GRATTAN Institute

Safer care saves money: How to improve patient care and save public money at the same time. Methodological supplement

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1 Introduction

This methodological supplement provides detailed explanation of six pieces of the analysis in *Safer care saves money*:

- Our estimates of the costs of complications.
- Our comparison of the costs and funding implications of complications.
- Our estimates of the cost savings to be made from improving safety performance.
- The relationship between hospitals' cost efficiency and performance.
- Our analysis of sentinel events using routine data.
- Our modelling of hospital safety performance by specialty.

The first three sections relate to the econometric analysis we undertook to estimate the cost of complications. These sections are organised as follows. Chapter 2 describes the data we used. Chapter 3 reviews previous approaches to using regression analysis to estimate the cost of complications. Chapter 4 describes our regression model and discusses our key results.

In Chapter 5 we discuss how we compared the costs and funding implications of complications for individual hospitals.

In Chapter 6 we describe how we estimated the cost savings to be made from improving safety performance.

In Chapter 7 we explain how we assessed the relationship between hospitals' cost efficiency and performance in the area of medical multiday cardiology admissions.

In Chapter 8 we explain how we identified sentinel events in the routine data.

Finally, in Chapter 9 we provide an overview of the method we used to analyse the distribution of hospital risk by specialty.

2 Data used to estimate the cost of complications

In estimating the costs of complications, our core dataset is the 2014-15 National Hospital Cost Data Collection (NHCDC) for the public sector. This unique dataset is the primary input to determining the National Efficient Price (NEP) and National Efficient Cost (NEC) for the funding of public hospital services.[1] We are grateful to the Independent Hospital Pricing Authority (IHPA) for providing this data and their assistance during our preparation of this report. The data file received from IHPA contained patient, episode and cost information for 5,282,843 admissions of acute and newborn care in public hospitals.

2.1 Cleaning and preparation

Our initial cleaning and preparation of the data involved the following:

- We dropped admissions that involved an operating room procedure that was unrelated to the principal diagnosis, or involved atypical or invalid information. These admissions have a Diagnosis Related Group (DRG) prefix of '8' or '9', respectively.[2] Our data has the 6th, 7th and 8th versions of the Australian Refined DRG (AR-DRG) reported. If any of the versions had an '8' or '9' prefix, it was excluded. This dropped 11,946 admissions.
- We dropped admissions of newborn care (care types 7.1 and 7.2), leaving just acute admissions (care type 1). This dropped a further 53,806 admissions.
- We truncated to 40 columns both our diagnosis code array (down from 100) and our procedure code array (down from 50). This is because the algorithm we use to identify complications in the data – the Classification of Hospital Acquired Diagnoses Plus (CHADx+) – only reads up to the 40th column. We do not consider this a material loss of information as there are just 1,104 admissions with more than 40 diagnosis codes, and 201 admissions with more than 40 procedure codes.
- We dropped admissions at hospitals that did not record a single condition onset flag equal to one (COF=1) – that is, hospitals that did not record any diagnoses as being hospital acquired. We considered that an absence of COF=1 likely reflected a coding issue, although that this was potentially less true for some small hospitals which may have genuinely not had any hospital-acquired diagnoses. This exclusion dropped 16 hospitals and a further 12,356 admissions in total.[3]

As we proceeded with our analysis, the following additional exclusions were required:

- We dropped a further two admissions that were found to have invalid diagnosis codes.
- We dropped a further 10 admissions involving a patient who was intersex or whose sex was indeterminate, and three admissions where sex was not stated or inadequately described. We made

1. See: https://www.ihpa.gov.au/what-we-do/nhcdc.
2. The DRG system is a patient classification system developed to provide a clinically meaningful way of relating the number and type of patients treated in a hospital to the resources required by the hospital. Each DRG represents a class of patients with similar clinical conditions requiring similar hospital resources; AIHW (2016, p. 5).
3. We also examined the ratios at individual hospitals of the number of valid condition onset flags reported (*i.e.* equal to 1 or 2) to the number of diagnosis codes reported. The lowest ratio observed at a hospital was 0.97, suggesting that all hospitals were reporting a condition onset flag for essentially every diagnosis code they reported (although coding practices in some states or hospitals may mean that they are more or less likely to record COF=1).

these exclusions because we use a binary classification of sex for computational simplicity in our regression analysis.

- We dropped a further 296 admissions that had an error DRG after their DRG was reassigned excluding those additional diagnoses and procedures that were identified as being complications by the CHADx+ algorithm. Our use of this reassigned DRG variable is explained later in this supplement.

In total, we excluded 78,419 admissions leaving 5,204,424 admissions and 328 hospitals in our core data.

2.2 Identifying complications in our data

We used the CHADx+ version 1.4 program for SAS to identify complications in our data.[4] This program was provided by the Victorian Department of Health and Human Services. We describe CHADx+ in detail in Section 1.2.1 of the methodological supplement to our previous report *All complications should count: Using our data to make hospitals safer*.[5]

CHADx+ v.1.4 includes a data-cleaning algorithm that 'turns off' instances of COF=1 for any diagnoses that could not have been acquired during the hospital admission. Prior to application of this algorithm, 9.6 per cent of the episodes in our data had at least one diagnosis code that had been flagged as hospital acquired. After application, this rate fell to 9.4 per cent.

CHADx+ v.1.4 contains a number of different specifications relative to the versions of CHADx that appear to have been used in other analyses. It was crucial for us to investigate and understand these differences in order to:

- have comfort that we assigned CHADx+ classes to our data correctly; and
- understand differences between our results and those published elsewhere.

For these purposes, we primarily compared our CHADx+ assignment against CHADx data published by the Australian Institute of Health and Welfare (AIHW) in its 2014-15 Admitted Patient Care report (see Table 2.1 on the following page and Table 2.2 on page 7).[6] The AIHW appears to have used CHADx version 5, as this was the version that was on the Australian Commission on Safety and Quality in Health Care's (ACSQHC) website in December 2014 when AIHW reportedly accessed it.[7]

4. See Jackson et al. (2009) for more information about CHADx.
5. Danks and Duckett (2018).
6. Tables 8.5 and 8.6 of AIHW (2016).
7. According to the references list in AIHW (ibid.).

Table 2.1: Comparison with AIHW of most prevalent individual CHADx classes

AIHW CHADx	AIHW CHADx description	AIHW data	Our data	CHADx+ v.1.4	CHADx+ v.1.4 description	Comment
5.06	Hypotension	51,421	56,126	5.07	Hypotension	
15.02	Electrolyte disorders without dehydration	46,092	56,821	15.02	Electrolyte disorders /fluid management	CHADx v.5 does not assign 15.02 if volume depletion also present
5.03	Cardiac arrhythmias, conduction disturbances and abnormal heart beat	39,841	38,952	5.04	Conduction disturbances / abnormal heart beat	5.03 in CHADx v.5 covers both 5.03 and 5.04 from CHADx+ v.1.4
12.07	Second degree perineal laceration	38,790	46,436	12.07	Second degree perineal laceration	CHADx+ v.1.4 assigns MCHADx 12 regardless of the status of the COF
7.05	Nausea and vomiting	26,110	26,952	7.04	Nausea and vomiting	
7.04	Constipation	25,660	25,638	7.03	Constipation	
12.09	Maternal haemorrhage	28,059	42,001	12.09	Maternal haemorrhage	CHADx+ v.1.4 assigns MCHADx 12 regardless of the status of the COF
8.03	Dermatitis, rash and other skin effects	21,488	24,407	8.04	Dermatitis, rash and other skin effects	8.04 in CHADx+ v.1.4 is spread across 8.03 and 8.04 in CHADx v.5
13.11	Other neonatal complications	25,052	2,044	13.10	Other neonatal complications	We have excluded admissions involving newborn care from our data
12.01	Foetal heart rate abnormalities	22,604	26,837	12.01	Foetal heart rate abnormalities	CHADx+ v.1.4 assigns MCHADx 12 regardless of the status of the COF
10.04	Alterations to mental state	19,926	17,102	10.03	Delirium	10.04 in CHADx v.5 covers both 10.03 and 10.04 from CHADx+ v.1.4
9.02	Urinary tract infection	16,669	14,958	4.16	Hospital-acquired urinary tract infection	4.16 in CHADx+ covers 9.02 and some components 9.04 from CHADx v.5
12.14	Breast disorders associated with childbirth	15,083	19,718	12.14	Breast disorders associated with childbirth	CHADx+ v.1.4 assigns MCHADx 12 regardless of the status of the COF
12.15	Other disorders predominately related to pregnancy	18,623	n/a	n/a	n/a	12.15 in CHADx v.5 covers a range of classes from CHADx+ v.1.4
15.01	Dehydration / volume depletion	18,514	20,954	15.01	Dehydration/volume depletion	
2.16	Adverse effects due to other drugs	16,738	17,363	2.16	Complications due to other drugs	
12.06	First degree and unspecified perineal laceration	15,449	18,694	12.06	First degree and unspecified perineal laceration	CHADx+ v.1.4 assigns MCHADx 12 regardless of the status of the COF
9.04	Other complications and symptoms of the urinary system	14,299	16,055	9.03	Other complications and symptoms of the urinary system	See comment above in regard to urinary tract infection
17.12	Other symptoms	15,314	14,753	17.11	Other symptoms	
17.04	Chest pain	15,373	15,456	17.04	Chest pain	

In summary, the main differences in specifications are:

- CHADx+ v.1.4 assigns individual classes in Major CHADx Class 12 (MCHADx 12) regardless of the status of the COF. This makes our incidence of MCHADx 12 considerably higher. It also means that our incidence of at least one CHADx (10.1 per cent) is higher than our incidence of episodes with at least one diagnosis code that has been flagged as hospital acquired (9.4 per cent).
- CHADx 15.02 is 'Electrolyte disorders / fluid management' in CHADx+ v.1.4, whereas it is 'Electrolyte disorders without dehydration' in CHADx v.5. This is given effect in CHADx v.5 by not counting instances of 15.02 whenever diagnosis code E86 'Volume depletion' is present in the admission. When we apply this exclusion to our data, our incidence of CHADx 15.02 falls significantly.
- MCHADx 4 has undergone large-scale recategorisation in CHADx v.5 relative to CHADx+ v.1.4. Among many material changes, the most notable is the recategorisation of Urinary Tract Infections to CHADx 9.02 in CHADx v.5 from CHADx 4.16 in CHADx+ v.1.4. This means that our incidence of MCHADx 4 is high.
- Our incidence of MCHADx 4 may also be high on account of specifications in CHADx v.5 that seek to eliminate the double counting of sepsis. These specifications are not in CHADx+ v.1.4.
- In CHADx v.5, MCHADx 5, 8, 10 and 14 to 17 have additional criteria that under certain conditions re-assign a CHADx that would have otherwise been in one of these classes to one of MCHADx 1, 2 or 3. CHADx+ v.1.4 does not have these additional criteria. This absence might explain our low incidence of MCHADx 1 and 2 and slightly high incidence of some other MCHADx.

