initiatives in both the United States and England aimed at reducing unplanned hospital admission volumes. If hospitals reduce their unplanned admission rates by lowering the proportion of low-severity patients that they admit, they will consequently record higher mortality rates amongst the admitted population. This may in turn create incorrect concerns about the quality of care provided during patient admissions if hospitals are also being judged on their standardized mortality rates.

**REFERENCES**

Aldridge, C., Bion, J., Boyal, A., Chen, Y.-F., Clancy, M., Evans, T., Girling, A., Lord, J., Mannion, R., Rees, P., Roseveare, C., Rudge, G., Sun, J., Tarrant, C., Temple, M., Watson, S., Lilford, R., 2016. Weekend specialist intensity and admission mortality in acute hospital trusts in England: a cross-sectional study. The Lancet 388, 178–186.

An, R., 2017. Impact of weekend admission on in-hospital mortality among U.S. adults, 2003-2013. Ann. Epidemiol. 27, 790–795.

Aylin, P., 2016. Re: Higher weekend death rate is flawed, study finds. BMJ 353, i2598.

Aylin, P., Yunus, A., Bottle, A., Majeed, A., Bell, D., 2010. Weekend mortality for emergency admissions. A large, multicentre study. Qual. Saf. Health Care 19, 213–217.

Bell, C.M., Redelmeier, D.A., 2001. Mortality among Patients Admitted to Hospitals on Weekends as Compared with Weekdays. N. Engl. J. Med. 345, 663–668.

Black, N., 2016. Is hospital mortality higher at weekends? If so, why? The Lancet 388, 108–111.

Bloor, K., Freemantle, N., Maynard, A., 2012. Trends in consultant clinical activity and the effect of the 2003 contract change: retrospective analysis of secondary data. J. R. Soc. Med. 105, 472–479.

Brekke, K.R., Gravelle, H., Siciliani, L., Straume, O.R., 2014. Patient choice, mobility and competition among health care providers. Dev. Health Econ. Public Policy 12, 1–26.

Canadian Institute for Health Information, 2017. Hospital Standardized Mortality Ratio (HSMR) [WWW Document]. URL http://indicatorlibrary.cihi.ca/pages/viewpage.action?pageId=1114189 (accessed 5.15.17).

Department for Communities and Local government, 2015. The English Indices of Deprivation 2015 Statistical Release.

Ellis, R., 1998. Creaming, skimping and dumping: provider competition on the intensive and extensive margins. J. Health Econ. 17, 537–555.

Gestel, Y.R.B.M. van, Lemmens, V.E.P.P., Lingsma, H.F., Hingh, I.H.J.T. de, Rutten, H.J.T., Coebergh, J.W.W., 2012. The hospital standardized mortality ratio fallacy: a narrative review. Med. Care 50, 662–667.

Girling, A.J., Hofer, T.P., Wu, J., Chilton, P.J., Nicholl, J.P., Mohammed, M.A., Lilford, R.J., 2012. Case-mix adjusted hospital mortality is a poor proxy for preventable mortality: a modelling study. BMJ Qual. Saf. 21, 1052–1056.

Gupta, K., Wachter, R., Kachalia, A., 2017. Financial incentives and mortality: taking pay for performance a step too far. BMJ Qual. Saf. 26, 164–168.

Health & Social Care Information Centre, 2013. Hospital Episode Statistics (HES) Analysis Guide.

Heckman, J.J., 1979. Sample Selection Bias as a Specification Error. Econometrica 47, 153–61.

House of Commons Library, 2015. Research Briefings - Accident and Emergency Statistics [WWW Document]. URL http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN06964#fullreport (accessed 8.6.15).

Laudicella, M., Li Donni, P., Smith, P.C., 2013. Hospital readmission rates: Signal of failure or success? J. Health Econ. 32, 909–921.

Laudicella, M., Martin, S., Li Donni, P., Smith, P.C., 2017. Do Reduced Hospital Mortality Rates Lead to Increased Utilization of Inpatient Emergency Care? A Population-Based Cohort Study. Health Serv. Res.

Lilford, R.J., Chen, Y.-F., 2015. The ubiquitous weekend effect: moving past proving it exists to clarifying what causes it. BMJ Qual. Saf. bmjqs-2015-004360.

Meacock, R., Anselmi, L., Kristensen, S.R., Doran, T., Sutton, M., 2017. Higher mortality rates amongst emergency patients admitted to hospital at weekends reflect a lower probability of admission. J. Health Serv. Res. Policy 22, 12–19.

Meacock, R., Doran, T., Sutton, M., 2015. What are the Costs and Benefits of Providing Comprehensive Seven-day Services for Emergency Hospital Admissions? Health Econ. 24, 907–912.

Miraldo, M., Goddard, M., Smith, P.C., 2006. The incentive effects of payment by results ( No. 19), CHE Research Papers. York.

National Audit Office, 2013. Emergency admissions to hospital: managing the demand.

NHS Digital, 2012a. Summary Hospital-level Mortality Indicator [WWW Document]. URL http://content.digital.nhs.uk/SHMI (accessed 5.15.17).

NHS Digital, 2012b. Hospital Episode Statistics [WWW Document]. URL http://content.digital.nhs.uk/hes (accessed 4.11.17).

NHS Digital, 2016. Seven-day Services - England, April 2015 - March 2016, Experimental statistics [WWW Document]. URL http://digital.nhs.uk/catalogue/PUB22253 (accessed 11.9.17).

NHS Digital, 2018. HES Data Dictionary Admitted Patient Care.

NHS England, Seven Days a Week Forum, 2013. Evidence base and clinical standards for the care and onward transfer of acute inpatients.

Omoigui, N.A., Miller, D.P., Brown, K.J., Annan, K., Cosgrove, D., Lytle, B., Loop, F., Topol, E.J., 1996. Outmigration For Coronary Bypass Surgery in an Era of Public Dissemination of Clinical Outcomes. Circulation 93, 27–33.

Pauls, L.A., Johnson-Paben, R., McGready, J., Murphy, J.D., Pronovost, P.J., Wu, C.L., 2017. The Weekend Effect in Hospitalized Patients: A Meta-Analysis. J. Hosp. Med. 12, 760–766.

Puhani, P., 2000. The Heckman Correction for Sample Selection and Its Critique. J. Econ. Surv. 14, 53–68.

Royal College of Physicians, 2015. Consultant physicians [WWW Document]. RCP Lond. URL https://www.rcplondon.ac.uk/education-practice/advice/consultant-physicians (accessed 3.20.19).

Schmulewitz, L., Proudfoot, A., Bell, D., 2005. The impact of weekends on outcome for emergency patients. Clin. Med. 5, 621–625.

Wyatt, S., Child, K., Hood, A., Cooke, M., Mohammed, M.A., 2017. Changes in admission thresholds in English emergency departments. Emerg Med J 34, 773–779.