In addition to these major differences, there are a number of other changes in specifications that help explain differences between our

Table 2.2: Comparison with AIHW of Major CHADx classes

Major CHADx class (as named in AIHW)	AIHW data	Our data
MCHADx 1 Post-procedural complications	73,665	66,406
MCHADx 2 Adverse drug events	50,654	35,379
MCHADx 3 Accidental injuries	20,847	18,931
MCHADx 4 Specific infections	19,879	68,270
MCHADx 5 Cardiovascular complications	96,997	108,103
MCHADx 6 Respiratory complications	44,851	40,629
MCHADx 7 Gastrointestinal complications	72,315	67,237
MCHADx 8 Skin conditions	35,683	34,906
MCHADx 9 Genitourinary complications	56,051	48,610
MCHADx 10 Hospital-acquired psychiatric states	33,134	34,695
MCHADx 11 Early pregnancy complications	795	832
MCHADx 12 Labour, delivery and postpartum complications	114,609	163,157
MCHADx 13 Perinatal complications	59,149	6,386
MCHADx 14 Haematological disorders	24,689	30,343
MCHADx 15 Metabolic disorders	78,174	82,483
MCHADx 16 Nervous system complications	8,928	9,452
MCHADx 17 Other complications	87,465	87,748

results and those published by the AIHW. For brevity, we do not go through these here.

Finally, we chose not to count ventilatory support (CHAPx 1.01 and 1.02) as a complication when it occurred during an emergency admission. In many of these admissions the use of ventilatory support would be expected and therefore not a 'complication'. Other classes of CHADx and CHAPx may to a lesser extent also reflect routine, in-hospital developments. Indeed, as was pointed out to us by one stakeholder, even in some elective admissions ventilatory support would be anticipated. However, it was beyond the scope of our work to parse all CHADx and CHAPx classes for this issue. Ventilatory support in emergency admissions was singled out because it could be easily addressed, is costly and relatively common, and to consider it a complication could lead to significantly overstating the total cost of complications to the hospital system.

3 Review of previous approaches to estimating the cost of complications

Our first step in conducting our own econometric analysis of the costs of hospital-acquired complications was to review the methods used in the three major contributions to the literature that are particularly relevant to the Australian setting:

- Jackson, T., Nghiem, H.S., Rowell, D., Jorm, C., & Wakefield, J. (2011). 'Marginal costs of hospital-acquired conditions: information for priority-setting for patient safety programmes and research'. *Journal of Health Services Research & Policy*, 16(3), 141-146.
- Jackson, T., Fong, A., Liu, M., Murray, K., Walz, L., Houston, C., & Dean, S. (2013, under review). *Incremental costs of hospital-acquired complications in Alberta, Canada*.
- Health Policy Analysis (2013). *Analysis of hospital-acquired diagnoses and their effect on case complexity and resource use – Final report*. Australian Commission on Safety and Quality in Health Care, Sydney.

3.1 Jackson et al. (2011)

The authors estimated incremental costs of CHADx using public hospital data from Victoria and Queensland from 2005-06 and 2006-07, respectively.

They identified that the cost of a hospital episode includes: the cost of treating the primary diagnosis (*i.e.* the reason for admission); any additional costs attributable to co-morbidities; and the cost of any hospital-acquired diagnoses.

They then defined the 'uncomplicated treatment cost' as the portion of each episode's cost that is attributable to the principal diagnosis and co-morbidities. This is calculated for each AR-DRG as the mean cost of all episodes with no CHADx present. The 'mean corrected treatment cost' is then calculated as the portion of each episode's cost that remains after subtracting the relevant AR-DRG's uncomplicated treatment cost.

The authors then regressed mean corrected treatment cost on dummy variables representing:

- the presence of individual CHADx classes;
- whether the patient died in hospital; and
- whether the episode was sameday.

Despite the dependent variable not being normally distributed, the authors considered that standard linear regression techniques (*i.e.* OLS) were appropriate given their large sample size (consistent with the findings of Lumley et al., 2002). The merit of log transformation was considered against the merit of more-easily interpretable regression coefficients.

The authors found coefficients on the CHADx variables that are mainly positive and significant; and coefficients on the death and same day dummies that are negative and significant. Overall, the regression had an adjusted R-squared of 0.193.

Finally, the authors recognised that their estimates of incremental costs do not reflect any non-random and potentially likely clustering of the presence of multiple CHADx.

3.1.1 Bolbocean et al. (2012) response

In 2012, the Journal of Health Services Research & Policy published a response by Bolbocean et al. to Jackson et al. (2011). This response

raised a number of criticisms, most of which appear to have been heeded in subsequent regression approaches.

The main criticisms were:

- Additional patient risk factors should have been included as control variables in the regression model, such as age and comorbidities.
- GLS should have been used instead of OLS because the assumption of independent disturbances is likely violated.

The response concluded that the costs reported by Jackson et al. (2011) were likely overstated owing to the potential deficiencies that Bolbocean et al. identified.

3.2 Jackson et al. (2013)

In this subsequent paper, the authors estimated incremental costs of adapted CHADx using data from eight large hospitals in Alberta, Canada from 2008-09.

They used a generalised linear model (GLM) with a gamma distribution and log link relationship between total cost of the episode and 144 CHADx classes, controlling for: the mean cost of uncomplicated cases in each Case Mix Group (equivalent to AR-DRG); sameday admissions; and death.

In support of this approach, the authors noted:

- Inclusion of the mean cost of the uncomplicated case as a variable in the model allows interpretation of coefficients (after antilog transformation) as median incremental costs.
- Results of a modified Park test suggested the use of a gamma distribution.
- GLM was chosen over OLS due to the cost data being highly skewed (skewness of 17.8).

The authors evaluated their model using a Cox and Snell maximum likelihood R-squared – they found a value of 0.68.

3.3 Health Policy Analysis (2013)

The authors estimated the incremental costs of hospital-acquired complications (including CHADx) using the 2011-12 NHCDC for a select number of Adjacent DRGs (AdjDRGs).[8] The AdjDRGs of interest were determined by the ACSQHC, which commissioned the report. The report also looked at he effects of hospital-acquired complications on AR-DRG assignment and length of stay.

Initial exclusions applied to the data were: hospitals not reporting the COF; hospitals not in peer groups A1 to C2; and episodes that were not acute care or newborn care with qualified days.

The authors estimated four models that, respectively, estimated the incremental cost impact of the presence of: at least one hospital-acquired diagnosis; the MCHADx classes; individual CHADx classes from among 33 classes of interest; individual CHADx classes from among all 145 classes (although with pregnancy and childbirth-related classes in MCHADx 11 to 13 grouped together).

Each model used the same set of control dummies:

- Hospital – to control for differences in hospital efficiency.
- Patient Clinical Complexity Level (PCCL) – to control for within-AdjDRG heterogeneity. Introduced as a class variable, such that parameters are estimated for each PCCL separately.

8. An AdjDRG is a set of DRGs differentiated by their relative complexity and resource consumption. For example, the AdjDRG E66 'Major Chest Trauma' comprises the DRGs E66A, E66B and E66C which are, respectively, 'Major Chest Trauma' 'with catastrophic complications or comorbidities', 'with severe or moderate complications or comorbidities', and 'without complications or comorbidities'. An AdjDRG can have between one and four levels of resource consumption.

- Age – broken into the groups 0 to 14, 15 to 44, 70 to 84 and 85+ (such that the base case is a patient aged 45 to 69).
- Emergency admission.
- Death.
- Episodes transferred within less than two days – these episodes often have lower costs than others in the same AdjDRG on account of the patient likely being transferred to another care facility where the episode of care is presumably continued.
- Sameday admission.

Each of the four models was estimated for each of the 22 AdjDRGs of interest. Moreover, AdjDRGs were regrouped following the removal of both hospital-acquired diagnoses and procedure codes that lead to assignment to tracheostomy and ventilation AR-DRGs (AdjDRG A06).

The authors stated they removed the latter because of previous research that showed that 'many episodes with very significant hospital-acquired conditions are likely to end up in these AR-DRGs'.[9] Our interpretation of this was as follows. It would appear that, in some of these episodes, the complications have necessitated procedures that have in turn determined the AR-DRG assignment. If only the complication diagnosis were removed, then AR-DRG assignment would still reflect the procedures that might not have needed to occur. Therefore, the relevant procedure codes also need to be removed in order to 'properly' reassign the AR-DRG.

Regressions were undertaken using OLS as well as GLM with a log link and gamma distribution (the authors noted the previous use of this approach for skewed cost data). Models were also estimated both including sameday admissions (with the sameday control variable included) and for overnight admissions only. In their reporting, the authors focused on results for overnight admissions only.

Incremental costs were estimated by comparing predicted cost of the uncomplicated admission (*i.e.* assuming no CHADx were present in that admission) with predicted cost of the admission with the presence of the CHADx of interest (and seemingly no other CHADx). This difference was calculated for each episode in the dataset, then means and medians taken.

9. Health Policy Analysis (2013, p. 33).

4 Our approach to estimating the cost of complications

We looked to build upon the work of Health Policy Analysis (2013) and others by specifying a new regression model for estimating the incremental costs of complications as defined by CHADx+.

There are a number of reasons why we took a new approach:

- We were interested in estimating the incremental costs of CHADx+ across a broad range of hospital admissions, not just a select number of AdjDRGs.
- Because we were interested primarily in single estimates of the incremental cost of individual complications across a broad range of hospital admissions, we estimated our model(s) across admissions from multiple DRGs while controlling for (among other things) DRG and admission complexity within the model(s). This is in contrast to Health Policy Analysis (ibid.), which estimated its models for each AdjDRG of interest individually.
- We sought to better control for patient risk factors by including additional control variables.

4.1 Model specification

We followed the basic approach set out in Health Policy Analysis (ibid.) and elsewhere. This involved regressing the cost of a hospital admission on variables indicating: the presence of complications; and other characteristics of the admission or the patient that are determinants of the admission's cost.

More specifically, our basic model took the following form:

$$T = \alpha + \beta\,\delta_{\text{complication}} + \sum_{j=1}^{18} \gamma_j\,\delta_{\text{comorb}_j} + \sum_{k=1}^{328} \gamma_k\,\delta_{\text{hospital}_k} + \sum_{\ell=1}^{748} \gamma_\ell\,\delta_{\text{DRG}_\ell} + \sum_{m=1}^{M} \gamma_m\,\delta_{\text{control}_m} + \varepsilon$$

where:

T is the total cost of a hospital admission. Note that, as explained in Section 4.3, our main estimation approach actually uses the natural log of total cost.

$\delta_{\text{complication}}$ is a dummy variable that indicates whether there was during the admission at least one of any complication. We also used a second specification where this term is replaced by $\sum_{i=1}^{175} \beta_i \delta_i$, which indicates whether there was during the admission at least one occurrence of the i-th individual CHADx+ class (of 175 in total: 16 minor CHAPx classes and 159 minor CHADx classes).

δ_{comorb_j} is a dummy variable that indicates whether the j-th refined body system category of the Multipurpose Australian Comorbidity Scoring System (MACSS) applied to the patient (of 18 in total).[10]

$\delta_{\text{hospital}_k}$ is a dummy variable that indicates whether the admission occurred at the k-th hospital in the sample (of 328 in total).

δ_{DRG_ℓ} is a dummy variable that indicates whether the ℓ-th DRG in the sample applied to the episode (of 748 in total).

10. Toson et al. (2016). Our refined body system categories are explained in Section 1.3.4 of Danks and Duckett (2018).

$\delta_{\text{control}_m}$ includes dummy variables indicating whether the patient was:

- female;
- an Aboriginal and/or Torres Strait Islander;
- an emergency admission;
- aged 0 to 14;
- aged 15 to 44;
- aged 70 to 84;
- aged 85+;
- whether they died during the admission;
- whether they were transferred to another care facility within two days; or
- whether the admission was sameday.

Each variable is discussed in more detail below.

A notable omission from the model specification is length of stay. It's reasonable to expect that the length of a hospital admission is a significant determinant of the admission's cost. However, length of stay is likely related to our variable of interest – the presence of a complication. It's possible that complications lead to longer lengths of stay, other things being equal. We want our regression to attribute the additional cost of the longer length of stay to the complication.

4.1.1 Dependent variable – total cost

Our dependent variable is the total cost of the admission. We calculated total cost by summing all direct and overhead cost buckets. This includes 'ED Pro cost', which are the costs incurred in the emergency department by patients admitted via the emergency department.

4.1.2 Independent variables

Complications

As discussed, we identified complications in our data using CHADx+ v.1.4. We estimated two model specifications. First, we estimated the incremental effect on cost of the presence of at least one of any complication (the 'any complication model'). This approach is consistent with the approach in *All complications should count: Using our data to make hospitals safer*, where at least one of any complication was the dependent variable in our regression analysis of hospital performance.

Second, we estimated the incremental effects on cost of each individual class of CHADx+ (the 'individual complications model'). This approach allows us to identify the individual classes of complications that are most costly.

Comorbidities

We would expect inclusion of DRG to go a considerable way in controlling for our expectation that sicker and more complex patients will tend to incur more costs.

Yet we went further in controlling for the 'sickness' of patients by including variables that represent the MACSS. These types of comorbidity scoring systems are widely used to 'risk adjust' patient data in health care analysis.

For simplicity, we used our refined body system categories,[11] which condense the 102 MACSS labels to 18 categories. Moreover, MACSS are assigned after the removal of CHADx+ diagnoses and procedures, and procedures that lead to assignment to AdjDRG A06 (tracheostomy and/or ventilation). This was to try to ensure that our comorbidity

11. See Section 1.3.4 of Danks and Duckett (2018) for an explanation of our refined body system categories.

variable reflected only those comorbidities that the patient had upon admission, and to avoid multicollinearity between this variable and the CHADx+ variables in our model.

Hospital

We included the identity of the hospital in the regression to control for potential differences in the efficiency and coding practices of different hospitals.

DRG

Different types of hospital admission will of course tend to incur different amounts of cost. Admissions that involve sicker patients or more-complex procedures will tend to incur more costs.

DRGs identify clinically and/or procedurally similar episodes that may be expected, other things being equal, to incur a similar costs.

The DRGs we used were assigned after the removal of CHADx+ diagnoses and procedures, and procedures that lead to assignment to AdjDRG A06 (tracheostomy and/or ventilation). This approach was employed by Health Policy Analysis (2013), and recognises 'that the presence of a [CHADx] diagnosis is the variable of interest, therefore modelling should not control for these factors'.[12]

Female

Given the potential for different complexities owing to the differences in male and female body systems, we included a dummy for whether a patient was female.

12. Health Policy Analysis (2013, p. 39).

Aboriginal and/or Torres Strait Islander

The health disadvantage experienced on average by Indigenous Australians is well established.[13] To control for any such disadvantage present in our data, manifest in greater 'sickness' or 'complexity' not adequately controlled for elsewhere, we included a dummy variable that indicates whether a patient was Aboriginal and/or Torres Strait Islander. Those explicitly not Aboriginal and/or Torres Strait Islander and those whose Indigenous status was not reported were grouped together.

Emergency admissions

We expected that emergency admissions might have a different cost profile to other admissions as they likely involve less planning and control of the care provided (at least initially). In addition, emergency admissions may involve increased overhead costs.

Age

We included age dummies to control for the differences that we might expect from people of different ages in 'sickness', complexity, and ability to recover from illness, injury or procedures. We used the same age brackets as Health Policy Analysis (ibid.).

Death

Whether the patient died in hospital was used as a dummy variable in each of Jackson et al. (2011), Jackson et al. (2013) and Health Policy Analysis (2013). We also used the variable.

We envisaged two countervailing effects that death may have on the cost of a hospital admission.

13. AIHW (2015).

On the one hand, death essentially truncates an episode of care, meaning the costs of ongoing care that would otherwise have been provided are not incurred.

On the other hand, patients that die in hospital are likely to be among the 'sickest' and most complex, with the most severe complications. In this case, we might expect patients that eventually die in hospital to have relatively higher costs of care during their admission.

Early transfer

We considered that an admission that has been transferred to another care facility within two days may have lower costs (all else equal) than others in the same DRG as the episode of care is presumably continued at the second facility.

Sameday admissions

We considered that admissions that begin and end on the same day may be materially less complex and resource intensive than other admissions, including those from the same DRG.

4.2 Data

4.2.1 Outliers

We considered whether outliers should be trimmed from our data. At the high end, our cost series increases exponentially and there are no obvious outliers to cull.

Moreover, there is valuable information in the high end of the tail that is relevant to complications and their cost: the incidence of complications and the relative contribution to total cost increases as you go higher – see Table 4.1. As such, we did not trim data at the high end.

Table 4.1: Complications and cost at the high end of the data

Percentile of cost	Admissions	Incidence of CHADx+	Share of total cost	Share of total cost ÷ share of total admissions
99.9th	5,204	86.4%	4.7%	46.7
99.5th	26,022	78.6%	11.8%	23.6
99th	52,044	73.8%	17.2%	17.2
95th	260,221	55.5%	38.8%	7.8
90th	520,442	45.7%	53.1%	5.3

Source: Grattan analysis of National Hospital Cost Data Collection.

At the low end of the data, we looked at two trimming approaches that we considered might assist the goodness-of-fit of our regression as well as clean the data of admissions that had an erroneously low reported cost.[14] We ran our regressions excluding admissions in the lowest one per cent and five per cent of cost.

Neither of these trimming approaches were found to have a material impact on our regressions. As such, and for simplicity, we did not trim data at the low end.

Finally, none of the previous analyses reviewed reported trimming their data before conducting regressions.

4.2.2 Descriptive statistics

Table 4.2 on the next page and Table 4.3 on the following page provide descriptive statistics for the variables used in our regressions.

14. We envisaged that such errors might arise as a reporting or costing system artefact. It was beyond our scope of work to research hospitals' reporting and costing systems in further detail.

Table 4.2: Descriptive statistics for dependent variable – cost

Observations	5,204,424
Mean	$5,104
Standard deviation	$12,396
Skewness	19
1st percentile	$130
25th percentile	$653
50th percentile	$2,010
75th percentile	$5,262
99th percentile	$47,169

Source: Grattan analysis of National Hospital Cost Data Collection.

Table 4.3: Descriptive statistics for independent variables

Variable	**Mean**
At least one of any CHADx+	0.109
Comorbidities	
Infectious diseases	0.053
Neoplasms	0.095
Endocrine, metabolic or immune diseases	0.075
Diabetes	0.101
Blood diseases	0.037
Mental disorders	0.049
Drug or alcohol use	0.031
Diseases of the nervous system or sense organs	0.025
Eye disease	0.024
Diseases of the circulatory system	0.108
Diseases of the respiratory system	0.054
Diseases of the digestive system	0.086
Chronic renal disease	0.238
Diseases of the genitourinary system	0.065
Pregnancy, childbirth and puerperium	0.051
Chronic skin ulcer	0.004
Diseases of the musculoskeletal system and connective tissue	0.033
Other	0.132
Controls	
Female	0.512
Indigenous status	0.070
Emergency	0.428
Age 0-14	0.077
Age 15-44	0.276
Age 70-84	0.231
Age 85+	0.064
Death	0.006
Early transfer	0.035
Sameday	0.541

Source: Grattan analysis of National Hospital Cost Data Collection.

4.3 Estimation approach

Following the literature, we hypothesised that a GLM with a log link and gamma distribution was an appropriate estimation approach. As with other analyses, our dependent variable was highly skewed (see Table 4.2 on the previous page).

We followed Jackson et al. (2013) and used a modified Park test to confirm our choice of distribution. We also followed the approach suggested by Glick (2015) to perform this test in Stata.

We found that the coefficient on the log of the predicted cost when regressed against the square of the residuals was 2.0 for both the any complication and individual complications models. This supports a gamma distribution.

We also estimated our model using OLS, and compare results in Section 4.5.3 on page 25.

4.4 Estimation results

4.4.1 Complications

In the any complication model the estimated coefficient on the complication variable was 0.43 with a p-value of 0.0.

In the individual complications model, estimated coefficients on the complication variables ranged from −0.27 to 0.92. There were 163 positive coefficients of which 150 statistically significant at the 95 per cent confidence interval,[15] and 11 negative coefficients of which five were statistically significant.[16]

15. Hereafter, all references to statistical significance are with regard to the 95 per cent confidence interval.
16. There were no instances of CHAPx 4.01 in the sample therefore the number of coefficients reported sums to 174 rather than 175.

In Section 4.5 on page 19 we describe how we translated these coefficient estimates into dollar estimates of the incremental costs of complications.

The statistically significant, negative coefficient estimates were somewhat puzzling. The affected complications were:

- CHADx 5.11 ‘Cardiogenic and other shock’
- CHADx 11.03 ‘Other complications prior to labour and delivery’
- CHADx 13.08 ‘Jaundice’ (neonatal)
- CHADx 14.03 ‘Coagulation defects’
- CHAPx 6.00 ‘Fluid management’

We have not fully investigated the reasons behind these negative coefficients, because they are not widespread or large enough to significantly alter our key results. Moreover, negative coefficients have been found – including on some of the same complications – in other studies; see Jackson et al. (2011).

Nevertheless, we suspect that the negative coefficients may reflect one or more of the following factors:

- They represent a ‘true’ effect on cost. For instance, in regard to CHAPx 6.00, fluid administration has been found in some studies to reduce length of stay; see Nossaman et al. (2015).
- They represent a truncated episode effect due to death for complications that are associated with higher rates of mortality, namely CHADx 5.11 and 14.03.
- They are artefacts of the regression process.

4.4.2 DRG

In the any complication model, estimated coefficients on DRG ranged from −3.89 to 0.83. In the individual complications model, the range was −3.17 to 0.43. Around 99 per cent of estimated coefficients were statistically significant in both models.

4.4.3 Hospital

The estimated coefficients on hospital in both models ranged from around −1.7 to 2.7. Around 93 per cent of coefficients were statistically significant in both models.

4.4.4 Comorbidities

Table 4.4 shows the estimated coefficients on the comorbidity variables. They were almost all positive and all statistically significant. They are also quite similar across both models.

The negative coefficient on 'Chronic renal disease' most likely reflects the fact that the vast majority of patients with this comorbidity are in hospital for sameday haemodialysis. The average cost of these admissions is much lower than the average cost overall.

4.4.5 Controls

Table 4.5 on the next page shows the estimated coefficients for the control variables. Regarding each variable:

- Females were less costly to treat, although the intuitive reason for this is not clear and the size of the effect is immaterial in any case. Moreover, the coefficient in the individual complications model was not statistically significant, and the coefficient in the any complication model was only just significant with a p-value of 0.04.

Table 4.4: Comorbidity coefficients

	Any complication model	Individual complications model
Infectious diseases	0.25	0.21
Neoplasms	0.11	0.11
Endocrine, metabolic or immune diseases (excl. Diabetes)	0.17	0.16
Diabetes	0.04	0.04
Blood diseases	0.26	0.25
Mental disorders	0.27	0.26
Drug and alcohol use	0.05	0.05
Diseases of the nervous system or sense organs	0.22	0.2
Eye disease	0.01	0.02
Diseases of the circulatory system	0.17	0.16
Diseases of the respiratory system	0.17	0.17
Diseases of the digestive system	0.16	0.16
Chronic renal disease	−0.01	−0.01
Diseases of the genitourinary system (excl chronic renal disease)	0.07	0.07
Pregnancy, childbirth and puerperium	0.21	0.22
Chronic skin ulcer	0.09	0.08
Diseases of the musculoskeletal system and connective tissue	0.15	0.14
Congenital abnormalities; symptoms, signs and ill-defined conditions; any injury or poisoning; factors influencing health status and contact with health services	0.13	0.12

Source: Grattan analysis of National Hospital Cost Data Collection.

- People who are Aboriginal and/or Torres Strait Islander were more costly to treat, and this accords with the health disadvantage they experience on average. However, the size of the effect was immaterial and not statistically significant in either model.
- Emergency admissions were more costly, and this accords with the theory that care may be provided in a less planned and controlled manner at least initially, and these episodes may involve additional overhead costs. Coefficients were statistically significant in both models.
- Coefficients on the age variables were statistically significant but very small. The negative coefficient for people over 85 was slightly larger, perhaps reflecting fewer complex procedures occurring for the very elderly.
- The any complication model found that patients that die were more costly to treat. This seems to support the 'sicker' and more complex patient effect over the truncated episode effect (see previous discussion). However, the individual complications model found death to have a negative effect on cost. Coefficients were statistically significant in both models. It may be the case that in the individual complications model the regression was able to assign to individual complications the additional cost of patients that die rather than attributing this additional cost to the death variable. This possibly left the coefficient on the death variable to reflect the truncated episode effect.

4.5 Cost estimates

4.5.1 Any complication model

We estimated the incremental cost of at least one of any complication by first creating a series equal to:

- the estimated model's predicted cost of an admission; minus
- the estimated model's predicted cost of the admission assuming that there were no complications.

Of course, if there were no complications in an admission, then the value of the series for that admission is zero.

The average of this series, $6,004, is our estimate of the incremental cost of at least one of any complication for acute admissions at hospitals in the NHCDC. The total of this series, $3.4 billion, is our estimate of the total cost of complications for these admissions.

Given the total cost of admissions in our sample is $26.6 billion, we find that complications constitute 13 per cent of total costs. This is in line with the estimates of 12 per cent in Health Policy Analysis (2013) and 15 per cent in Jackson et al. (2011). However, results are not directly comparable owing to sample and methodology differences to those analyses.

Table 4.5: Control coefficients

	Any complication model	Individual complications model
Female	−0.002	−0.001
Aboriginal and/or Torres Strait Islander	0.001	0.001
Emergency	0.044	0.050
Age 0 to 14	0.009	0.005
Age 15 to 44	−0.010	−0.011
Age 70 to 84	−0.012	−0.012
Age 85+	−0.028	−0.026
Death	0.030	−0.043
Early transfer	−0.260	−0.259
Sameday	−0.916	−0.926
Constant	11.245	10.537

Source: Grattan analysis of National Hospital Cost Data Collection.

We also find that our estimated model performs well in predicting the total cost of admissions in sample. Over all admissions, the model overpredicts the cost of admissions by just 0.3 per cent. Over admissions involving complications, the model underpredicts the cost by just 0.2 per cent.

4.5.2 Individual complications model

Our aim was to derive estimates of the incremental cost of individual complications that were consistent with our estimate of the total cost of complications from the any complication model ($3.4 billion). This sub-section explains how we came to these estimates, and the issues we needed to address in doing so.

Issues with incremental cost estimates in the individual complications model

Our first step in estimating the incremental cost of individual complications was similar to the approach described in the previous sub-section for the any complication model. We created a series for each complication that was equal to:

- the estimated model's predicted cost of an admission; minus
- the estimated model's predicted cost of an admission assuming that the individual complication of interest was not present.

Thus we created 175 incremental cost series, one series for each of the 175 individual complications – see Table 4.6. Each value of these series is an estimate of the incremental cost of the relevant complication *given the other complications present in the admission*. Note that in Table 4.6 the estimates for individual admissions are indicative only, whereas the total cost estimates in the bottom row are actual estimates.

Table 4.6: Example of incremental cost series

Admission	CHAPx 1.01	CHAPx 1.02	...	CHADx 17.11	
1	$50,000	–		$4,000	
2	–	$5,000		–	
3	–	–		$6,000	
⋮					
5,204,424	$80,000	–		–	
Total	$377m	$188m	...	$71m	$9,945m

Notes: Figures in the 'Total' row are actual estimates, whereas other entries in the table are indicative only.

Source: Grattan analysis of National Hospital Cost Data Collection.

Table 4.6 shows that the sum of the total costs of individual complications is $9.9 billion. This is significantly higher than the estimate of the total cost of complications of $3.4 billion from our any complication model. This is for two reasons.

First, the totals of these incremental cost series are not additive. To explain, recall that each series represents the incremental cost of the relevant complication *given the other complications present in the admission*. Now assume that there are just two complications: x and y. If we add together the total costs of x and y, we are calculating the total cost of complications as:

- The incremental cost of x given the presence of y; plus
- The incremental cost of y given the presence of x.

This calculation of the total cost of complications is incorrect. It essentially double counts the incremental cost impact of complications. The correct calculation is:

- The incremental cost of x given no other complications (or of y given no other complications); plus
- The incremental cost of y given the presence of x (or of x given the presence of y).

When we *correctly* calculate the total cost of complications from the individual complications model, we get a figure of $5.4 billion.

This estimate of $5.4 billion remains materially higher than the estimate of $3.4 billion. This brings us to the second reason for the difference between the estimates of the total cost of complications between the two models.

Before we explore this second reason, note that we can conclude that the $5.4 billion estimate is overstated because:

- as set out in Section 4.5.1 on page 19, the any complication model accurately predicts the cost of admissions; and
- the individual complications model overestimates the cost of all admissions by 7 per cent, and overestimates the cost of admissions involving complications by 16 per cent.

One reason for this overestimating is the multiplicative effect of the coefficients on our complication variables. Given we are using a log link, the estimated coefficient on a particular complication represents the estimated percentage change in cost given the presence of that complication. As more and more complications are present in an admission, the dollar impact of a given percentage change grows higher and higher.

Table 4.7 demonstrates the consequences of this multiplicative effect. The model performs reasonably well when predicting the cost of admissions with four or fewer complications. However, the model performs increasingly poorly for admissions with five or more complications.

Table 4.7: Prediction performance of individual complications model

Number of complications	Number of admissions	Actual cost	Predicted cost	Over-prediction
0	4,636,423	$16,800m	$17,000m	1%
1 to 4	511,959	$7,000m	$6,600m	−6%
5 to 9	48,400	$1,800m	$2,300m	27%
10 to 14	5,958	$585m	$1,178m	101%
15 to 19	1,349	$232m	$770m	232%
20 to 24	310	$75m	$373m	399%
25 to 29	23	$7m	$54m	644%
30 to 32	2	$1m	$12m	1874%
All admissions	**5,204,424**	**$26,600m**	**$28,300m**	**7%**
At least one complication	*568,001*	*$9,800m*	*$11,400m*	*16%*

Source: Grattan analysis of National Hospital Cost Data Collection.

Scaling estimates of incremental cost

We address the issues outlined above by scaling our estimates of the total cost of individual complications such that they sum to the 'true' estimated cost of complications (*i.e.* the $3.4 billion estimate from the any complication model). This allows us to come to estimates of the incremental cost of individual complications that are consistent with what we consider to be the 'true' cost of complications. This approach also allows for the incremental cost of a given complication to reflect the presence of others.

To explain our method in detail, consider CHAPx 1.01. As Table 4.6 on the previous page shows, the total cost of CHAPx 1.01 given the other complications that were present is $377 million. We consider that CHAPx 1.01 is responsible for $377 million / $9.9 billion = 4 per cent of the total cost of complications. We then apply this percentage to

the 'true' estimated cost of complications, $3.4 billion, to yield a scaled estimate of the total cost of CHAPx 1.01 of $129 million.

We then divided the scaled estimates of the total cost of individual complications by their respective incidence to derive estimates of the average incremental cost per occurrence. That is, we divided the scaled estimate of the total cost of CHAPx 1.01 ($129 million) by the number of times this complication occurred (4,975) to get our estimate of the incremental cost of CHAPx 1.01 per occurrence (around $26,000).

Comparison with previous analyses

Comparison of our estimates with those in Jackson et al. (2011) and Health Policy Analysis (2013) is complicated by differences in the CHADx versions and samples used. Nevertheless, we can observe some broad similarities which serves to demonstrate both that our results appear sensible and that the costs of certain complications have been persistent through time.

Table 4.8 on the following page shows the 10 individual CHADx classes that we have estimated to have the highest average incremental cost. Note we have just listed CHADx classes because previous analyses did not look at CHAPx. We see that all analyses have found transplant complications, sepsis and wound disruptions to be among the most costly complications per occurrence.

Resistance to methicillin is the only other complication that appears among the most costly in the results of both Jackson et al. (2011) and Health Policy Analysis (2013). This complication does not appear among our most costly complications, most likely because in the version of CHADx we used it is grouped with other, potentially less costly types of infections in '4.07 Antibiotic resistant infections'.

Table 4.9 on page 24 shows the 10 individual CHADx classes that we have estimated to have the highest total cost. Dollar estimates are not reported for Jackson et al. (2011) and Health Policy Analysis (2013) because different sample sizes mean magnitudes cannot be compared. Instead we are interested in relative costliness, and it can be seen that results across the three analyses are quite consistent with the same complications generally appearing in each analysis's top 10.

Table 4.8: Top 10 CHADx with highest average incremental cost
Acute admissions, NHCDC, 2014-15

	CHADx	No.	Cost	Previous CHADx definition/number	Comparison with Jackson et al. (2011)	Comparison with Health Policy Analysis (2013)
1.13	Complications of transplants	699	$26,717	1.14	Quite costly at $7,079 but not in top 10.	Finds a 'very high cost impact' but estimates suppressed due to low number of occurrences
4.19	Hospital-acquired abscesses	395	$20,308	Spread across 6.08, 7.07, 9.04, 9.05, 14.04 and 16.03.	Cannot compare due to changes in definition of this CHADx class.	Cannot compare due to changes in definition of this CHADx class.
4.20	Other hospital-acquired infections	5,755	$14,660	Spread across 4.05, 6.08, 9.05, 16.03, 17.01, 17.09.	Cannot compare due to changes in definition of this CHADx class.	Cannot compare due to changes in definition of this CHADx class.
4.03	Sepsis due to Staph	929	$13,578	Different types of sepsis grouped together under 4.01.	10th most costly at $9,400.	Finds a 'very high cost impact' but estimates suppressed due to low number of occurrences
4.02	Sepsis due to Strep	534	$10,694	As above.	As above.	As above.
8.02	Pressure injury, Stages 3 & 4	2,484	$10,238	All stages of pressure injury grouped together in 8.01.	Quite costly at $8,435 but not in top 10.	Somewhat costly at $5,892 but not in top 10.
10.02	Adjustment disorders	751	$9,892	10.03	Somewhat costly at $6,167 but not in top 10.	Not particularly costly at $3,031.
4.09	Hospital-acquired pneumonia	11,596	$9,235	Included in 6.03 with influenza / bronchitis	Somewhat costly at $5,496 but not in top 10.	Somewhat costly $5,710 but not in top 10.
1.08	Disruption of wound	3,304	$9,229	1.08	9th most costly at $9,529.	2nd most costly at $12,200.
4.11	Device / implant-related infections	6,031	$8,728	Spread across 1.01, 1.07, 1.11, 1.12, 1.13	Cannot compare due to changes in definition of this CHADx class.	Cannot compare due to changes in definition of this CHADx class.

Notes: Excluding complications with fewer than 100 occurrences.

Source: Grattan analysis of National Hospital Cost Data Collection.

Table 4.9: Top 10 CHADx with highest total cost
Acute admissions, NHCDC, 2014-15

	CHADx	No.	Cost	Previous CHADx definition/number	Comparison with Jackson et al. (2011)	Comparison with Health Policy Analysis (2013)
15.02	Electrolyte disorders / fluid management	56,821	$208m	15.02 but not if dehydration also occurred	6th most costly	Most costly
4.09	Hospital-acquired pneumonia	11,596	$107m	Included in 6.03 with influenza / bronchitis	3rd most costly	5th most costly
7.03	Constipation	25,638	$98m	7.04	9th most costly	6th most costly
5.07	Hypotension	56,126	$96m	5.06	Not in top 10	4th most costly
8.04	Dermatitis, rash and other skin effects	24,407	$93m	Spread across 8.03 and 8.04	8.03 and 8.04 combined would be 7th most costly	8.03 and 8.04 combined would be just outside top 10
4.12	Hospital-acquired C_Diff and other GI infections	13,200	$91m	7.01	7th most costly	Not in top 10
4.20	Other hospital-acquired infections	5,755	$84m	Spread across 4.05, 6.08, 9.05, 16.03, 17.01, 17.09.	Cannot compare due to changes in definition of this CHADx class.	Cannot compare due to changes in definition of this CHADx class.
5.04	Conduction disturbances / abnormal heart beat	38,952	$81m	Included in 5.03 along with 'Major cardiac arrhythmias'	Just outside top 10	2nd most costly
4.16	Hospital-acquired urinary tract infection	14,958	$71m	9.02 and 9.04	4th most costly	3rd most costly
8.01	Pressure injury Stages 1 & 2	8,559	$67m	All stages of pressure injury grouped together in 8.01.	5th most costly	9th most costly

Source: Grattan analysis of National Hospital Cost Data Collection.

4.5.3 Comparison with OLS estimation

Any complication model

Estimating our any complication model using OLS yields an estimate of the total cost of complications of $3.2 billion. This is 7 per cent lower than the $3.4 billion estimate using GLM with a log link and gamma distribution. This provides comfort that our overall cost estimate is not overly sensitive to the estimation approach used and thus supports the reliability of the estimate.

We also find that OLS performs very well in predicting the total cost of admissions in the sample. It predicts to within one dollar the total costs of both all admissions and just admissions involving complications.

Individual complications model

Similar to estimates using GLM log gamma, we scaled OLS estimates of the costs of individual complications such that they summed to the estimate of the total cost of complications from the any complication model estimated using OLS ($3.2 billion). This is because we also observed an overestimating effect in the OLS estimation – it overpredicted the cost of admissions involving a complication by 3 per cent.

Recall that we attributed overestimation by GLM log gamma to the multiplicative effect of the complication coefficients. However, this effect does not exist in the OLS estimation because we are not using a log link – estimated coefficients represent absolute changes in cost due to the presence of complications. Therefore, something else must be causing the overestimation in this instance.

It is possible that complications have a marginal effect on cost that decreases with the number of other complications present on admission. For example, a minor infection might materially increase the cost of treating an otherwise healthy patient if it extends their hospitalisation by a day or two. However, the incremental cost of this infection might become insignificant if the patient has already had their hospitalisation extended a number of weeks by a number of more serious complications.

If complications do have a decreasing marginal effect, then the fixed, absolute changes estimated by OLS will overpredict the cost of admissions where there are multiple complications present.

Comparing OLS with GLM log gamma, we observe that estimates of the cost of individual complications are somewhat sensitive to estimation approach, but nevertheless still show broad similarities.

Table 4.10 shows the 10 individual CHADx+ classes that we estimated to have the highest average incremental cost using OLS.

Table 4.10: Top 10 CHADx+ with highest average incremental cost using OLS estimation

		OLS		GLM	
	Description	**Cost**	**Rank**	**Cost**	**Rank**
4.19	Hospital-acquired abscesses	$27,540	1	$20,308	3
1.13	Complications of transplants	$26,155	2	$26,717	1
1.01*	Invasive ventilatory support	$23,850	3	$25,956	2
4.03	Sepsis due to Staph	$20,823	4	$13,758	6
3.05	Injury due to assault	$18,435	5	$8,435	16
1.14	Complications of reattachment and amputations	$17,273	6	$7,880	22
3.04*	Thrombectomy	$15,285	7	$20,288	4
1.08	Disruption of wound	$14,068	8	$9,229	12
10.06	Patient self harm	$13,339	9	$7,896	21
4.02	Sepsis due to Strep	$12,881	10	$10,694	8

Notes: Excluding complications with fewer than 100 occurrences. An asterisk (*) indicates a hospital-acquired procedure (CHAPx). Instances of ventilatory support during emergency admissions not considered complications.

Source: Grattan analysis of National Hospital Cost Data Collection.

The cost estimates for transplant complications, invasive ventilatory support and sepsis due to streptococcus are all quite similar.

The difference between estimates is somewhat larger for abscesses, sepsis due to staphylococcus, thrombectomies and wound disruptions, but the ordinal costliness of these complications remains similar across the two estimation approaches.

The difference in both estimate and ordinal costliness is much larger for injuries due to assault, reattachment/amputation complications and patient self harm.

Overall, there is sufficient similarity to provide comfort as to the reliability our estimates. This comparison does, however, suggest that policymakers should be aware of potential sensitivity to estimation approach before acting on cost estimates for certain classes of complication.

Table 4.11 shows the 10 individual CHADx+ classes that we estimated to have the highest total cost using OLS. It shows that the ordinal costliness of complications across the two estimation approaches is quite similar – nine of the top 10 most costly complications as estimated by OLS appear in the top 11 most costly complications as estimated by GLM log gamma. This is important because it means identifying complications for reduction in terms of relative financial priority is not particularly sensitive to estimation approach.

However, there are some material differences in dollar estimates.[17] This means policymakers need to consider estimation approach carefully before deciding, say, the amount of money that should be invested in reducing a particular complication.

Table 4.11: Top 10 CHADx+ with highest total cost using OLS estimation

		OLS		GLM	
	Description	**Cost**	**Rank**	**Cost**	**Rank**
2.02*	Transfusion	$221m	1	$206m	2
1.01*	Invasive ventilatory support	$119m	2	$129m	3
15.02	Electrolyte disorders / fluid management	$108m	3	$208m	1
4.09	Hospital-acquired pneumonia	$88m	4	$107m	4
8.04	Dermatitis, rash and other skin effects	$84m	5	$93m	7
4.16	Hospital-acquired urinary tract infection	$75m	6	$71m	11
4.20	Other hospital-acquired infections	$71m	7	$84m	9
7.03	Constipation	$69m	8	$98m	5
4.12	Hospital-acquired C_Diff and other GI infections	$69m	9	$91m	8
2.16	Complications due to other drugs	$61m	10	$55m	16

Notes: An asterisk (*) indicates a hospital-acquired procedure (CHAPx). Instances of ventilatory support during emergency admissions not considered complications.

Source: Grattan analysis of National Hospital Cost Data Collection.

17. To some extent these differences are to be expected given each set of estimates has been scaled to a different estimate of the total cost of complications.

4.5.4 Grossing up estimates for all hospital admissions

To this point we have described how we estimated the cost of complications using data solely from the NHCDC. However, the cost estimates presented in *Safer care saves money* have been grossed up using data from the National Hospital Morbidity Dataset (NHMD). We did this because:

- we wished to present estimates for all (acute) hospital activity in Australia;
- some public hospitals do not participate in the public sector NHCDC; and
- private hospitals do not participate in the public sector NHCDC.

Our basic approach was to apply the estimates described above of the average incremental cost of individual complications to the incidence of individual complications observed in the NHMD. Thus the fundamental assumptions underlying our estimates are that the average incremental cost of a given complication is the same throughout all public hospitals and across public and private hospitals.

We had to take a slightly different approach for MCHADx 2 and 3. As discussed on page 8 of *All complications should count (Methodological supplement)*, we were unable to detect in the NHMD a number of individual complications within those two MCHADx classes owing to the structure of the data we had. To gross up estimates of the costs of MCHADx 2 and 3, we first took each of those classes' share of the total cost of complications excluding those classes in the NHCDC. These shares were then applied to our grossed-up total cost of complications excluding those classes for public and private hospitals. Table 4.12 shows our calculations.

Table 4.12: Grossed up estimates for MCADx 2 and 3

		Estimated total cost ($ M)			
		NHCDC	NHMD		
			Public	Private	Total
All complications		3 400			
excl. MCHADx 2 & 3	(T)	3 200			
MCHADx 2		106.4			
as a % of (T)	(A)	3.3%			
MCHADx 3		95.9			
as a % of (T)	(B)	3.0%			
(T) grossed up	(C)		4 100	1 100	5 200
MCHADx 2	(A) × (C)		136.3	36.0	172.3
MCHADx 3	(B) × (C)		122.9	32.5	155.4
All complications grossed up and adjusted for MCHADx2 & 3			**4 400**	**1 200**	**5 500**

Comparing estimates between public and private hospitals

The incidence of complications, and therefore estimates of the costs of complications, are not directly comparable between public and private hospitals. Casemix differs between public and private hospitals. The COF may also be under-reported in private hospital data, leading to lower incidences of complications. In its hospital statistics report for 2014-15, the AIHW reported:[18]

> For 2014–15, the COF data were provided for about 98% of public hospital separations and 77% of private hospital separations. . . . For New South Wales, data were not provided for 7.5% of public hospital separations and 86% of private hospital separations.

18. AIHW (2016).

5 Funding implications of complications

Figure 1.1 of *Safer care saves money*, reproduced here as Figure 5.1, plots the increase in funding that a hospital receives due to complications against the estimated cost of those complications. The 20 hospitals with the most admissions in the 2014-15 NHCDC are shown. This section explains how we constructed the data presented in this figure.

5.1 Change in funding due to complications

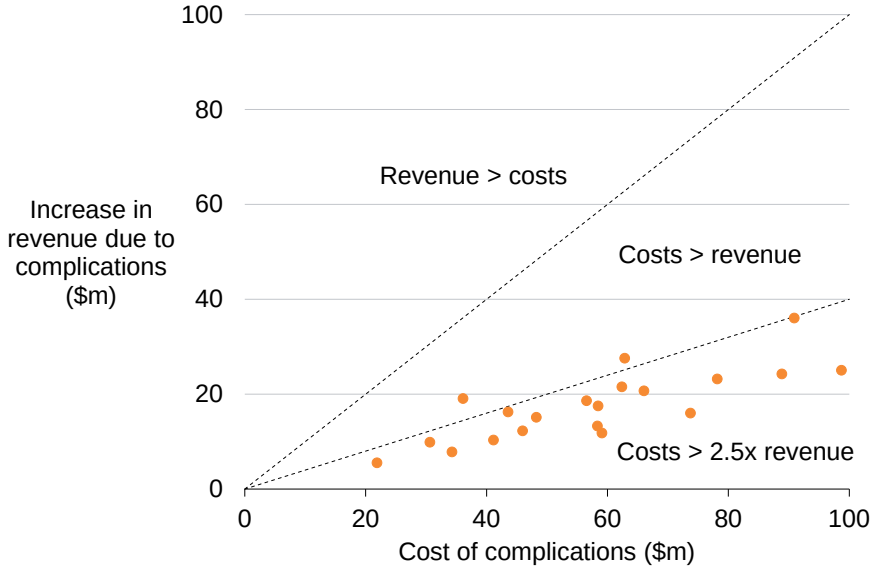
We used IHPA's Excel-based tool to calculate National Weighted Activity Units (NWAU).[19] First, we calculated the NWAU of each admission using the DRG that was actually assigned to that admission. Second, we calculated the NWAU of each admission using the DRG assigned after removal of those additional diagnoses and procedures that were identified as being complications by the CHADx+ algorithm.

The difference between these two NWAU values, multiplied by the National Efficient Price (NEP) for 2014-15, $5,007, gave us the change in funding for an admission due to complications. We then summed the change in funding for all of a hospital's admissions.

5.2 Cost of complications

We estimated the cost of complications for a given hospital by estimating our any complication model using admission data just from that hospital. We therefore ran 20 individual regressions, one for each of the hospitals plotted in the figure. We also excluded admissions that were not funded through the health service budget.

Figure 5.1: Complications cost hospitals more than the revenue they receive for treating those complications
Largest 20 public hospitals in NHCDC, acute admissions, 2014-15



Source: Independent Hospital Pricing Authority; Grattan analysis of the National Hospital Cost Data Collection.

19. Available at: https://www.ihpa.gov.au/what-we-do/pricing/national-weighted-activity-unit-nwau-calculators/nwau-calculators-2014-15.

6 Savings estimates

Figure 1.2 of *Safer care saves money*, reproduced here as Figure 6.1, shows our estimates of potential savings if all hospitals could be made as safe as the safest 25 per cent and 10 per cent of hospitals. This section explains how we constructed the data presented in this figure.

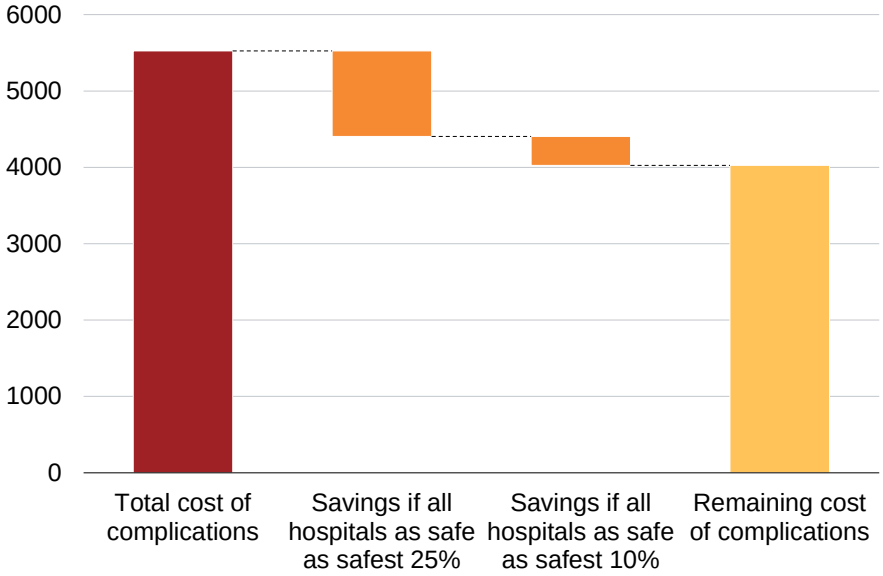
The numbers underlying this figure are derived using our estimates of:

- the total cost of complications in all Australian hospitals ($5.5 billion, described earlier in this supplement);
- the average incremental cost of at least one of any complication ($5.5 billion divided by 908,012, the number of admissions with at least one of any complication in the 2014-15 NHMD); and
- the share of admissions that would become complication free if safety performance improved, as shown in Figure 2.2 of *All complications should count: Using our data to make hospitals safer*.

Figure 2.2 of *All complications should count: Using our data to make hospitals safer* indicates that 0.4 per cent of admissions would become complication free if HACs were eliminated, and 1.7 per cent would become complication free if safety was improved to best quartile performance. This performance analysis was conducted over data for the three years 2012-13 to 2014-15, during which the average annual number of admissions was 8,391,986. Applying the aforementioned percentages, eliminating HACs and improving safety to best quartile performance is therefore estimated to make 184,197 admissions complication free. Multiplying this by the average incremental cost of at least one of any complication yields savings of $1.1 billion – depicted as the first orange column in Figure 6.1.

Figure 6.1: Reducing complication rates could lead to savings of $1.5 billion each year

$ million per year



Source: Grattan analysis of National Hospital Cost Data Collection and National Hospital Morbidity Dataset; Duckett et al. (2018).

Figure 2.2 of *All complications should count: Using our data to make hospitals safer* also indicates that a further 0.7 per cent of admissions would become complication free if safety was improved to best decile performance. This equates to an additional 62,357 admissions becoming complication free and $379 million of savings – depicted as the second orange column in Figure 6.1.

This simple methodology ignores some inconsistencies between the data and approaches used in our cost and performance estimates, namely:

- Our cost estimates are derived from 2014-15 data only, whereas performance estimates are taken from across the period 2012-13 to 2014-15.
- Our cost estimates are based on a definition of complications that excludes ventilatory support when it occurred during an emergency admission, whereas the definition used in our performance modelling made no such exclusion.

However, we derived estimates using a more complicated methodology which attempted to address these inconsistencies and found no significant change in our savings estimates.

7 Cost efficiency vs safety performance

Figure 2.1 of *Safer care saves money*, reproduced here as Figure 7.1, presents the relationship between individual hospitals' cost efficiency and their safety performance for multiday medical cardiology admissions. This section explains how we constructed the data presented in this figure.

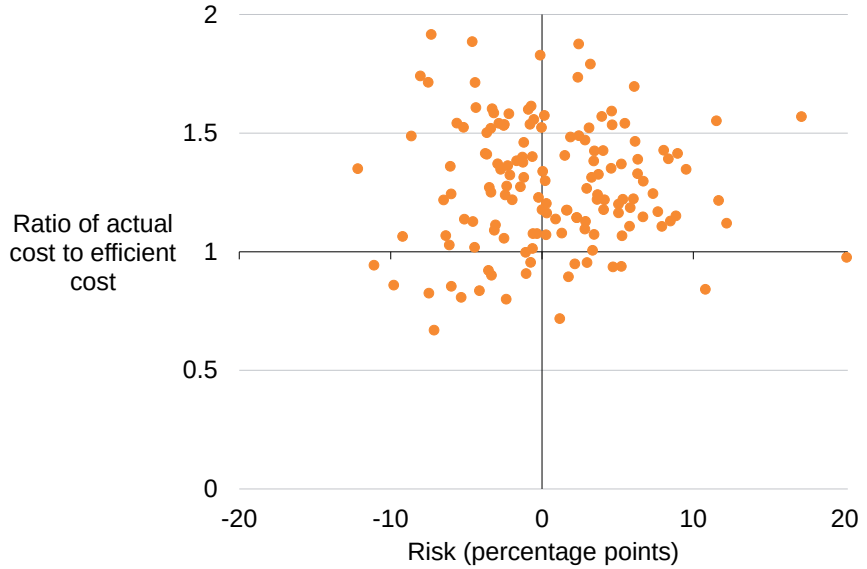
7.1 Cost efficiency estimates

The measure of cost efficiency we used was the ratio of the actual cost of admissions to a simple estimate of the efficient cost of admissions. We estimated efficient costs as the NEP multiplied by the NWAU inlier weight for the DRG of the admission.[20] We took the NEP and inlier weights from IHPA's annual determinations.[21]

7.2 Safety performance estimates

Although we modelled hospital performance in multiday medical cardiology admissions using data from the NHMD as part of the analysis for *All complications should count: Using our data to make hospitals safer*, we needed to replicate the analysis using data from the NHCDC. This is because we needed to link hospitals' performance estimates with their cost efficiency estimates, and these latter estimates could only be derived from the NHCDC. Moreover, we were unable to link the identity of individual hospitals between the NHMD and NHCDC.

Figure 7.1: Hospital safety performance in medical cardiology is unrelated to hospital efficiency in that specialty
Multiday cardiology admissions that do not involve a major procedure, public hospitals in the NHCDC, 2012-15



Notes: A small number of hospitals had cost ratios greater than two and are not shown.

Source: Independent Hospital Pricing Authority; Grattan analysis of the National Hospital Cost Data Collection.

20. The inlier weight may be just one of many factors that determine the NWAU value of an admission. However, we considered that an estimate based on use of the inlier weight alone was sufficient for our purposes here. Moreover, there was no NWAU calculator for 2012-13 available on IHPA's website at the time of writing.
21. Available at: https://www.ihpa.gov.au/what-we-do/national-efficient-price-determination.

For consistency with the modelling of multiday medical cardiology in *All complications should count: Using our data to make hospitals safer*, we broadly followed the methodology set out there and applied it to the NHCDC for the three years 2012-13 to 2014-15.[22]

We made just four changes to the methodology. First, we excluded from the sample admissions at hospitals that were found to be under-reporting the COF over the three years looked at; that is, hospitals for which the ratio of valid COFs reported (*i.e.* 1 or 2) to diagnosis codes reported was less than 0.96. This improved our cleaning of the data for poor-quality coding.

Second, we did not exclude admissions at hospitals that were high outliers in terms of their COF=1 rate. While this may make our results less conservative, we observed that the high rates of COF=1 for some hospitals were unlikely to be erroneous owing to their patient risk profile. As such, there may not be a strong basis for excluding these hospitals.

Third, we did not include the Socio-Economic Indexes for Areas (SEIFA) as a risk adjustment variable because we did not have sufficient location data in the NHCDC.

Fourth and finally, we did not include the scope variable which measures a hospital's degree of specialisation (see Section 1.3.5 of Danks and Duckett (2018)). This allowed scope effects to be observed as part of variation in performance.

Our measure of safety performance is the risk of a complication that is associated with hospital performance. As explained in Section 3.1.2 of *All complications should count (Methodological supplement)*, we defined 'risk' for a given hospital as:

- the estimated probability of a complication taking into account that hospital's performance, averaged over all patients in the sample; minus
- the estimated probability of a complication not taking into account hospital performance, averaged over all patients in the sample.

22. Note that our analysis of hospital risk by specialty used a new model that builds upon the methodology set out in *All complications should count (Methodological supplement)*. This new model is discussed in Chapter 9.

8 Sentinel event analysis

To analyse the frequency of sentinel events, we follow a similar strategy to Jackson et al. (2009) using the cause and diagnosis codes in Table 8.1 on the following page.

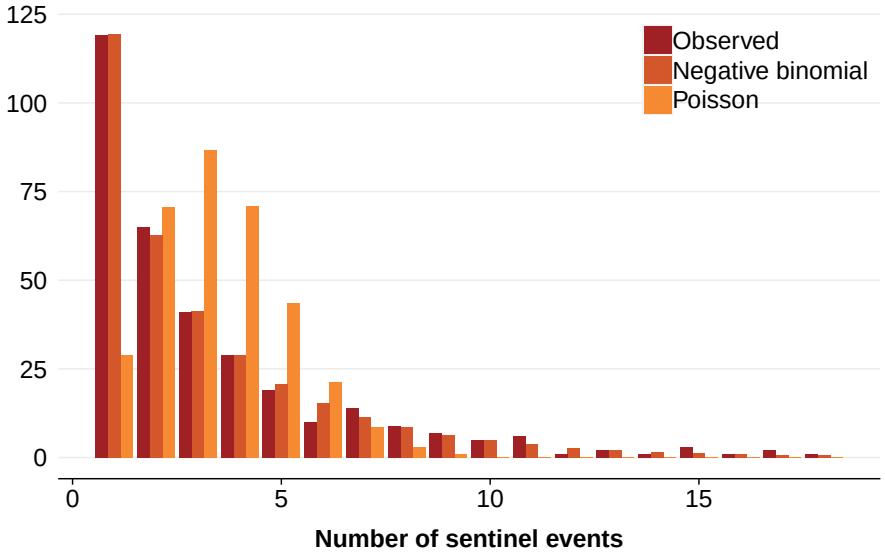
In particular, sentinel events were those admissions:

1. with a COF of 1
2. for sentinel events 2, 4, 6, 7—where the separation mode was 'died'
3. with a complication
4. for sentinel events 2 and 7—where the CHADx indicator was 1, and
5. for sentinel event 7—where the patient's cause coincided with a AR-DRG code starting with 'O' (*i.e.* a maternity patient).

Using the `MASS` package and the `vcd` packages, we tested how well Poisson and negative binomial distributions fit the distribution of sentinel events by hospital by year.[23] The negative binomial had a better fit, as the underlying distribution was highly dispersed. (Figure 8.1.)

Figure 8.1: A negative binomial distribution is a better fit of sentinel events than the Poisson distribution

Number of hospitals with the given number of sentinel events per year, 2013-15



Notes: Excludes hospital-years with zero sentinel events.

Source: Grattan analysis of National Hospital Morbidity Dataset.

23. Ripley (2018); Yee (2018); and Meyer et al. (2017).

Table 8.1: Sentinel events by code and description in routine administrative data

Sentinel event	Cause/diagnosis code	Description
SE1	Y633	Inadvertent exposure to radiation in medical care
	Y635	Inappropriate temperature local application and packing
	Y655	Performance of inappropriate operation
	Y658	Other specified misadventures during surgical and medical care
SE2	X60	Intent self poisn anlgsc antipyr antirhm
	X61	Intent selfpoison antiep sed-hyp psytrp
	X62	Intent selfpoison narc psychdyslpt NEC
	X63	Intent selfpoison oth aut nrv sys dr
	X64	Intent selfpoison oth NOS dr biol sub
	X65	Intentional selfpoisoning alcohol
	X66	Intent selfpoison orgnc solv hydcarb
	X670	Intent selfpoison motor vehicle exhaust
	X671	Intent selfpoison LPG
	X672	Intent selfpoison oth spec utility gas
	X678	Intent selfpoison oth spec gas/vapours
	X679	Intent selfpoison gas or vapours
	X68	Intentional selfpoison pesticides
	X69	Intent selfpoison oth/NOS chem nox sub
	X700	Intentional self-harm by hanging
	X701	Intentional self-harm by strangulation
	X702	Intentional self-harm by suffocating
	X710	Int selfharm drwn and submrs bath-tub
	X711	Int selfharm drwn and submrs swim-pool
	X712	Int selfharm drwn and submrs natural wtr
	X718	Int selfharm drwn and submrs oth spec wtr
	X719	Int selfharm drwn and submrs wtr
	X72	Intentional selfharm by handgun disch
	X741	Intentional self-harm by air rifle disch
	X742	Intentional self-harm by shotgun disch

Sentinel event	Cause/diagnosis code	Description
	X743	Intent self-harm sm calibre rifle disch
	X744	Intent self-harm by large calibre rifle
	X749	Intent self-harm oth and NOS firearm disch
	X75	Intent selfharm by explosive material
	X76	Intent selfharm by smoke fire and flames
	X77	Intent selfharm steam vapour hot obj
	X780	Int selfharm by knife
	X781	Int selfharm by razor blade
	X782	Int selfharm by hypdrmc needle and syrge
	X783	Int selfharm by glass
	X788	Int selfharm by other specified sharp object
	X789	Int selfharm by sharp object, unspecified
	X79	Intentional selfharm by blunt object
	X80	Intent selfharm jump from a high place
	X810	Intentional self-harm by jumping or lying before a train
	X811	Intentional self-harm by jumping or lying before a tram
	X812	Intentional self-harm by jumping or lying before a motor vehicle
	X818	Intentional self-harm by jumping or lying before other specified moving object
	X819	Intentional self-harm by jumping or lying before unspecified moving object
	X83	Intentional self harm by other specified means
	X84	Intentional self-harm by unspecified means
SE3	T815	FB accidentally left in body cavity or op wound following procedure
	T816	Acute reaction foreign substance accidentally left during a procedure
	Y610	FB left in body during surgical operation
	Y611	FB left in body during infusion or transfusion
	Y612	FB left in body kidney dialysis or other perfusion
	Y613	FB left in body during injection or immunisation
	Y614	FB left in body during endoscopic exam
	Y615	FB left in body during heart catheterisation
	Y616	FB left in body during aspiration, puncture and other catheterisation

Sentinel event	Cause/diagnosis code	Description
	Y617	FB left in body during removal of catheter or packing
	Y618	FB left in body during other surgical and medical care
	Y619	FB left in body during unspecified surgical and medical care
SE4	O880	Obstetric air embolism
	T703	Other effects of decompresion and barotrauma
	T790	Air embolism (traumatic)
	T800	Air embolism following infusion, transfusion and therapeutic injection
	O032	Spont abortion incomp complic embolism
	O037	Spont abortn compl or unspec w embolism
	O042	Medical abortn incomp w embolism
	O047	Medical abortn compl unspec w embolism
	O052	Oth abortion incomp w embolism
	O057	Oth abortn complete or unspec w embolism
	O062	Incomp abortion NOS w embolism
	O067	Complete or unspec abortn NOS w embolism
	O072	Failed medical abortn w embolism
	O077	Oth unspec fail attempt abortn w embol
	O08	Complications following abortion and ectopic and molar pregnancy
	O082	Embolism foll abortn ectop molar preg
SE5	T803	ABO incompatibility reaction
	Y650	Mismatched blood used in transfusion
SE6	Poisoning	by systemic antibiotics
	T360	Penicillins
	T361	Cephalosporins and other beta-lactam antibiotics
	T362	Chloramphenicol group
	T363	Macrolides
	T364	Tetracyclines
	T365	Aminoglycosides

Sentinel event	Cause/diagnosis code	Description
	T366	Rifamycins
	T367	Antifungal antibiotics, systemically used
	T368	Other systemic antibiotics
	T369	Systemic antibiotic, unspecified
	T370	Sulfonamides
	T371	Antimycobacterial drugs
	T372	Antimalarials and drugs acting on other blood protozoa
	T373	Other antiprotozoal drugs
	T374	Anthelminthics
	T375	Antiviral drugs
	T378	Other specified systemic anti-infectives and antiparasitics
	T379	Systemic anti-infective and antiparasitic, unspecified
	T380	Glucocorticoids and synthetic analogues
	T381	Thyroid hormones and substitutes
	T382	Antithyroid drugs
	T383	Insulin and oral hypoglycaemic [antidiabetic] drugs
	T384	Oral contraceptives
	T385	Other oestrogens and progestogens
	T386	Antigonadotrophins, anti-oestrogens, antiandrogens, not elsewhere classified
	T387	Androgens and anabolic congeners
	T388	Other and unspecified hormones and their synthetic substitutes
	T389	Other and unspecified hormone antagonists
	T390	Salicylates
	T391	4-Aminophenol derivatives
	T392	Pyrazolone derivatives
	T393	Other nonsteroidal anti-inflammatory drugs [NSAID]
	T394	Antirheumatics, not elsewhere classified
	T398	Other nonopioid analgesics and antipyretics, not elsewhere classified
	T399	Nonopioid analgesic, antipyretic and antirheumatic, unspecified
	T400	Opium
	T401	Heroin

Sentinel event	Cause/diagnosis code	Description
	T402	Other opioids
	T403	Methadone
	T404	Other synthetic narcotics
	T405	Cocaine
	T406	Other and unspecified narcotics
	T407	Cannabis (derivatives)
	T408	Lysergide [LSD]
	T409	Other and unspecified psychodysleptics [hallucinogens]
	T410	Inhaled anaesthetics
	T411	Intravenous anaethetics
	T4120	Unspecified general anaesthetic
	T4121	Gamma hydroxybutyrate
	T4122	Ketamine
	T4129	Other specified general anaesthetic
	T413	Local anaesthetics
	T414	Anaesthetic unspecified
	T415	Therapeutic gases
	T420	Hydantoin derivatives
	T421	Iminostilbenes
	T422	Succinimides and oxazolidinediones
	T423	Barbiturates
	T424	Benzodiazepines
	T425	Mixed antiepileptics, not elsewhere classified
	T426	Other antiepileptic and sedative-hypnotic drugs
	T427	Antiepileptic and sedative-hypnotic drugs, unspecified
	T428	Antiparkinsonism drugs and other central muscle-tone depressants
	T430	Tricyclic and tetracyclic antidepressants
	T431	Monoamine-oxidase-inhibitor antidepressants
	T432	Other and unspecified antidepressants
	T433	Phenothiazine antipsychotics and neuroleptics
	T434	Butyrophenone and thioxanthene neuroleptics

Sentinel event	Cause/diagnosis code	Description
	T435	Other and unspecified antipsychotics and neuroleptics
	T4360	Unspecified psychostimulants with potential for use disorder
	T4361	Psychostimulants with potential for use disorder, methylamphetamine
	T4362	Methylenedioxy methamphetamine
	T4369	Other psychostimulants with potential for use disorder
	T438	Other psychotropic drugs, not elsewhere classified
	T439	Psychotropic drug, unspecified
	T440	Anticholinesterase agents
	T441	Other parasympathomimetics [cholinergics]
	T442	Ganglionic blocking drugs, not elsewhere classified
	T443	Other parasympatholytics [anticholinergics and antimuscarinics] and spasmolytics, not elsewhere classified
	T444	Predominantly alpha-adrenoreceptor agonists, not elsewhere classified
	T445	Predominantly beta-adrenoreceptor agonists, not elsewhere classified
	T446	Alpha-Adrenoreceptor antagonists, not elsewhere classified
	T447	Beta-Adrenoreceptor antagonists, not elsewhere classified
	T448	Centrally acting and adrenergic-neuron-blocking agents, not elsewhere classified
	T449	Other and unspecified drugs primarily affecting the autonomic nervous system
	T450	Antiallergic and antiemetic drugs
	T451	Antineoplastic and immunosuppressive drugs
	T452	Vitamins, not elsewhere classified
	T453	Enzymes, not elsewhere classified
	T454	Iron and its compounds
	T455	Anticoagulants
	T456	Fibrinolysis-affecting drugs
	T457	Anticoagulant antagonists, vitamin K and other coagulants
	T458	Other primarily systemic and haematological agents
	T459	Primarily systemic and haematological agent, unspecified
	T460	Cardiac-stimulant glycosides and drugs of similar action
	T461	Calcium-channel blockers
	T462	Other antidysrhythmic drugs, not elsewhere classified

Sentinel event	Cause/diagnosis code	Description
	T463	Coronary vasodilators, not elsewhere classified
	T464	Angiotensin-converting-enzyme inhibitors
	T465	Other antihypertensive drugs, not elsewhere classified
	T466	Antihyperlipidaemic and antiarteriosclerotic drugs
	T467	Peripheral vasodilators
	T468	Antivaricose drugs, including sclerosing agents
	T469	Other and unspecified agents primarily affecting the cardiovascular system
	T470	Histamine H2-receptor antagonists
	T471	Other antacids and anti-gastric-secretion drugs
	T472	Stimulant laxatives
	T473	Saline and osmotic laxatives
	T474	Other laxatives
	T475	Digestants
	T476	Antidiarrhoeal drugs
	T477	Emetics
	T478	Other agents primarily affecting the gastrointestinal system
	T479	Agent primarily affecting the gastrointestinal system, unspecified
	T480	Oxytocic drugs
	T481	Skeletal muscle relaxants [neuromuscular blocking agents]
	T482	Other and unspecified agents primarily acting on muscles
	T483	Antitussives
	T484	Expectorants
	T485	Anti-common-cold drugs
	T486	Antiasthmatics, not elsewhere classified
	T487	Other and unspecified agents primarily acting on the respiratory system
	T490	Local antifungal, anti-infective and anti-inflammatory drugs, not elsewhere classified
	T491	Antipruritics
	T492	Local astringents and local detergents
	T493	Emollients, demulcents and protectants
	T494	Keratolytics, keratoplastics and other hair treatment drugs and preparations
	T495	Ophthalmological drugs and preparations

Sentinel event	Cause/diagnosis code	Description
	T496	Otorhinolaryngological drugs and preparations
	T497	Dental drugs, topically applied
	T498	Other topical agents
	T499	Topical agent, unspecified
	T500	Mineralocorticoids and their antagonists
	T501	Loop [high-ceiling] diuretics
	T502	Carbonic-anhydrase inhibitors, benzothiadiazides and other diuretics
	T503	Electrolytic, caloric and water-balance agents
	T504	Drugs affecting uric acid metabolism
	T505	Appetite depressants
	T506	Antidotes and chelating agents, not elsewhere classified
	T507	Analeptics and opioid receptor antagonists
	T508	Diagnostic agents
	T509	Other and unspecified drugs, medicaments and biological substances
	X40	Accidental poisoning by and exposure to nonopioid analgesics, antipyretics and antirheumatics
	X41	Accidental poisoning by and exposure to antiepileptic, sedative-hypnotic, antiparkinsonism and psychotropic drugs, not elsewhere classified
	X42	Accidental poisoning by and exposure to narcotics and psychodysleptics [hallucinogens], not elsewhere classified
	X43	Accidental poisoning by and exposure to other drugs acting on the autonomic nervous system
	X44	Accidental poisoning by and exposure to other and unspecified drugs, medicaments and biological substances
	X478	Accidental poisoning by and exposure to other specified gas and vapours
	X479	Accidental poisoning by and exposure to unspecified gas and vapours
	Y630	Excessive amount blood or other fluid in transfusion/infusion
	Y631	Incorrect dilution fluid during infusion
	Y632	Overdose radiation given during therapy
	Y634	Failure in dosage in electroshock or insulin-shock therapy
	Y636	Nonadministration drug, medicament or biological substance

Sentinel event	Cause/diagnosis code	Description
	Y638	Fail dosage during other surgical and medical care
	Y639	Fail dosage during other surgical and medical care
	Y639	Fail dosage during unspecified surgical and medical care
	Y651	Wrong fluid used in infusion
SE7	O95	Obstetric death of unspecified cause
	O960	Death from direct obstetric cause
	O961	Death from indirect obstetric cause
	O969	Death from obstetric cause, unspecified
	O970	Death from sequelae of direct obstetric cause
	O971	Death from sequelae of indirect obstetric cause
	O979	Death from sequelae of obstetric cause, unspecified
	O670	Intrapartum haemorrhage with coagulation defect
	O678	Other intrapartum haemorrhage
	O679	Intrapartum haemorrhage unspecified
	O720	Third-stage haemorrahge
	O721	Other immediate postpartum haemorrhage
	O722	Delayed and secondary postpartum haemorrhage
	T810	Haemorrhage and haematoma complicating a procedure, not elsewhere classified
	T811	Shock during or resulting from a procedure, not elsewhere classified
	T812	Accidental puncture and laceration during a procedure, not elsewhere classified
	T813	Disruption of operation wound, not elsewhere classified
	T8141	Wound infection following a procedure
	T8142	Sepsis following a procedure
	T817	Vascular complications following a procedure, not elsewhere classified
	T818	Other complications of procedures, not elsewhere classified
	T819	Unspecified complication of procedure
	Y843	Shock therapy as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure
	Y844	Aspiration of fluid as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure

Sentinel event	Cause/diagnosis code	Description
	Y845	Insertion of gastric or duodenal sound as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure
	Y846	Urinary catheterisation as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure
	Y847	Blood-sampling as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure
	Y848	Other medical procedures as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure
	Y849	Medical procedure, unspecified as the cause of abnormal reaction of the patient, or of later complication, without mention of misadventure at the time of the procedure

9 Specialty analysis

To analyse the distribution of hospital risk by specialty, we used a model that builds upon the method in *All complications should count (Methodological supplement)*.

The model was a gradient boosted classification tree built using the H2O.ai tool ported to R.[24] Two models were built: the first using patient-level predictors and the second using both patient and hospital predictors. (Table 9.1.) The difference in predictions between the two models was the 'risk'.

To prepare the data, we:

1. removed all admissions before July 2012 and in the last month (as records before this date were not complete across all hospitals)
2. ignored complications arising from emergency and ventilatory admissions
3. excluded non-obstetric sameday admissions
4. excluded any remaining chemotherapy and renal dialysis admissions (as there were too few to draw conclusions about hospital performance)

For Figure 1.4 in the main report, we calculated the average risk for each hospital-specialty combination, then subtracted the minimum average risk from the 10th, . . . , 90th percentiles of these averages to plot.

24. R Core Team (2018); LeDell et al. (2018); Dowle and Srinivasan (2018); Parsonage (2018a); Bache and Wickham (2014); Bates et al. (2018); Bates and Maechler (2018); Klik (2018); Wickham (2017); Parsonage (2018b); Garnier (2018a); Garnier (2018b); Parsonage et al. (2018); Slowikowski (2018); Wickham et al. (2018); and Wright et al. (2018).

Table 9.1: Patient and hospital predictors used in the specialty analysis

Predictor	Patient	Patient & Hospital
Admission mode	■	■
Urgency of admission	■	■
Number of procedures	■	■
Sex	■	■
Age	■	■
Month	■	■
AR-DRG	■	■
Resource consumption	■	■
Comorbidities (except chronic and pregnancy)	■	■
Public/private hospital		■
State		■
Hospital identifier		■

For Figure 1.5, the collection of averages for each specialty was plotted against the corresponding averages for other specialties in the same hospital. An OLS regression was then modelled and the adjusted R^2 plotted for each specialty.

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